Powertrain Blockset™

Reference

MATLAB® & SIMULINK®

R2022a

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Powertrain Blockset™ Reference

Revision History

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March 2017	Online only	Revised for Version 1.1 (Release 2017a)
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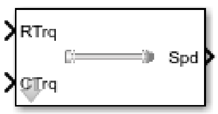
Contents

Drivetrain Blocks

Rotational Inertia

Ideal mechanical rotational inertia

Library: Powertrain Blockset / Drivetrain / Couplings
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Couplings



Description

The Rotational Inertia block implements an ideal mechanical rotational inertia.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrR`	Mechanical power from base shaft	P_{TR}	$P_{TR} = T_R\omega$
		`PwrC`	Mechanical power from follower shaft	P_{TC}	$P_{TC} = T_C\omega$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrDampLoss`	Power loss due to damping	P_d	$P_d = -b\|\omega\|^2$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredShft`	Rate change of stored internal torsional energy	P_s	$P_s = \omega\dot{\omega}J$

The equations use these variables.

T_R	Input torque
T_C	Output torque
ω	Driveshaft angular velocity
J	Rotational inertia
b	Rotational viscous damping
P_d	Power loss due to damping
P_s	Rate change of stored internal torsional energy

Ports

Input

`RTrq` — Input torque
scalar

Applied input driveshaft torque, T_R, in N·m.

Dependencies

To enable this port, for **Port Configuration**, select `Simulink`.

`CTrq` — Output torque
scalar

Load driveshaft torque, T_C, in N·m.

Dependencies

To enable this port, for **Port Configuration**, select `Simulink`.

`R` — Angular velocity and torque
two-way connector port

Angular velocity in rad/s. Torque is in N·m.

Dependencies

To enable this port, for **Port Configuration**, select `Two-way connection`.

`Inertia` — Input
scalar

Rotational inertia, in kg·m^2.

Dependencies

To create the `Inertia` port, select **External inertia input**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Variable	Units
Trq	R		Applied input driveshaft torque	T_R	N·m
	C		Output driveshaft torque	T_C	N·m
	Damp		Damping torque	$T_d = b\omega$	N·m
Spd			Angular driveshaft speed	ω	rad/s
PwrInfo	PwrTrnsfrd	PwrR	Mechanical power from base shaft	P_{TR}	W
		PwrC	Mechanical power from follower shaft	P_{TC}	W
	PwrNotTrnsfrd	PwrDampLoss	Power loss due to damping	P_d	W
	PwrStored	PwrStoredShft	Rate change of stored internal torsional energy	P_s	W

Dependencies

To enable this port, select **Output Info bus**.

Spd — Driveshaft speed
`scalar`

Angular driveshaft speed, ω, in rad/s.

Dependencies

To enable this port, for **Port Configuration**, select `Simulink`.

C — Angular velocity and torque
two-way connector port

Angular velocity in rad/s. Torque is in N·m.

Dependencies

To enable this port, for **Port Configuration**, select `Two-way connection`.

Parameters

Block Options

Port Configuration — Specify configuration
`Simulink` (default) | `Two-way connection`

Specify the port configuration.

Dependencies

Specifying `Simulink` creates these ports:

- `RTrq`
- `CTrq`
- `Spd`

Specifying `Two-way connection` creates these ports:

- `R`
- `C`

`Output Info bus` — Selection
`off` (default) | `on`

Select to create the `Info` output port.

`External inertia input` — Input rotational inertia
`off` (default) | `on`

Dependencies

To create the `Inertia` port, select **External inertia input**.

Parameters

`Rotational inertia, J` — Inertia
`.01` (default) | `scalar`

Rotational inertia, in kg·m^2.

Dependencies

To enable this parameter, clear **Input rotational inertia**.

`Torsional damping, b` — Damping
`.001` (default) | `scalar`

Torsional damping, in N·m· s/rad.

`Initial velocity, omega_o` — Angular
`0` (default) | `scalar`

Initial angular velocity, in rad/s.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

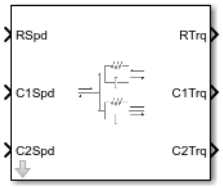
Split Torsional Compliance | Torsional Compliance

Introduced in R2017a

Split Torsional Compliance

Split torsional coupler

Library: Powertrain Blockset / Drivetrain / Couplings
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Couplings



Description

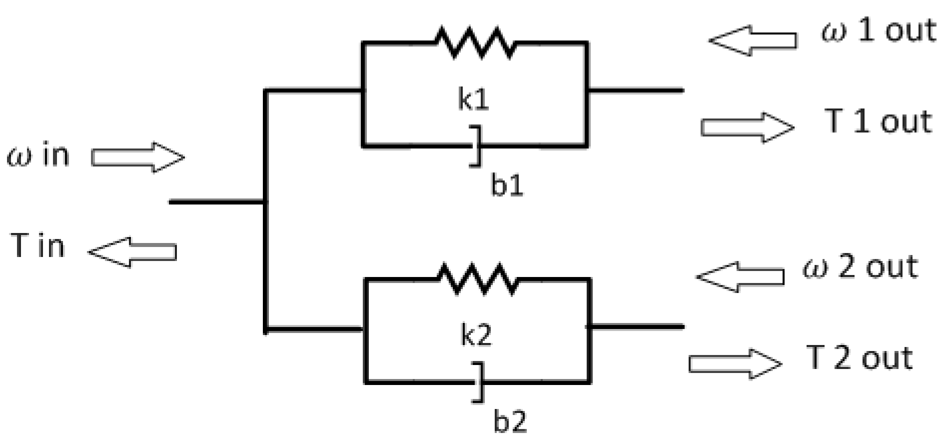
The Split Torsional Compliance block implements parallel spring-damper coupling between shafts. You can specify the type of coupling by selecting one of the **Coupling Configuration** parameters:

- `Shaft split` — Single input shaft coupled to two output shafts
- `Shaft merge` — Two input shafts coupled to a single output shaft

In fuel economy and emissions studies, you can use the Split Torsional Compliance block to model mechanical rotational compliance between common driveline elements such as motors, planetary gears, and clutches. For example, use the `Shaft split` configuration to couple a motor and two planetary gear sets. Use the `Shaft merge` configuration to couple a dual clutch transmission to an output shaft.

Shaft Split

For the `Shaft split` configuration, the block implements this schematic and equations.



$$T_{in} = -(\omega_{in} - \omega_{1out})b_1 - (\omega_{in} - \omega_{2out})b_2 - \theta_1 k_1 - \theta_2 k_2$$
$$T_{1out} = (\omega_{in} - \omega_{1out})b_1 + \theta_1 k_1$$
$$T_{2out} = (\omega_{in} - \omega_{2out})b_2 + \theta_2 k_2$$

$$\dot{\theta}_1 = (\omega_{in} - \omega_{1out})$$
$$\dot{\theta}_2 = (\omega_{in} - \omega_{2out})$$

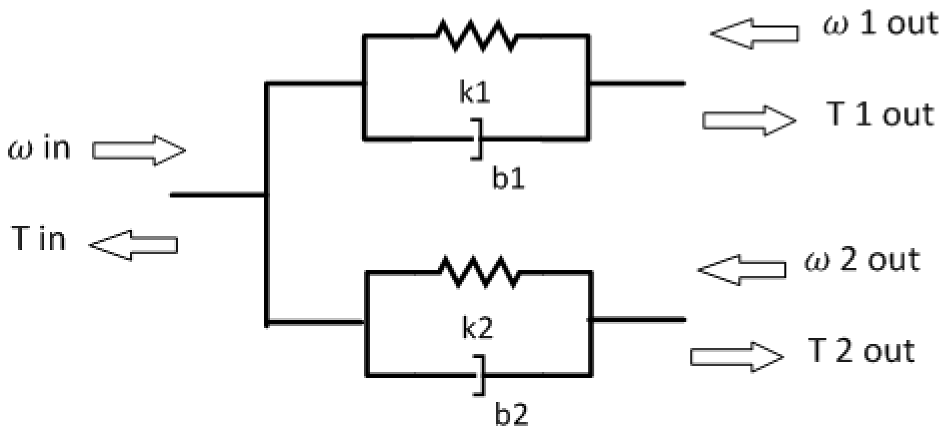
To account for frequency-dependent damping, both damping terms incorporate a low-pass filter.

The equations use these variables.

T_{in}	Resulting applied input reaction torque
ω_{in}	Input shaft rotational velocity
T_{1out}	Resulting applied torque to first output shaft
ω_{1out}	First output shaft rotational velocity
T_{2out}	Resulting applied torque to second output shaft
ω_{2out}	Second output shaft rotational velocity
θ_1, θ_2	First, second shaft rotation, respectively
b_1, b_2	First, second shaft viscous damping, respectively
k_1, k_2	First, second shaft torsional stiffness, respectively

Shaft Merge

For the `Shaft merge` configuration, the block implements this schematic and equations.



$$T_{out} = (-\omega_{out} + \omega_{1in})b_1 + (-\omega_{out} + \omega_{2in})b_2 + \theta_1 k_1 + \theta_2 k_2$$
$$T_{1out} = (\omega_{out} - \omega_{1in})b_1 - \theta_1 k_1$$
$$T_{2out} = (\omega_{out} - \omega_{2in})b_2 - \theta_2 k_2$$

$$\dot{\theta}_1 = (\omega_{1in} - \omega_{out})$$
$$\dot{\theta}_2 = (\omega_{2in} - \omega_{out})$$

To account for frequency-dependent damping, both damping terms incorporate a low-pass filter.

The equations use these variables.

T_{out}	Resulting applied output torque
ω_{out}	Output shaft rotational velocity
T_{1in}	Resulting reaction torque to first input shaft
ω_{1in}	First input shaft rotational velocity
T_{2in}	Resulting reaction torque to second input shaft
ω_{2in}	Second input shaft rotational velocity
θ_1, θ_2	First, second shaft rotation, respectively
b_1, b_2	First, second shaft viscous damping, respectively
k_1, k_2	First, second shaft torsional stiffness, respectively

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrR`	For the `Shaft split` configuration, mechanical power from input shaft	P_{TR}	$P_{TR} = -T_R\omega_R$
		`PwrC1`	For the `Shaft split` configuration, mechanical power from first output shaft	P_{TC1}	$P_{TC1} = -T_{C1}\omega_{C1}$
		`PwrC2`	For the `Shaft split` configuration, mechanical power from second output shaft	P_{TC2}	$P_{TC2} = -T_{C2}\omega_{C2}$
		`PwrC`	For the `Shaft merge` configuration, mechanical power from output shaft	P_{TC}	$P_{TC} = T_C\omega_C$

Bus Signal			Description	Variable	Equations
		PwrR1	For the Shaft merge configuration, mechanical power from first input shaft	P_{TR1}	$P_{TR1} = T_{R1}\omega_{R1}$
		PwrR2	For the Shaft merge configuration, mechanical power from second input shaft	P_{TR2}	$P_{TR2} = T_{R2}\omega_{R2}$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrDampLoss	Mechanical damping loss	P_d	$P_d = -\left(b_1\left\|\dot{\theta}_1\right\|^2 + b_2\left\|\dot{\theta}_2\right\|^2\right)$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredShft	Rate change in spring energy	P_s	$P_s = \left(k_1\theta_1\dot{\theta}_1 + k_2\theta_2\dot{\theta}_2\right)$

The equations use these variables.

T_R	Shaft R torque
T_C	Shaft C torque
ω_R	Shaft R angular velocity
ω_C	Shaft C angular velocity
θ	Coupled shaft rotation
k	Shaft torsional stiffness
b	Rotational viscous damping
P_t	Total mechanical power
P_d	Power loss due to damping
P_s	Rate change of stored spring energy

Ports

Input

`RSpd` — Input shaft speed
`scalar`

Input shaft rotational velocity, ω_{in}, in rad/s.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft split`

`C1Spd` — First output shaft speed
`scalar`

First output shaft rotational velocity, ω_{1out}, in rad/s.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft split`

`C2Spd` — Second output shaft speed
`scalar`

Second output shaft rotational velocity, ω_{2out}, in rad/s.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft split`

`CSpd` — Input speed
`scalar`

Output shaft rotational velocity, ω_{out}, in rad/s.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft merge`

`R1Spd` — First input shaft speed
`scalar`

First input shaft rotational velocity, ω_{1in}, in rad/s.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft merge`

R2Spd — Second input shaft speed
`scalar`

Second input shaft rotational velocity, ω_{2in}, in rad/s.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft merge`

R — Input shaft angular velocity and torque
two-way connector port

Input shaft angular velocity, ω_{in}, in rad/s and torque, T_{in}, in N·m.

Dependencies

To enable this port, select:

- **Port Configuration**>`Two-way connection`
- **Coupling Configuration**>`Shaft split`

R1 — First input shaft angular velocity and torque
two-way connector port

First input shaft angular velocity, ω_{1in}, in rad/s and torque, T_{1in}, in N·m.

Dependencies

To enable this port, select:

- **Port Configuration**>`Two-way connection`
- **Coupling Configuration**>`Shaft merge`

R2 — Second input shaft angular velocity and torque
two-way connector port

Second input shaft angular velocity, ω_{2in}, in rad/s and torque, T_{2in}, in N·m.

Dependencies

To enable this port, select:

- **Port Configuration**>`Two-way connection`
- **Coupling Configuration**>`Shaft merge`

Output

`Info` — Bus signal
bus

If you set **Coupling Configuration** to `Shaft split`, the Info bus contains these signals.

Signal			Description	Variable	Units
Trq	`R`		Input shaft torque	T_{in}	N·m
	`C1`		First output shaft torque	T_{1out}	N·m
	`C2`		Second output shaft torque	T_{2out}	N·m
	`Damp`	`C1`	First output shaft damping torque	$b_1\omega_{1out}$	N·m
		`C2`	Second output shaft damping torque	$b_2\omega_{2out}$	N·m
	`Spring`	`C1`	First output shaft spring torque	$k_1\theta_1$	N·m
		`C2`	Second output shaft spring torque	$k_2\theta_2$	N·m
Spd	`R`		Input shaft angular velocity	ω_{in}	rad/s
	`C1`		First output shaft angular velocity	ω_{1out}	rad/s
	`C2`		Second output shaft angular velocity	ω_{2out}	rad/s
	`deltadot1`		Difference in input and first output shaft angular velocity	$\dot{\theta}_1$	rad/s
	`deltadot2`		Difference in input and second output shaft angular velocity	$\dot{\theta}_2$	rad/s
PwrInfo	`PwrTrnsfrd`	`PwrR`	Mechanical power from input shaft	P_{TR}	W
		`PwrC1`	Mechanical power from first output shaft	P_{TC1}	W
		`PwrC2`	Mechanical power from second output shaft	P_{TC2}	W
	`PwrNotTrnsfrd`	`PwrDampLoss`	Mechanical damping loss	P_d	W
	`PwrStored`	`PwrStoredShft`	Rate change of stored internal torsional energy	P_s	W

If you set **Coupling Configuration** to `Shaft merge`, the Info bus contains these signals.

Signal		Description	Variable	Units
Trq	`C`	Output shaft torque	T_{out}	N·m
	`R1`	First input shaft torque	T_{1in}	N·m
	`R2`	Second input shaft torque	T_{2in}	N·m

Signal			Description	Variable	Units
	`Damp`	`R1`	First input shaft damping torque	$b_1\omega_{1in}$	N·m
		`R2`	Second in shaft damping torque	$b_2\omega_{2in}$	N·m
	`Spring`	`R1`	First input shaft spring torque	$k_1\theta_1$	N·m
		`R2`	Second in shaft spring torque	$k_2\theta_2$	N·m
Spd	`C`		Output shaft angular velocity	ω_{out}	rad/s
	`R1`		First input shaft angular velocity	ω_{1in}	rad/s
	`R2`		Second input shaft angular velocity	ω_{2in}	rad/s
	`deltadot1`		Difference in first input and output shaft angular velocity	$\dot{\theta}_1$	rad/s
	`deltadot2`		Difference in second input and output shaft angular velocity	$\dot{\theta}_2$	rad/s
PwrInfo	`PwrTrnsfrd`	`PwrC`	Mechanical power from output shaft	P_{TC}	W
		`PwrR1`	Mechanical power from first input shaft	P_{TR1}	W
		`PwrR2`	Mechanical power from second input shaft	P_{TR2}	W
	`PwrNotTrnsfrd`	`PwrDampLoss`	Mechanical damping loss	P_d	W
	`PwrStored`	`PwrStoredShft`	Rate change of stored internal torsional energy	P_s	W

Dependencies

To enable this port, select **Output Info bus**.

`RTrq` — Input shaft torque
`scalar`

Input shaft torque, T_{in}, in N·m.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft split`

`C1Trq` — First output shaft torque
`scalar`

First output shaft torque, T_{1out}, in N·m.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft split`

`C2Trq` — Second output shaft torque
`scalar`

Second output shaft torque, T_{2out}, in N·m.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft split`

`CTrq` — Output shaft torque
`scalar`

Output shaft torque, T_{out}, in N·m.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft merge`

`R1Trq` — First input shaft torque
`scalar`

First input shaft torque, T_{1in}, in N·m.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft merge`

`R2Trq` — Second input shaft torque
`scalar`

Second input shaft torque, T_{2in}, in N·m.

Dependencies

To enable this port, set both of these parameters:

- **Port Configuration** to `Simulink`
- **Coupling Configuration** to `Shaft merge`

`C1` — First output shaft angular velocity and torque
two-way connector port

First output shaft angular velocity, ω_{1out}, in rad/s and torque, T_{1out}, in N·m.

Dependencies

To enable this port, select:

- **Port Configuration**>`Two-way connection`
- **Coupling Configuration**>`Shaft split`

`C2` — Second output shaft angular velocity and torque
two-way connector port

Second output shaft angular velocity, ω_{2out}, in rad/s and torque, T_{2out}, in N·m.

Dependencies

To enable this port, select:

- **Port Configuration**>`Two-way connection`
- **Coupling Configuration**>`Shaft split`

`C` — Output shaft angular velocity and torque
two-way connector port

Output shaft angular velocity, ω_{out}, in rad/s and torque, T_{out}, in N·m.

Dependencies

To enable this port, select:

- **Port Configuration**>`Two-way connection`
- **Coupling Configuration**>`Shaft merge`

Parameters

Block Options

`Port Configuration` — Specify configuration
`Simulink` (default) | `Two-way connection`

Specify the port configuration.

`Coupling Configuration` — Specify configuration
`Shaft split` (default) | `Shaft merge`

Specify the coupling type.

`Output Info bus` — Selection
`off` (default) | `on`

Select to create the `Info` output port.

Coupling 1

`Torsional stiffness, k1` — Stiffness
`5e4` (default) | `scalar`

Rotational inertia, k_1, in N·m/rad.

`Torsional damping, b1` — Damping
`1e2` (default) | `scalar`

Torsional damping, b_1, in N·m· s/rad.

`Damping cutoff frequency, omega1_c` — Frequency
`3000` (default) | `scalar`

Damping cutoff frequency, in rad/s.

Coupling 2

`Torsional stiffness, k2` — Stiffness
`5e4` (default) | `scalar`

Rotational inertia, k_2, in N·m/rad.

`Torsional damping, b2` — Damping
`1e2` (default) | `scalar`

Torsional damping, b_2, in N·m· s/rad.

`Damping cutoff frequency, omega2_c` — Frequency
`3000` (default) | `scalar`

Damping cutoff frequency, in rad/s.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

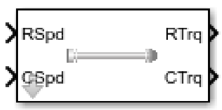
Rotational Inertia | Torsional Compliance

Introduced in R2017b

Torsional Compliance

Parallel spring-damper

Library: Powertrain Blockset / Drivetrain / Couplings
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Couplings



Description

The Torsional Compliance block implements a parallel spring-damper to couple two rotating driveshafts. The block uses the driveshaft angular velocities, torsional stiffness, and torsional damping to determine the torques.

$$T_R = -(\omega_R - \omega_C)b - \theta k$$

$$T_C = (\omega_R - \omega_C)b + \theta k$$

$$\dot{\theta} = (\omega_R - \omega_C)$$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrR`	Mechanical power from driveshaft R	P_{TR}	$P_{TR} = T_R\omega_R$
		`PwrC`	Mechanical power from driveshaft C	P_{TC}	$P_{TC} = T_c\omega_c$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrDampLoss`	Mechanical damping loss	P_d	$P_d = -b\lvert\dot{\theta}\rvert^2$

Bus Signal			Description	Variable	Equations
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredShft`	Rate change in spring energy	P_S	$P_s = -\theta k \dot{\theta}$

The equations use these variables.

T_R	Driveshaft R torque
T_C	Driveshaft C torque
ω_R	Driveshaft R angular velocity
ω_C	Driveshaft C angular velocity
θ	Coupled driveshaft rotation
k	Driveshaft torsional stiffness
b	Rotational viscous damping
P_d	Power loss due to damping
P_s	Rate change of stored spring energy

Ports

Input

RSpd — Driveshaft R angular velocity
`scalar`

Input driveshaft angular velocity, in rad/s.

Dependencies

To enable this port, for **Port Configuration**, select `Simulink`.

CSpd — Driveshaft C angular velocity
`scalar`

Output driveshaft angular velocity, in rad/s.

Dependencies

To enable this port, for **Port Configuration**, select `Simulink`.

R — Angular velocity and torque
two-way connector port

Angular velocity in rad/s. Torque is in N·m.

Dependencies

To enable this port, for **Port Configuration**, select `Two-way connection`.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Variable	Units
Trq	`R`		Input driveshaft torque	T_R	N·m
	`C`		Output driveshaft torque	T_C	N·m
	`Damp`		Damping torque	$T_S = b\dot{\theta}$	N·m
	`Spring`		Spring torque	$T_d = k\theta$	N·m
Spd	`R`		Input driveshaft angular velocity	ω_R	rad/s
	`C`		Output driveshaft angular velocity	ω_C	rad/s
	`deltadot`		Difference in input and output driveshaft angular velocity	$\dot{\theta}$	rad/s
PwrInfo	`PwrTrnsfrd`	`PwrR`	Mechanical power from driveshaft R	P_{TR}	W
		`PwrC`	Mechanical power from driveshaft C	P_{TC}	W
	`PwrNotTrnsfrd`	`PwrDampLoss`	Power loss due to damping	P_d	W
	`PwrStored`	`PwrStoredShft`	Rate change of stored internal kinetic energy	P_s	W

Dependencies

To enable this port, select **Output Info bus**.

`RTrq` — Driveshaft R torque
`scalar`

Input drive shaft torque, in N·m.

Dependencies

To enable this port, for **Port Configuration**, select `Simulink`.

`CTrq` — Driveshaft C torque
`scalar`

Applied output driveshaft torque, in N·m.

Dependencies

To enable this port, for **Port Configuration**, select `Simulink`.

C — Angular velocity and torque
two-way connector port

Angular velocity in rad/s. Torque is in N·m.

Dependencies

To enable this port, for **Port Configuration**, select `Two-way connection`.

Parameters

Block Options

`Port Configuration` — Specify configuration
`Simulink` (default) | `Two-way connection`

Specify the port configuration.

Dependencies

Specifying `Simulink` creates these ports:

- `RSpd`
- `CSpd`
- `RTrq`
- `CTrq`

Specifying `Two-way connection` creates these ports:

- `R`
- `C`

`Output Info bus` — Selection
`off` (default) | `on`

Select to create the `Info` output port.

`Torsional stiffness, k` — Inertia
`1e4` (default) | `scalar`

Torsional stiffness, in N·m/rad.

`Torsional damping, b` — Damping
`1e2` (default) | `scalar`

Torsional damping, in N·m· s/rad.

`Initial deflection, theta_o` — Angular
`0` (default) | `scalar`

Initial deflection, in rad.

`Initial velocity difference, domega_o` — Angular
`0` (default) | `scalar`

Initial velocity difference, in rad/s.

Damping cut-off frequency, omega_c — Frequency
3000 (default) | scalar

Damping cut-off frequency, in rad/s.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

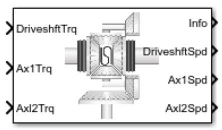
Rotational Inertia | Split Torsional Compliance

Introduced in R2017a

Limited Slip Differential

Limited differential as a planetary bevel gear

Library: Powertrain Blockset / Drivetrain / Final Drive Unit
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Final Drive Unit



Description

The Limited Slip Differential block implements a differential as a planetary bevel gear train. The block matches the driveshaft bevel gear to the crown (ring) bevel gear. You can specify:

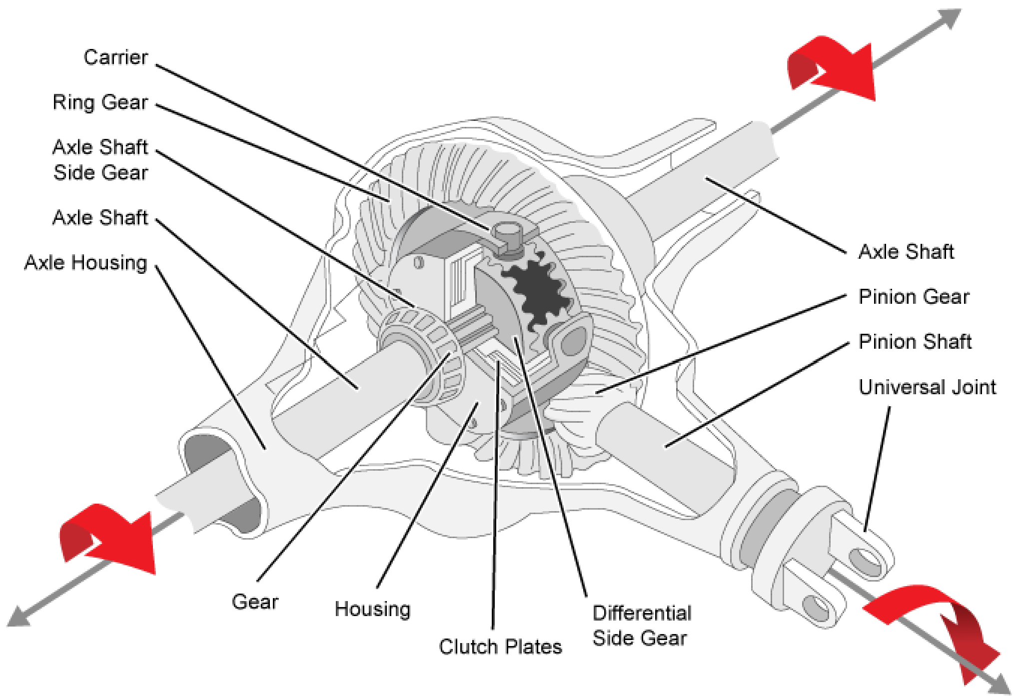
- Carrier-to-driveshaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier
- Type of slip coupling

Use the block in system-level driveline analysis to account for the power transfer from the transmission to the wheels. The block is suitable for use in hardware-in-the-loop (HIL) and optimization workflows. All the parameters are tunable.

In a limited slip differential, to prevent one of the wheels from slipping, the differential splits the torque applied to the left and right axles. With different torque applied to the axles, the wheels can move at different angular velocities, preventing slip. The block implements three methods for coupling the different torques applied to the axes:

- Pre-loaded ideal clutch
- Slip speed-dependent torque data
- Input torque dependent torque data

The block uses a coordinate system that produces positive tire and vehicle motion for standard engine, transmission, and differential configurations. The arrows indicate positive motion.



Efficiency

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
`Constant`	Constant efficiency that you can set with the **Constant efficiency factor, eta** parameter.
`Driveshaft torque, temperature and speed`	Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints: • **Efficiency lookup table, eta_tbl** • **Efficiency torque breakpoints, Trq_bpts** • **Efficiency speed breakpoints, omega_bpts** • **Efficiency temperature breakpoints, Temp_bpts** For the air temperature, you can either: • Select **Input temperature** to create an input port. • Set a **Ambient temperature, Tamb** parameter value. To select the interpolation method, use the **Interpolation method** parameter. For more information, see “Interpolation Methods”.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrDriveshft	Mechanical power from driveshaft	$\eta T_d \omega_d$
		PwrAxl1	Mechanical power from axle 1	$\eta T_1 \omega_1$
		PwrAxl2	Mechanical power from axle 2	$\eta T_2 \omega_2$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrMechLoss	Total power loss	$\dot{W}_{loss} = -(P_t + P_d + P_c) + P_s$ $P_t = \eta(T_d \omega_d + T_1 \omega_1 + T_2 \omega_2)$
		PwrDampLoss	Power loss due to damping	$P_d = -(b_1 \lvert\omega_1\rvert + b_2 \lvert\omega_2\rvert + b_d \lvert\omega_d\rvert)$
		PwrCplngLoss	Power loss due to clutch	$P_c = T_c \lvert\overline{\omega}\rvert$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredShft	Rate change of stored internal energy	$P_s = -(\omega_1 \dot{\omega}_1 J_1 + \omega_2 \dot{\omega}_2 J_2 + \omega_d \dot{\omega}_d J_d)$

Dynamics

The Limited Slip Differential block implements these differential equations to represent the mechanical dynamic response for the crown gear, left axle, and right axle.

Mechanical Dynamic Response	Differential Equation
Crown Gear	$\dot{\omega}_d J_d = \eta T_d - \omega_d b_d - T_i$
Left Axle	$\dot{\omega}_1 J_1 = \eta T_1 - \omega_1 b_1 - T_{i1}$
Right Axle	$\dot{\omega}_2 J_2 = \eta T_2 - \omega_2 b_2 - T_{i2}$

The block assumes rigid coupling between the crown gear and axles. These constraint equations apply.

$$\eta T_1 = \frac{N}{2} T_i - \frac{1}{2} T_c$$

$$\eta T_2 = \frac{N}{2} T_i + \frac{1}{2} T_c$$

$$\omega_d = \frac{N}{2}(\omega_1 + \omega_2)$$

The equations use these variables.

N	Carrier-to-driveshaft gear ratio
J_d	Rotational inertia of the crown gear assembly
b_d	Crown gear linear viscous damping
ω_d	Driveshaft angular speed
ϖ	Slip speed
J_1	Axle 1 rotational inertia
b_1	Axle 1 linear viscous damping
ω_1	Axle 1 speed
J_2	Axle 2 rotational inertia
b_2	Axle 2 linear viscous damping
ω_2	Axle 2 angular speed
η	Efficiency
T_d	Driveshaft torque
T_1	Axle 1 torque
T_2	Axle 2 torque
T_i	Axle internal resistance torque
T_{i1}	Axle 1 internal resistance torque
T_{i2}	Axle 2 internal resistance torque
μ	Coefficient of friction
R_{eff}	Effective clutch radius
R_o	Annular disk outer radius
R_i	Annular disk inner radius
F_c	Clutch force
T_c	Clutch torque
μ	Coefficient of friction

Table blocks in the Limited Slip Differential have these parameter settings:

- **Interpolation method** — `Linear`
- **Extrapolation method** — `Clip`

Ideal Clutch Coupling

The ideal clutch coupling model uses the axle slip speed and friction to calculate the clutch torque. The friction coefficient is a function of the slip speed.

$$T_c = F_c N \mu(|\varpi|) R_{eff} \tanh(4|\varpi|)$$

The disc radii determine the effective clutch radius over which the clutch force acts.

$$R_{eff} = \frac{2(R_o3 - R_i3)}{3(R_o2 - R_i2)}$$

The angular velocities of the axles determine the slip speed.

$$\varpi = \omega_1 - \omega_2$$

Slip Speed Coupling

To calculate the clutch torque, the slip speed coupling model uses torque data that is a function of slip speed. The angular velocities of the axles determine the slip speed.

$$\varpi = \omega_1 - \omega_2$$

Input Torque Coupling

To calculate the clutch torque, the input torque coupling model uses torque data that is a function of input torque.

The Open Differential block assumes rigid coupling between the crown gear and axles. These constraint equations apply.

$$\eta T_{i1} = \quad \eta T_{i2} = \frac{N}{2} T_i$$

$$\omega_d = \frac{N}{2}(\omega_1 + \omega_2)$$

Ports

Inputs

`DriveshftTrq` — Torque
`scalar`

Applied input torque, typically from the engine crankshaft, in N·m.

`Axl1Trq` — Torque
`scalar`

Axle 1 torque, T_1, in N·m.

`Axl2Trq` — Torque
`scalar`

Axle 2 torque, T_2, in N·m.

`Temp` — Temperature
`scalar`

Temperature, in K.

Dependencies

To enable this port:

- Set **Efficiency factors** to `Driveshaft torque, speed and temperature`.
- Select **Input temperature**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
`Driveshft`	`DriveshftTrq`		Driveshaft torque	N·m
	`DriveshftSpd`		Driveshaft speed	rad/s
`Axl1`	`Axl1Trq`		Axle 1 torque	N·m
	`Axl1Spd`		Axle 1 speed	rad/s
`Axl2`	`Axl2Trq`		Axle 2 torque	N·m
	`Axl2Spd`		Axle 2 speed	rad/s
`Cplng`	`CplngTrq`		Torque coupling	N·m
	`CplngSlipSpd`		Slip speed	rad/s
`PwrInfo`	`PwrTrnsfrd`	`PwrDriveshft`	Mechanical power from driveshaft	W
		`PwrAxl1`	Mechanical power from axle 1	W
		`PwrAxl2`	Mechanical power from axle 2	W
	`PwrNotTrnsfrd`	`PwrMechLoss`	Total power loss	W
		`PwrDampLoss`	Power loss due to damping	W
		`PwrCplngLoss`	Power loss due to clutch	W
	`PwrStoredShft`	`PwrStoredShft`	Rate change of stored internal energy	W

`DriveshftSpd` — Angular speed
`scalar`

Driveshaft angular speed, ω_d, in rad/s.

`Axl1Spd` — Angular speed
`scalar`

Axle 1 angular speed, ω_1, in rad/s.

`Axl2Spd` — Angular speed
`scalar`

Axle 2 angular speed, ω_2, in rad/s.

Parameters

Block Options

`Efficiency factors` — Specify configuration

`Constant` (default) | `Driveshaft torque, speed and temperature`

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
`Constant`	Constant efficiency that you can set with the **Constant efficiency factor, eta** parameter.
`Driveshaft torque, temperature and speed`	Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints: • **Efficiency lookup table, eta_tbl** • **Efficiency torque breakpoints, Trq_bpts** • **Efficiency speed breakpoints, omega_bpts** • **Efficiency temperature breakpoints, Temp_bpts** For the air temperature, you can either: • Select **Input temperature** to create an input port. • Set a **Ambient temperature, Tamb** parameter value. To select the interpolation method, use the **Interpolation method** parameter. For more information, see “Interpolation Methods”.

`Interpolation method` — Method

`Flat` | `Nearest` | `Linear point-slope` | `Linear Lagrange` | `Cubic spline`

For more information, see “Interpolation Methods”.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Input temperature` — Create input port

`off` (default) | `on`

Select to create input port `Temp` for the temperature.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

Open Differential

`Crown wheel (ring gear) located` — Specify crown wheel connection

`To the left of center-line` (default) | `To the right of center-line`

Specify the crown wheel connection to the driveshaft.

Carrier to drive shaft ratio, NC/ND — Ratio
4 (default) | scalar

Carrier-to-driveshaft gear ratio, N.

Carrier inertia, Jd — Inertia
.1 (default) | scalar

Rotational inertia of the crown gear assembly, J_d, in kg·m^2. You can include the driveshaft inertia.

Carrier damping, bd — Damping
1e-3 (default) | scalar

Crown gear linear viscous damping, b_d, in N·m·s/rad.

Axle 1 inertia, Jw1 — Inertia
.1 (default) | scalar

Axle 1 rotational inertia, J_1, in kg·m^2.

Axle 1 damping, bw1 — Damping
1e-3 (default) | scalar

Axle 1 linear viscous damping, b_1, in N·m·s/rad.

Axle 2 inertia, Jw2 — Inertia
.1 (default) | scalar

Axle 2 rotational inertia, J_2, in kg·m^2.

Axle 2 damping, bw2 — Damping
1e-3 (default) | scalar

Axle 2 linear viscous damping, b_2, in N·m·s/rad.

Axle 1 initial velocity, omegaw1o — Angular velocity
0 (default) | scalar

Axle 1 initial velocity, ω_{o1}, in rad/s.

Axle 2 initial velocity, omegaw2o — Angular velocity
0 (default) | scalar

Axle 2 initial velocity, ω_{o2}, in rad/s.

Constant efficiency factor, eta — Efficiency
1 (default) | scalar

Constant efficiency, η.

Dependencies

To enable this parameter, set **Efficiency factors** to `Constant`.

`Efficiency lookup table, eta_tbl` — Lookup table
`M`-by-`N`-by-`L` array

Dimensionless array of values for efficiency as a function of:

- `M` input torques
- `N` input speed
- `L` air temperatures

Each value specifies the efficiency for a specific combination of torque, speed, and temperature. The array size must match the dimensions defined by the torque, speed, and temperature breakpoint vectors.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency torque breakpoints, Trq_bpts` — Torque breakpoints
`[25, 50, 75, 100, 150, 200, 250]` (default) | 1-by-`M` vector

Vector of input torque, breakpoints for efficiency, in N·m.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency speed breakpoints, omega_bpts` — Speed breakpoints
`[52.4 78.5 105 131 157 183 209 262 314 419 524]` (default) | 1-by-`N` vector

Vector of speed, breakpoints for efficiency, in rad/s.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency temperature breakpoints, Temp_bpts` — Temperature breakpoints
`[290 358]` (default) | 1-by-`L` vector

Vector of ambient temperature breakpoints for efficiency, in K.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Ambient temperature, Tamb` — Ambient temperature
`297.15` (default) | `scalar`

Ambient air temperature, T_{air}, in K.

Dependencies

To enable this parameter:

- Set **Efficiency factors** to `Driveshaft torque, speed and temperature`.
- Clear **Input temperature**.

Slip Coupling

`Coupling type` — Torque coupling
`Pre-loaded ideal clutch` (default) | `Slip speed dependent torque data` | `Input torque dependent torque data`

Specify the type of torque coupling.

`Number of disks, Ndisks` — Torque coupling
`4` (default) | `scalar`

Number of disks.

Dependencies

To enable the ideal clutch parameters, select `Pre-loaded ideal clutch` for the **Coupling type** parameter.

`Effective radius, Reff` — Radius
`.20` (default) | `scalar`

The effective radius, R_{eff}, used with the applied clutch friction force to determine the friction force. The effective radius is defined as:

$$R_{eff} = \frac{2(R_o3 - R_i3)}{3(R_o2 - R_i2)}$$

The equation uses these variables.

R_o	Annular disk outer radius
R_i	Annular disk inner radius

Dependencies

To enable the clutch parameters, select `Pre-loaded ideal clutch` for the **Coupling type** parameter.

`Nominal preload force, Fc` — Force
`500` (default) | `scalar`

Nominal preload force, in N.

Dependencies

To enable the clutch parameters, select `Pre-loaded ideal clutch` for the **Coupling type** parameter.

`Friction coefficient vector, muc` — Friction
`[.16 0.13 0.115 0.11 0.105 0.1025 0.10125]` (default) | `vector`

Friction coefficient vector.

Dependencies

To enable the clutch parameters, select `Pre-loaded ideal clutch` for the **Coupling type** parameter.

`Slip speed vector, dw` — Angular velocity
`[0 10 20 40 60 80 100]` (default) | `vector`

Slip speed vector, in rad/s.

Dependencies

To enable the clutch parameters, select `Pre-loaded ideal clutch` for the **Coupling type** parameter.

`Torque - slip speed vector, Tdw` — Torque
`[-100, -90, -50, -5, 0, 5, 50, 90, 100]` (default) | `vector`

Torque vector, in N·m.

Dependencies

To enable the slip speed parameters, select `Slip speed dependent torque data` for the **Coupling type** parameter.

`Slip speed vector, dwT` — Angular velocity
`[-200, -175, -100, - 50, 0, 50, 100, 175, 200]` (default) | `vector`

Slip speed vector, in rad/s.

Dependencies

To enable the slip speed parameters, select `Slip speed dependent torque data` for the **Coupling type** parameter.

`Torque - input torque vector, TTin` — Torque
`[-200 -175 -100 - 50 0 50 100 175 200]` (default) | `vector`

Torque vector, in N·m.

Dependencies

To enable the input torque parameters, select `Input torque dependent torque data` for the **Coupling type** parameter.

`Input torque vector, Tin` — Torque
`[-200 -175 -100 - 50 0 50 100 175 200]` (default) | `vector`

Torque vector, in N·m.

Dependencies

To enable the input torque parameters, select `Input torque dependent torque data` for the **Coupling type** parameter.

`Coupling time constant, tauC` — Constant
`.01` (default) | `scalar`

Coupling time constant, in s.

References

[1] Deur, J., Ivanović, V., Hancock, M., and Assadian, F. "Modeling of Active Differential Dynamics." In ASME proceedings. *Transportation Systems*. Vol. 17, pp: 427-436.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

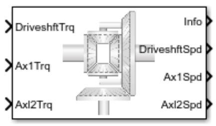
Open Differential

Introduced in R2017a

Open Differential

Differential as a planetary bevel gear

Library: Powertrain Blockset / Drivetrain / Final Drive Unit
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Final Drive Unit



Description

The Open Differential block implements a differential as a planetary bevel gear train. The block matches the driveshaft bevel gear to the crown (ring) bevel gear. You can specify:

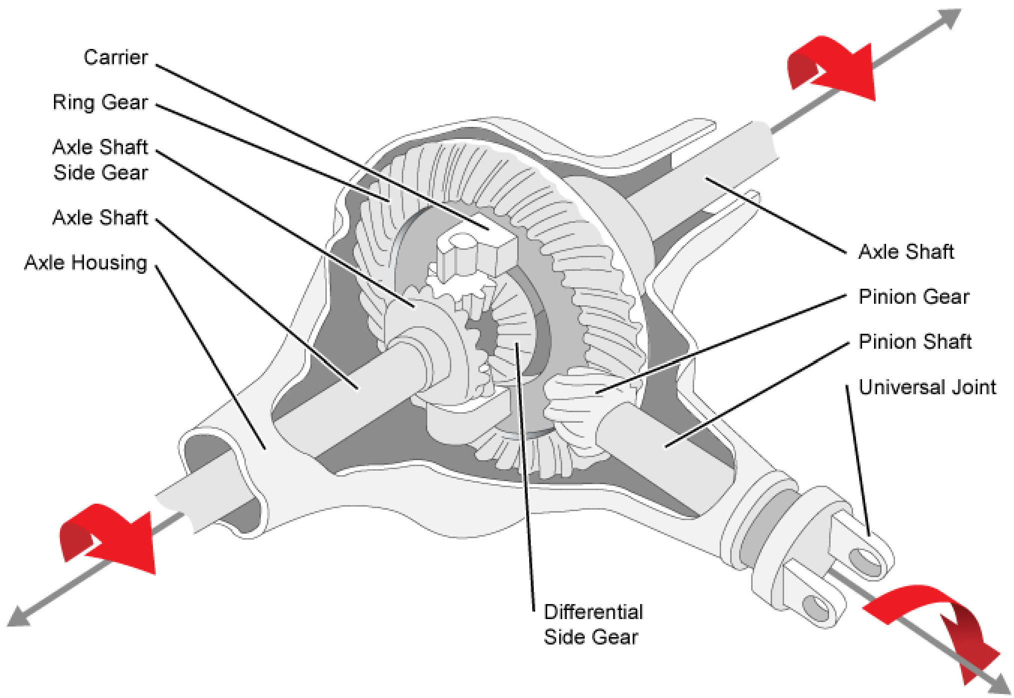
- Carrier-to-driveshaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier

Use the Open Differential block to:

- Dynamically couple the post-transmission driveshaft to the wheel axles or universal joints
- Model simplified or older drivetrains when optimal traction control does not require passive or active torque vectoring
- Model mechanical power splitting in generic gearbox and drive line scenarios

The block is suitable for use in hardware-in-the-loop (HIL) and optimization workflows. All the parameters are tunable.

The block uses a coordinate system that produces positive tire and vehicle motion for standard engine, transmission, and differential configurations. The arrows indicate positive motion.



Efficiency

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
`Constant`	Constant efficiency that you can set with the **Constant efficiency factor, eta** parameter.
`Driveshaft torque, temperature and speed`	Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints: • **Efficiency lookup table, eta_tbl** • **Efficiency torque breakpoints, Trq_bpts** • **Efficiency speed breakpoints, omega_bpts** • **Efficiency temperature breakpoints, Temp_bpts** For the air temperature, you can either: • Select **Input temperature** to create an input port. • Set a **Ambient temperature, Tamb** parameter value. To select the interpolation method, use the **Interpolation method** parameter. For more information, see "Interpolation Methods".

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrDriveshft`	Mechanical power from driveshaft	$\eta T_d \omega_d$
		`PwrAxl1`	Mechanical power from axle 1	$\eta T_1 \omega_1$
		`PwrAxl2`	Mechanical power from axle 2	$\eta T_2 \omega_2$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrMechLoss`	Total power loss	$\dot{W}_{loss} = -(P_t + P_d) + P_s$ $P_t = \eta T_d \omega_d + \eta T_1 \omega_1 + \eta T_2 \omega_2$
		`PwrDampLoss`	Power loss due to damping	$P_d = -(b_1 \lvert\omega_1\rvert + b_2 \lvert\omega_2\rvert + b_d \lvert\omega_d\rvert)$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredShft`	Rate change of stored internal energy	$P_s = -(\omega_1 \dot{\omega}_1 J_1 + \omega_2 \dot{\omega}_2 J_2 + \omega_d \dot{\omega}_d J_d)$

Dynamics

The Open Differential block implements these differential equations to represent the mechanical dynamic response for the crown gear, left axle, and right axle.

Mechanical Dynamic Response	Differential Equation
Crown Gear	$\dot{\omega}_d J_d = \eta T_d - \omega_d b_d - T_i$
Left Axle	$\dot{\omega}_1 J_1 = \eta T_1 - \omega_1 b_1 - T_{i1}$
Right Axle	$\dot{\omega}_2 J_2 = \eta T_2 - \omega_2 b_2 - T_{i2}$

The Open Differential block assumes rigid coupling between the crown gear and axles. These constraint equations apply.

$$\eta T_{i1} = \eta T_{i2} = \frac{N}{2} T_i$$

$$\omega_d = \frac{N}{2}(\omega_1 + \omega_2)$$

The equations use these variables.

N	Carrier-to-driveshaft gear ratio
J_d	Rotational inertia of the crown gear assembly
b_d	Crown gear linear viscous damping
ω_d	Driveshaft angular speed
η	Differential efficiency
J_1	Axle 1 rotational inertia
b_1	Axle 1 linear viscous damping
ω_1	Axle 1 speed
J_2	Axle 2 rotational inertia
b_2	Axle 2 linear viscous damping
ω_2	Axle 2 angular speed
T_d	Driveshaft torque
T_1	Axle 1 torque
T_2	Axle 2 torque
T_i	Driveshaft internal resistance torque
T_{i1}	Axle 1 internal resistance torque
T_{i2}	Axle 2 internal resistance torque

Ports

Inputs

`DriveshftTrq` — Torque
`scalar`

Applied input torque, typically from the engine crankshaft, in N·m.

`Axl1Trq` — Torque
`scalar`

Axle 1 torque, T_1, in N·m.

`Axl2Trq` — Torque
`scalar`

Axle 2 torque, T_2, in N·m.

`Temp` — Temperature
`scalar`

Temperature, in K.

Dependencies

To enable this port:

- Set **Efficiency factors** to `Driveshaft torque, speed and temperature`.
- Select **Input temperature**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
`Driveshft`	`DriveshftTrq`		Driveshaft torque	N·m
	`DriveshftSpd`		Driveshaft speed	rad/s
`Axl1`	`Axl1Trq`		Axle 1 torque	N·m
	`Axl1Spd`		Axle 1 speed	rad/s
`Axl2`	`Axl2Trq`		Axle 2 torque	N·m
	`Axl2Spd`		Axle 2 speed	rad/s
`PwrInfo`	`PwrTrnsfrd`	`PwrDriveshft`	Mechanical power from driveshaft	W
		`PwrAxl1`	Mechanical power from axle 1	W
		`PwrAxl2`	Mechanical power from axle 2	W
	`PwrTrnsfrd`	`PwrMechLoss`	Total power loss	W
		`PwrDampLoss`	Power loss due to damping	W
	`PwrStored`	`PwrStoredShft`	Rate change of stored internal energy	W

`DriveshftSpd` — Angular speed
`scalar`

Driveshaft angular speed, ω_d, in rad/s.

`Axl1Spd` — Angular speed
`scalar`

Axle 1 angular speed, ω_1, in rad/s.

`Axl2Spd` — Angular speed
`scalar`

Axle 2 angular speed, ω_2, in rad/s.

Parameters

Block Options

`Efficiency factors` — Specify configuration

`Constant` (default) | `Driveshaft torque, speed and temperature`

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
`Constant`	Constant efficiency that you can set with the **Constant efficiency factor, eta** parameter.
`Driveshaft torque, temperature and speed`	Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints: • **Efficiency lookup table, eta_tbl** • **Efficiency torque breakpoints, Trq_bpts** • **Efficiency speed breakpoints, omega_bpts** • **Efficiency temperature breakpoints, Temp_bpts** For the air temperature, you can either: • Select **Input temperature** to create an input port. • Set a **Ambient temperature, Tamb** parameter value. To select the interpolation method, use the **Interpolation method** parameter. For more information, see "Interpolation Methods".

`Interpolation method` — Method

`Flat` | `Nearest` | `Linear point-slope` | `Linear Lagrange` | `Cubic spline`

For more information, see "Interpolation Methods".

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Input temperature` — Create input port

`off` (default) | `on`

Select to create input port `Temp` for the temperature.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Crown wheel (ring gear) located` — Specify crown wheel connection

`To the left of center-line` (default) | `To the right of center-line`

Specify the crown wheel connection to the driveshaft.

`Carrier to drive shaft ratio, Ndiff` — Ratio
`4` (default) | `scalar`

Carrier-to-driveshaft gear ratio, N, dimensionless.

`Carrier inertia, Jd` — Inertia
`.1` (default) | `scalar`

Rotational inertia of the crown gear assembly, J_d, in kg·m^2. You can include the driveshaft inertia.

`Carrier damping, bd` — Damping
`1e-3` (default) | `scalar`

Crown gear linear viscous damping, b_d, in N·m·s/rad.

`Axle 1 inertia, Jw1` — Inertia
`.1` (default) | `scalar`

Axle 1 rotational inertia, J_1, in kg·m^2.

`Axle 1 damping, bw1` — Damping
`1e-3` (default) | `scalar`

Axle 1 linear viscous damping, b_1, in N·m·s/rad.

`Axle 2 inertia, Jw2` — Inertia
`.1` (default) | `scalar`

Axle 2 rotational inertia, J_2, in kg·m^2.

`Axle 2 damping, bw2` — Damping
`1e-3` (default) | `scalar`

Axle 2 linear viscous damping, b_2, in N·m·s/rad.

`Axle 1 initial velocity, omegaw1o` — Angular velocity
`0` (default) | `scalar`

Axle 1 initial velocity, ω_{o1}, in rad/s.

`Axle 2 initial velocity, omegaw2o` — Angular velocity
`0` (default) | `scalar`

Axle 2 initial velocity, ω_{o2}, in rad/s.

Efficiency

`Constant efficiency factor, eta` — Efficiency
`1` (default) | `scalar`

Constant efficiency, η.

Dependencies

To enable this parameter, set **Efficiency factors** to `Constant`.

`Efficiency lookup table, eta_tbl` — Lookup table
`M`-by-`N`-by-`L` array

Dimensionless array of values for efficiency as a function of:

- `M` input torques
- `N` input speed
- `L` air temperatures

Each value specifies the efficiency for a specific combination of torque, speed, and temperature. The array size must match the dimensions defined by the torque, speed, and temperature breakpoint vectors.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency torque breakpoints, Trq_bpts` — Torque breakpoints
`[25, 50, 75, 100, 150, 200, 250]` (default) | 1-by-`M` vector

Vector of input torque, breakpoints for efficiency, in N·m.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency speed breakpoints, omega_bpts` — Speed breakpoints
`[52.4 78.5 105 131 157 183 209 262 314 419 524]` (default) | 1-by-`N` vector

Vector of speed, breakpoints for efficiency, in rad/s.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency temperature breakpoints, Temp_bpts` — Temperature breakpoints
`[290 358]` (default) | 1-by-`L` vector

Vector of ambient temperature breakpoints for efficiency, in K.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Ambient temperature, Tamb` — Ambient temperature
`297.15` (default) | `scalar`

Ambient air temperature, T_{air}, in K.

Dependencies

To enable this parameter:

- Set **Efficiency factors** to `Driveshaft torque, speed and temperature`.
- Clear **Input temperature**.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

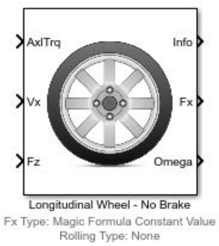
Limited Slip Differential

Introduced in R2017a

Longitudinal Wheel

Longitudinal wheel with disc, drum, or mapped brake

Library: Powertrain Blockset / Drivetrain / Wheels
Vehicle Dynamics Blockset / Wheels and Tires



Description

The Longitudinal Wheel block implements the longitudinal behavior of an ideal wheel. You can specify the longitudinal force and rolling resistance calculation method, and brake type. Use the block in driveline and longitudinal vehicle simulations where low frequency tire-road and braking forces are required to determine vehicle acceleration, braking, and wheel-rolling resistance. For example, you can use the block to determine the torque and power requirements for a specified drive cycle or braking event. The block is not suitable for applications that require combined lateral slip.

There are four types of Longitudinal Wheel blocks. Each block implements a different brake type.

Block Name	Brake Type Setting	Brake Implementation
Longitudinal Wheel - No Brake	`None`	None
Longitudinal Wheel - Disc Brake	`Disc`	Brake that converts the brake cylinder pressure into a braking force.
Longitudinal Wheel - Drum Brake	`Drum`	Simplex drum brake that converts the applied force and brake geometry into a net braking torque.
Longitudinal Wheel - Mapped Brake	`Mapped`	Lookup table that is a function of the wheel speed and applied brake pressure.

The block models longitudinal force as a function of wheel slip relative to the road surface. To calculate the longitudinal force, specify one of these **Longitudinal Force** parameters.

Setting	Block Implementation
`Magic Formula constant value`	Magic Formula with constant coefficient for stiffness, shape, peak, and curvature.
`Magic Formula pure longitudinal slip`	Magic Formula with load-dependent coefficients that implement equations 4.E9 through 4.E18 in *Tire and Vehicle Dynamics*.
`Mapped force`	Lookup table that is a function of the normal force and wheel slip ratio.

To calculate the rolling resistance torque, specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
`None`	None
`Pressure and velocity`	Method in *Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance*. The rolling resistance is a function of tire pressure, normal force, and velocity.
`ISO 28580`	Method specified in ISO 28580:2018, *Passenger car, truck and bus tyre rolling resistance measurement method — Single point test and correlation of measurement results*.
`Magic Formula`	Magic formula equations from 4.E70 in *Tire and Vehicle Dynamics*. The magic formula is an empirical equation based on fitting coefficients.
`Mapped torque`	Lookup table that is a function of the normal force and spin axis longitudinal velocity.

To calculate vertical motion, specify one of these **Vertical Motion** parameters.

Setting	Block Implementation
`None`	Block passes the applied chassis forces directly through to the rolling resistance and longitudinal force calculations.
`Mapped stiffness and damping`	Vertical motion depends on wheel stiffness and damping. Stiffness is a function of tire sidewall displacement and pressure. Damping is a function of tire sidewall velocity and pressure.

Rotational Wheel Dynamics

The block calculates the inertial response of the wheel subject to:

- Axle losses
- Brake and drive torque
- Tire rolling resistance
- Ground contact through the tire-road interface

The input torque is the summation of the applied axle torque, braking torque, and moment arising from the combined tire torque.

$$T_i = T_a - T_b + T_d$$

For the moment arising from the combined tire torque, the block implements tractive wheel forces and rolling resistance with first order dynamics. The rolling resistance has a time constant parameterized in terms of a relaxation length.

$$T_d(s) = \frac{1}{\frac{|\omega| R_e}{L_e} s + 1}(F_x R_e + M_y)$$

To calculate the rolling resistance torque, you can specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
`None`	Block sets rolling resistance, M_y, to zero.
`Pressure and velocity`	Block uses the method in SAE *Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance*. The rolling resistance is a function of tire pressure, normal force, and velocity. Specifically, $$M_y = R_e\left\{a + b\|V_x\| + cV_x2\right\}\left\{F_z\beta p_i\alpha\right\}\tanh(4V_x)$$
`ISO 28580`	Block uses the method specified in ISO 28580:2018, *Passenger car, truck and bus tyre rolling resistance measurement method — Single point test and correlation of measurement results*. The method accounts for normal load, parasitic loss, and thermal corrections from test conditions. Specifically, $$M_y = R_e\left(\frac{F_zC_r}{1 + K_t(T_{amb} - T_{meas})} - F_{pl}\right)\tanh(\omega)$$
`Magic Formula`	Block calculates the rolling resistance, M_y, using the Magic Formula equations from 4.E70 in *Tire and Vehicle Dynamics*. The magic formula is an empirical equation based on fitting coefficients.
`Mapped torque`	For the rolling resistance, M_y, the block uses a lookup table that is a function of the normal force and spin axis longitudinal velocity.

If the brakes are enabled, the block determines the braking locked or unlocked condition based on an idealized dry clutch friction model. Based on the lock-up condition, the block implements these friction and dynamic models.

If	Lock-Up Condition	Friction Model	Dynamic Model
$\omega \neq 0$ or $T_S < \|T_i + T_f - \omega b\|$	Unlocked	$T_f = T_k$ where, $T_k = F_cR_{eff}\mu_k\tanh[4(-\omega_d)]$ $T_s = F_cR_{eff}\mu_s$ $R_{eff} = \frac{2(R_o3 - R_i3)}{3(R_o2 - R_i2)}$	$\dot{\omega}J = -\omega b + T_i + T_o$
$\omega = 0$ and $T_S \geq \|T_i + T_f - \omega b\|$	Locked	$T_f = T_s$	$\omega = 0$

The equations use these variables.

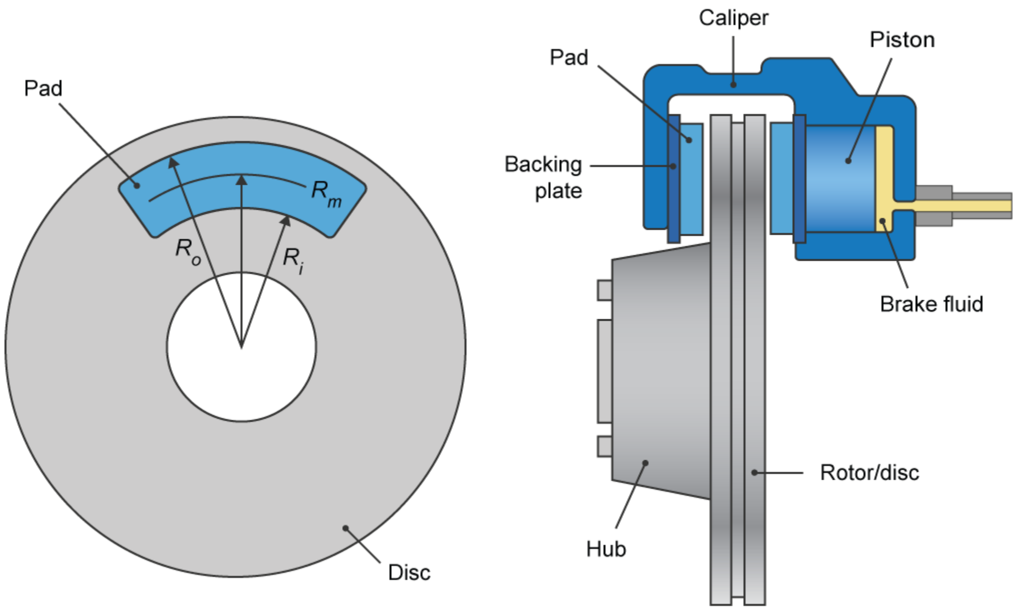
ω	Wheel angular velocity
a	Velocity-independent force component
b	Linear velocity force component
c	Quadratic velocity force component
L_e	Tire relaxation length
J	Moment of inertia

M_y	Rolling resistance torque
T_a	Applied axle torque
T_b	Braking torque
T_d	Combined tire torque
T_f	Frictional torque
T_i	Net input torque
T_k	Kinetic frictional torque
T_o	Net output torque
T_s	Static frictional torque
F_c	Applied clutch force
F_x	Longitudinal force developed by the tire road interface due to slip
R_{eff}	Effective clutch radius
R_o	Annular disk outer radius
R_i	Annular disk inner radius
R_e	Effective tire radius while under load and for a given pressure
V_x	Longitudinal axle velocity
F_z	Vehicle normal force
C_r	Rolling resistance constant
T_{amb}	Ambient temperature
T_{meas}	Measured temperature for rolling resistance constant
F_{pl}	Parasitic force loss
K_t	Thermal correction factor
α	Tire pressure exponent
β	Normal force exponent
p_i	Tire pressure
μ_s	Coefficient of static friction
μ_k	Coefficient of kinetic friction

Brakes

Disc

If you specify the **Brake Type** parameter `Disc`, the block implements a disc brake. This figure shows the side and front views of a disc brake.



A disc brake converts brake cylinder pressure from the brake cylinder into force. The disc brake applies the force at the brake pad mean radius.

The block uses these equations to calculate brake torque for the disc brake.

$$T = \begin{cases} \frac{\mu P \pi B_a{}^2 R_m N_{pads}}{4} & \text{when } N \neq 0 \\ \frac{\mu_{static} P \pi B_a{}^2 R_m N_{pads}}{4} & \text{when } N = 0 \end{cases}$$

$$Rm = \frac{Ro + Ri}{2}$$

The equations use these variables.

T	Brake torque
P	Applied brake pressure
N	Wheel speed
N_{pads}	Number of brake pads in disc brake assembly
μ_{static}	Disc pad-rotor coefficient of static friction
μ	Disc pad-rotor coefficient of kinetic friction
B_a	Brake actuator bore diameter
R_m	Mean radius of brake pad force application on brake rotor
R_o	Outer radius of brake pad

R_i	Inner radius of brake pad

Drum

If you specify the **Brake Type** parameter `Drum`, the block implements a static (steady-state) simplex drum brake. A simplex drum brake consists of a single two-sided hydraulic actuator and two brake shoes. The brake shoes do not share a common hinge pin.

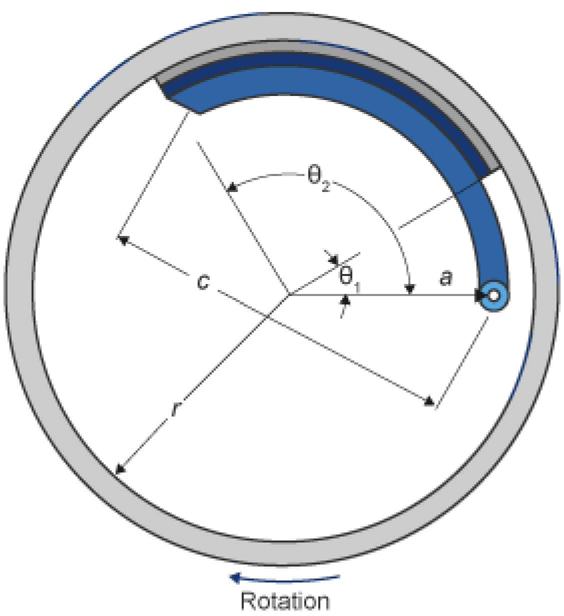
The simplex drum brake model uses the applied force and brake geometry to calculate a net torque for each brake shoe. The drum model assumes that the actuators and shoe geometry are symmetrical for both sides, allowing a single set of geometry and friction parameters to be used for both shoes.

The block implements equations that are derived from these equations in *Fundamentals of Machine Elements*.

$$T_{rshoe} = \left(\frac{\pi \mu c r (\cos\theta_2 - \cos\theta_1) B_a{}^2}{2\mu(2r\left(\cos\theta_2 - \cos\theta_1\right) + a\left(\cos^2\theta_2 - \cos^2\theta_1\right)) + ar(2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T_{lshoe} = \left(\frac{\pi \mu c r (\cos\theta_2 - \cos\theta_1) B_a{}^2}{-2\mu(2r\left(\cos\theta_2 - \cos\theta_1\right) + a\left(\cos^2\theta_2 - \cos^2\theta_1\right)) + ar(2\theta_1 - 2\theta_2 + \sin 2\theta_2 - \sin 2\theta_1)} \right) P$$

$$T = \begin{cases} T_{rshoe} + T_{lshoe} & \text{when } N \neq 0 \\ (T_{rshoe} + T_{lshoe}) \dfrac{\mu_{static}}{\mu} & \text{when } N = 0 \end{cases}$$



The equations use these variables.

T	Brake torque
P	Applied brake pressure
N	Wheel speed

μ_{static}	Disc pad-rotor coefficient of static friction
μ	Disc pad-rotor coefficient of kinetic friction
T_{rshoe}	Right shoe brake torque
T_{lshoe}	Left shoe brake torque
a	Distance from drum center to shoe hinge pin center
c	Distance from shoe hinge pin center to brake actuator connection on brake shoe
r	Drum internal radius
B_a	Brake actuator bore diameter
Θ_1	Angle from shoe hinge pin center to start of brake pad material on shoe
Θ_2	Angle from shoe hinge pin center to end of brake pad material on shoe

Mapped

If you specify the **Brake Type** parameter `Mapped`, the block uses a lookup table to determine the brake torque.

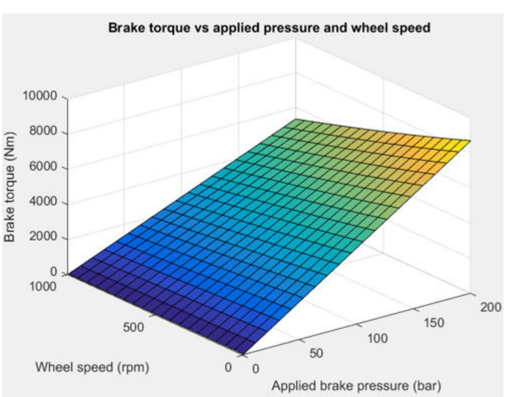
$$T = \begin{cases} f_{brake}(P, N) & \text{when } N \neq 0 \\ \left(\frac{\mu_{static}}{\mu}\right) f_{brake}(P, N) & \text{when } N = 0 \end{cases}$$

The equations use these variables.

T	Brake torque
$f_{brake}(P, N)$	Brake torque lookup table
P	Applied brake pressure
N	Wheel speed
μ_{static}	Friction coefficient of drum pad-face interface under static conditions
μ	Friction coefficient of disc pad-rotor interface

The lookup table for the brake torque, $f_{brake}(P, N)$, is a function of applied brake pressure and wheel speed, where:

- T is brake torque, in N·m.
- P is applied brake pressure, in bar.
- N is wheel speed, in rpm.



Longitudinal Force

To model the Longitudinal Wheel block longitudinal forces, you can use the Magic Formula. The model provides a steady-state *tire characteristic function* $F_x = f(\kappa, F_z)$, the longitudinal force F_x on the tire, based on:

- Vertical load F_z
- Wheel slip κ

The Magic Formula model uses these variables.

Ω	Wheel angular velocity
r_w	Wheel radius
V_x	Wheel hub longitudinal velocity
$r_w\Omega$	Tire tread longitudinal velocity
$V_{sx} = r_w\Omega - V_x$	Wheel slip velocity
$\kappa = V_{sx}/\lvert V_x\rvert$	Wheel slip
F_z, F_{z0}	Vertical load and nominal vertical load on tire
$F_x = f(\kappa, F_z)$	Longitudinal force exerted on the tire at the contact point. Also a characteristic function f of the tire.

Magic Formula Constant Value

If you set **Longitudinal Force** to `Magic Formula constant value`, the block implements the Magic Formula as a specific form of the tire characteristic function, characterized by four dimensionless coefficients (B, C, D, E), or stiffness, shape, peak, and curvature:

$$F_x = f(\kappa, F_z) = F_z D \sin\left(C \tan^{-1}[\ \{B\kappa - E[B\kappa - \tan^{-1}(B\kappa)\ ]\ \}\ ]\ \right)$$

The slope of f at $\kappa = 0$ is $BCD \cdot F_z$.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

Magic Formula Pure Longitudinal Slip

If you set **Longitudinal Force** to `Magic Formula pure longitudinal slip`, the block implements a more general Magic Formula using dimensionless coefficients that are functions of the tire load. The block implements the longitudinal force equations in Chapter 4 of *Tire and Vehicle Dynamics*, including 4.E9 through 4.E18:

$$F_{x0} = D_x \sin\left(C_x \tan^{-1}\left[\ \{B_x\kappa_x - E_x[B_x\kappa_x - \tan^{-1}(B_x\kappa_x)\ ]\}\ ]\ \right) + S_{Vx}$$

where:

$$\kappa_x = \kappa + S_{Hx}$$

$$C_x = p_{Cx1}\lambda_{Cx}$$

$$D_x = \mu_x F_z \varsigma_1$$

$$\mu_x = (p_{Dx1} + p_{Dx2}df_z)(1 + p_{px3}dp_i + p_{px4}dp_i 2)(1 - p_{Dx3}\gamma^2)\lambda *_{\mu x}$$

$$E_x = (p_{Ex1} + p_{Ex2}df_z + p_{Ex3}df_z 2)[1 - p_{Ex4}\mathrm{sgn}(\kappa_x)]\ \lambda_{Ex}$$

$$K_{x\kappa} = F_z(p_{Kx1} + p_{Kx2}df_z)\exp(p_{Kx3}df_z)(1 + p_{px1}dp_i + p_{px2}dp_i 2)$$

$$B_x = K_{x\kappa}/(C_x D_x + \varepsilon_x)$$

$$S_{Hx} = p_{Hx1} + p_{Hx2}df_z$$

$$S_{Vx} = F_z \cdot (p_{Vx1} + p_{Vx2}df_z)\lambda_{Vx}\lambda'_{\mu x}\varsigma_1$$

S_{Hx} and S_{Vx} represent offsets to the slip and longitudinal force in the force-slip function, or horizontal and vertical offsets if the function is plotted as a curve. μ_x is the longitudinal load-dependent friction coefficient. ε_x is a small number inserted to prevent division by zero as F_z approaches zero.

Vertical Dynamics

If you select no vertical degrees-of-freedom by setting **Vertical Motion** to `None`, the block passes the applied chassis forces directly through to the rolling resistance and longitudinal force calculations.

If you set **Vertical Motion** to `Mapped stiffness and damping`, the vertical motion depends on wheel stiffness and damping. Stiffness is a function of tire sidewall displacement and pressure. Damping is a function of tire sidewall velocity and pressure.

$$Fztire(z, \dot{z}, P_{tire}) = F_{zk}(z, P_{tire}) + F_{zb}(\dot{z}, P_{tire})$$

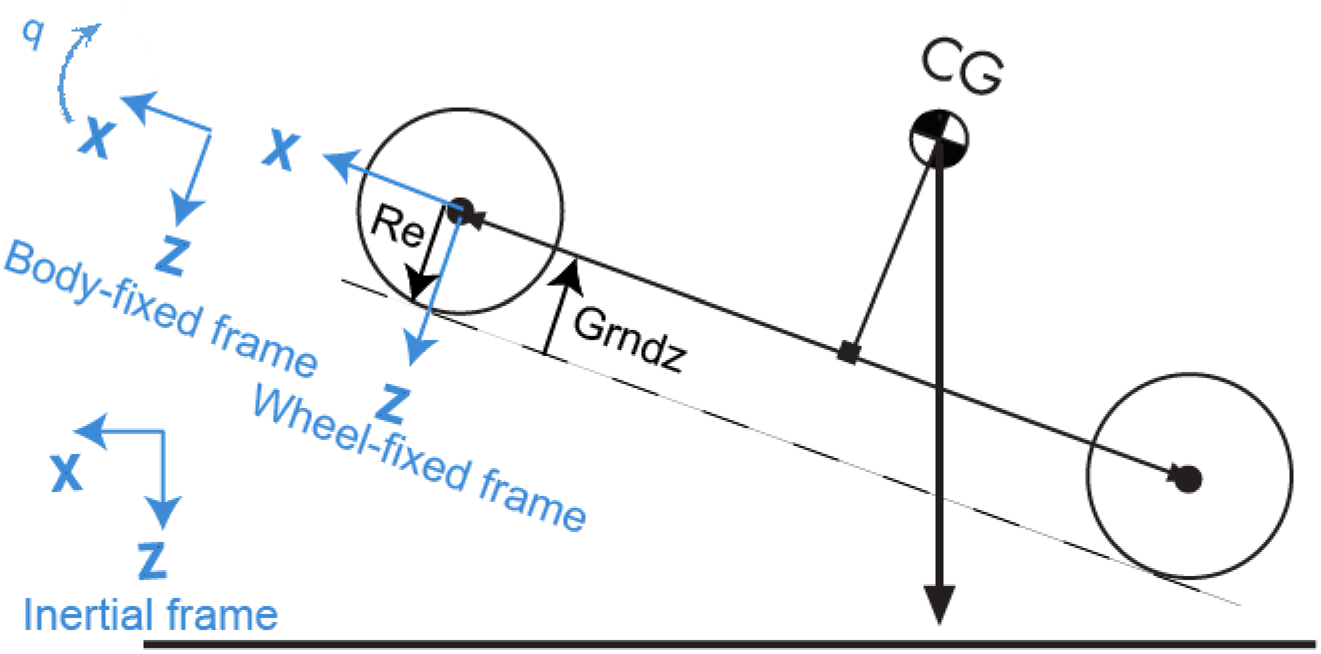
The block determines the vertical response using this differential equation.

$$\ddot{z}m = Fztire - F_z - mg$$

When you disable the vertical degree-of-freedom, the input normal force from the vehicle passes directly to the longitudinal and rolling force calculations.

$$\ddot{z} = \dot{z} = m = 0$$
$$Fztire = mg$$

The block uses the wheel-fixed frame to resolve the vertical forces.



The equations use these variables.

$Fztire$	Tire normal force along the wheel-fixed *z*-axis
m	Axle mass
F_{zk}	Tire normal force due to wheel stiffness along the wheel-fixed *z*-axis
F_{zb}	Tire normal force due to wheel damping along the wheel-fixed *z*-axis
F_z	Suspension or vehicle normal force along the wheel-fixed *z*-axis
P_{Tire}	Tire pressure
$z, \dot{z}, \ddot{z}$	Tire displacement, velocity, and acceleration, respectively, along the wheel-fixed *z*-axis

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks	PwrRoad	Tractive power applied from the axle	$P_{road} = F_x V_x$
		PwrAxlTrq	External torque applied by the axle to the wheel	$P_T = T\omega$

Bus Signal			Description	Equations
	• Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrFz`	Vertical force applied to the wheel by the vehicle or suspension	$P_{Fz} = F_z\dot{z}$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrSlip`	Tractive power loss	$P_{\kappa} = F_xV_x + (-F_{cp}R_e + M_y)\omega$
		`PwrMyRoll`	Rolling resistance power	$P_{My} = M_y\omega$
		`PwrMyBrk`	Braking power	$P_{brk} = M_{brk}\omega$
		`PwrMyb`	Rolling viscous damping loss	$P_b = -b\omega^2$
		`PwrFzDamp`	Vertical damping power	$P_{Fzb} = \quad F_{zb}\dot{z}$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredzdot`	Rate of change of vertical kinetic energy	$P_{\dot{z}} = m\ddot{z}\dot{z}$
		`PwrStoredq`	Rate of change of rotational kinetic energy	$P_{\omega} = I_{yy}\dot{\omega}\omega$
		`PwrStoredFsFzSprng`	Rate of change of stored sidewall potential energy	$P_{Fzk} = F_{zk}\dot{z}_x$
		`PwrStoredGrvty`	Rate of change of gravitational potential energy	$P_g = -mg\dot{Z}$

The equations use these variables.

ω	Wheel angular velocity
b	Linear velocity force component
F_x	Longitudinal force developed by the tire road interface due to slip
F_{cp}	Tire slip force at contact patch
F_z	Vehicle normal force
F_{zb}	Tire normal force due to wheel damping
F_{zk}	Tire normal force due to wheel stiffness
I_{yy}	Wheel rotational inertia
M_{brk}	Braking moment
M_y	Rolling resistance torque
R_e	Effective tire radius while under load and for a given pressure
T	Axle torque applied on wheel
V_x	Longitudinal axle velocity

$z, \dot{z}, \ddot{z}$	Tire displacement, velocity, and acceleration, respectively
ω	Wheel angular velocity
$\dot{Z}$	Vehicle vertical velocity along the vehicle-fixed z-axis

Ports

Input

`BrkPrs` — Brake pressure
`scalar`

Brake pressure, in Pa.

Dependencies

To enable this port, for the **Brake Type** parameter, specify one of these types:

- `Disc`
- `Drum`
- `Mapped`

`AxlTrq` — Axle torque
`scalar`

Axle torque, T_a, about wheel spin axis, in N·m.

`Vx` — Velocity
`scalar`

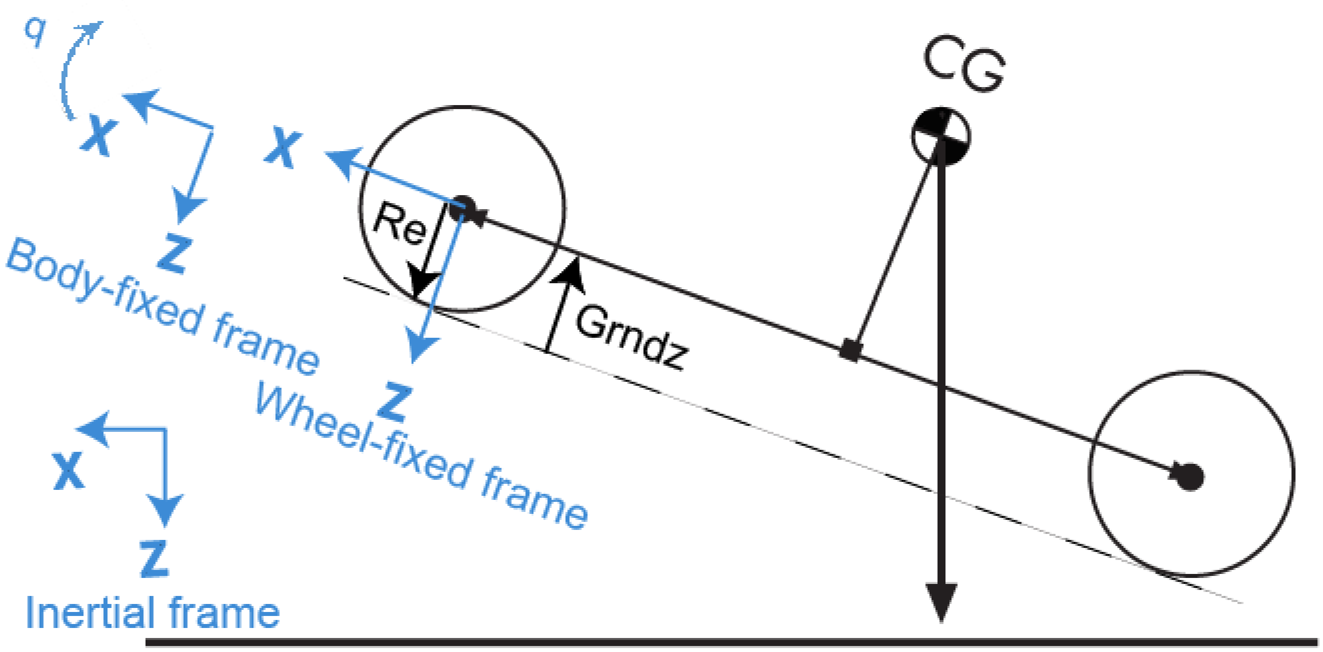
Axle longitudinal velocity along vehicle(body)-fixed x-axis, in m/s.

`Fz` — Normal force
`scalar`

Absolute value of suspension or vehicle normal force along body-fixed z-axis, in N.

`Gnd` — Ground displacement
`scalar`

Ground displacement, `Grndz`, along negative wheel-fixed z-axis, in m.



Dependencies

To create Gnd:

- Set **Vertical Motion** to `Mapped stiffness and damping`.
- On the **Vertical** pane, select **Input ground displacement**.

`lam_mux` — Friction scaling factor
`scalar`

Longitudinal friction scaling factor, dimensionless.

Dependencies

To enable this port, select **Input friction scale factor**.

`TirePrs` — Tire pressure
`scalar`

Tire pressure, in Pa.

Dependencies

To enable this port:

- Set one of these parameters:
  - **Longitudinal Force** to `Magic Formula pure longitudinal slip`.
  - **Rolling Resistance** to `Pressure and velocity` or `Magic Formula`.
  - **Vertical Motion** to `Mapped stiffness and damping`.

- On the **Wheel Dynamics** pane, select **Input tire pressure**.

`Tamb` — Ambient temperature
`scalar`

Ambient temperature, T_{amb}, in K.

Dependencies

To enable this port:

1. Set **Rolling Resistance** to `ISO 28580`.
2. On the **Rolling Resistance** pane, select to **Input ambient temperature**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
`AxlTrq`	Axle torque about body-fixed *y*-axis	N·m
`Omega`	Wheel angular velocity about body-fixed *y*-axis	rad/s
`Omegadot`	Wheel angular acceleration about body-fixed *y*-axis	rad/s^2
`Fx`	Longitudinal vehicle force along body-fixed *x*-axis	N
`Fz`	Vertical vehicle force along body-fixed *z*-axis	N
`Fzb`	Tire normal force due to wheel damping along the wheel-fixed *z*-axis	N
`Fzk`	Tire normal force due to wheel stiffness along the wheel-fixed *z*-axis	N
`My`	Rolling resistance torque about body-fixed *y*-axis	N·m
`Myb`	Rolling resistance torque due to damping about body-fixed *y*-axis	N·m
`Kappa`	Slip ratio	NA
`Vx`	Vehicle longitudinal velocity along body-fixed *x*-axis	m/s
`Re`	Wheel effective radius along wheel-fixed *z*-axis	m

Signal			Description	Units
BrkTrq			Brake torque about body-fixed *y*-axis	N·m
BrkPrs			Brake pressure	Pa
z			Wheel vertical deflection along wheel-fixed *z*-axis	m
zdot			Wheel vertical velocity along wheel-fixed *z*-axis	m/s
zddot			Wheel vertical acceleration along wheel-fixed *z*-axis	m/s^2
Gndz			Ground displacement along negative of wheel-fixed *z*-axis (positive input produces wheel lift)	m
GndFz			Vertical wheel force on ground along negative of wheel-fixed *z*-axis	N
TirePrs			Tire pressure	Pa
Fpatch			Tractive power applied from the axle	
PwrInfo	PwrTrnsfrd	PwrRoad	External torque applied by the axle to the wheel	W
		PwrAxlTrq	Vertical force applied to the wheel by the vehicle or suspension	W
		PwrFz	Tractive power loss	W
	PwrNotTrnsfrd	PwrSlip	Rolling resistance power	W
		PwrMyRoll	Braking power	W
		PwrMyBrk	Rolling viscous damping loss	W
		PwrMyb	Vertical damping power	W
		PwrFzDamp	Rate of change of vertical kinetic energy	W
	PwrStored	PwrStoredzdot	Rate of change of rotational kinetic energy	W
		PwrStoredq	Rate of change of stored sidewall potential energy	W
		PwrStoredFsFzSprng	Rate of change of gravitational potential energy	W
		PwrStoredGrvty	Tractive power applied from the axle	W

Fx — Longitudinal axle force
scalar

Longitudinal force acting on axle, along body-fixed *x*-axis, in N. Positive force acts to move the vehicle forward.

`Omega` — Wheel angular velocity
`scalar`

Wheel angular velocity, about body-fixed *y*-axis, in rad/s.

`z` — Wheel vertical deflection
`scalar`

Wheel vertical deflection along wheel-fixed *z*-axis, in m.

Dependencies

To enable this port, set **Vertical Motion** to `Mapped stiffness and damping`.

`zdot` — Wheel vertical velocity
`scalar`

Wheel vertical velocity along wheel-fixed *z*-axis, in m/s.

Dependencies

To enable this port, set **Vertical Motion** to `Mapped stiffness and damping`.

Parameters

Block Options

`Longitudinal Force` — Select type
`Magic Formula constant value` (default) | `Magic Formula pure longitudinal slip` | `Mapped force`

The block models longitudinal force as a function of wheel slip relative to the road surface. To calculate the longitudinal force, specify one of these **Longitudinal Force** parameters.

Setting	Block Implementation
`Magic Formula constant value`	Magic Formula with constant coefficient for stiffness, shape, peak, and curvature.
`Magic Formula pure longitudinal slip`	Magic Formula with load-dependent coefficients that implement equations 4.E9 through 4.E18 in *Tire and Vehicle Dynamics*.
`Mapped force`	Lookup table that is a function of the normal force and wheel slip ratio.

Dependencies

Selecting	Enables These Parameters
`Magic Formula constant value`	**Pure longitudinal peak factor, Dx** **Pure longitudinal shape factor, Cx** **Pure longitudinal stiffness factor, Bx** **Pure longitudinal curvature factor, Ex**

Selecting	Enables These Parameters
`Magic Formula pure longitudinal slip`	**Cfx shape factor, PCX1** **Longitudinal friction at nominal normal load, PDX1** **Frictional variation with load, PDX2** **Frictional variation with camber, PDX3** **Longitudinal curvature at nominal normal load, PEX1** **Variation of curvature factor with load, PEX2** **Variation of curvature factor with square of load, PEX3** **Longitudinal curvature factor with slip, PEX4** **Longitudinal slip stiffness at nominal normal load, PKX1** **Variation of slip stiffness with load, PKX2** **Slip stiffness exponent factor, PKX3** **Horizontal shift in slip ratio at nominal normal load, PHX1** **Variation of horizontal slip ratio with load, PHX2** **Vertical shift in load at nominal normal load, PVX1** **Variation of vertical shift with load, PVX2** **Linear variation of longitudinal slip stiffness with tire pressure, PPX1** **Quadratic variation of longitudinal slip stiffness with tire pressure, PPX2** **Linear variation of peak longitudinal friction with tire pressure, PPX3** **Quadratic variation of peak longitudinal friction with tire pressure, PPX4** **Linear variation of longitudinal slip stiffness with tire pressure, PPX1** **Slip speed decay function scaling factor, lam_muV** **Brake slip stiffness scaling factor, lam_Kxkappa** **Longitudinal shape scaling factor, lam_Cx** **Longitudinal curvature scaling factor, lam_Ex**

Selecting	Enables These Parameters
	Longitudinal horizontal shift scaling factor, lam_Hx **Longitudinal vertical shift scaling factor, lam_Vx**
`Mapped force`	**Slip ratio breakpoints, kappaFx** **Normal force breakpoints, FzFx** **Longitudinal force map, FxMap**

`Rolling Resistance` — Select type

`None` (default) | `Pressure and velocity` | `ISO 28580` | `Magic Formula` | `Mapped torque`

To calculate the rolling resistance torque, specify one of these **Rolling Resistance** parameters.

Setting	Block Implementation
`None`	None
`Pressure and velocity`	Method in *Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance*. The rolling resistance is a function of tire pressure, normal force, and velocity.
`ISO 28580`	Method specified in ISO 28580:2018, *Passenger car, truck and bus tyre rolling resistance measurement method — Single point test and correlation of measurement results*.
`Magic Formula`	Magic formula equations from 4.E70 in *Tire and Vehicle Dynamics*. The magic formula is an empirical equation based on fitting coefficients.
`Mapped torque`	Lookup table that is a function of the normal force and spin axis longitudinal velocity.

Dependencies

Selecting	Parameters
`Pressure and velocity`	**Velocity independent force coefficient, aMy** **Linear velocity force component, bMy** **Quadratic velocity force component, cMy** **Tire pressure exponent, alphaMy** **Normal force exponent, betaMy**

Selecting	Parameters
ISO 28580	**Parasitic losses force, Fpl** **Rolling resistance constant, Cr** **Thermal correction factor, Kt** **Measured temperature, Tmeas** **Parasitic losses force, Fpl** **Ambient temperature, Tamb**
Magic Formula	**Rolling resistance torque coefficient, QSY** **Longitudinal force rolling resistance coefficient, QSY2** **Linear rotational speed rolling resistance coefficient, QSY3** **Quartic rotational speed rolling resistance coefficient, QSY4** **Camber squared rolling resistance torque, QSY5** **Load based camber squared rolling resistance torque, QSY6** **Normal load rolling resistance coefficient, QSY7** **Pressure load rolling resistance coefficient, QSY8** **Rolling resistance scaling factor, lam_My**
Mapped torque	**Spin axis velocity breakpoints, VxMy** **Normal force breakpoints, FzMy** **Rolling resistance torque map, MyMap**

Brake Type — Select type

None | Disc | Drum | Mapped

There are four types of Longitudinal Wheel blocks. Each block implements a different brake type.

Block Name	Brake Type Setting	Brake Implementation
Longitudinal Wheel - No Brake	None	None
Longitudinal Wheel - Disc Brake	Disc	Brake that converts the brake cylinder pressure into a braking force.
Longitudinal Wheel - Drum Brake	Drum	Simplex drum brake that converts the applied force and brake geometry into a net braking torque.

Block Name	Brake Type Setting	Brake Implementation
Longitudinal Wheel - Mapped Brake	`Mapped`	Lookup table that is a function of the wheel speed and applied brake pressure.

`Vertical Motion` — Select type
`None` (default) | `Mapped stiffness and damping`

To calculate vertical motion, specify one of these **Vertical Motion** parameters.

Setting	Block Implementation
`None`	Block passes the applied chassis forces directly through to the rolling resistance and longitudinal force calculations.
`Mapped stiffness and damping`	Vertical motion depends on wheel stiffness and damping. Stiffness is a function of tire sidewall displacement and pressure. Damping is a function of tire sidewall velocity and pressure.

Selecting	Enables These Parameters	Creates These Output Ports
`Mapped stiffness and damping`	**Wheel and unsprung mass, m** **Initial deflection, zo** **Initial velocity, zdoto** **Gravitational acceleration, g** **Vertical deflection breakpoints, zFz** **Pressure breakpoints, pFz** **Force due to deflection, Fzz** **Vertical velocity breakpoints, zdotFz** **Force due to velocity, Fzzdot** **Ground displacement, Gndz** **Input ground displacement**	`z` `zdot`

`Longitudinal scaling factor, lam_x` — Friction scaling factor
`1` (default)

Longitudinal friction scaling factor, dimensionless.

Dependencies

To enable this parameter, clear **Input friction scale factor**.

`Input friction scale factor` — Selection
`Off` (default)

Create input port for longitudinal friction scaling factor.

Dependencies

Selecting this parameter:

- Creates input port `lam_mux`.
- Disables parameter **Longitudinal scaling factor, lam_x**.

Wheel Dynamics

`Axle viscous damping coefficient, br` — Damping
`0.001` (default) | `scalar`

Axle viscous damping coefficient, *br*, in N·m·s/rad.

`Wheel inertia, Iyy` — Inertia
`0.8` (default) | `scalar`

Wheel inertia, in kg·m^2.

`Wheel initial angular velocity, omegao` — Wheel speed
`0` (default) | `scalar`

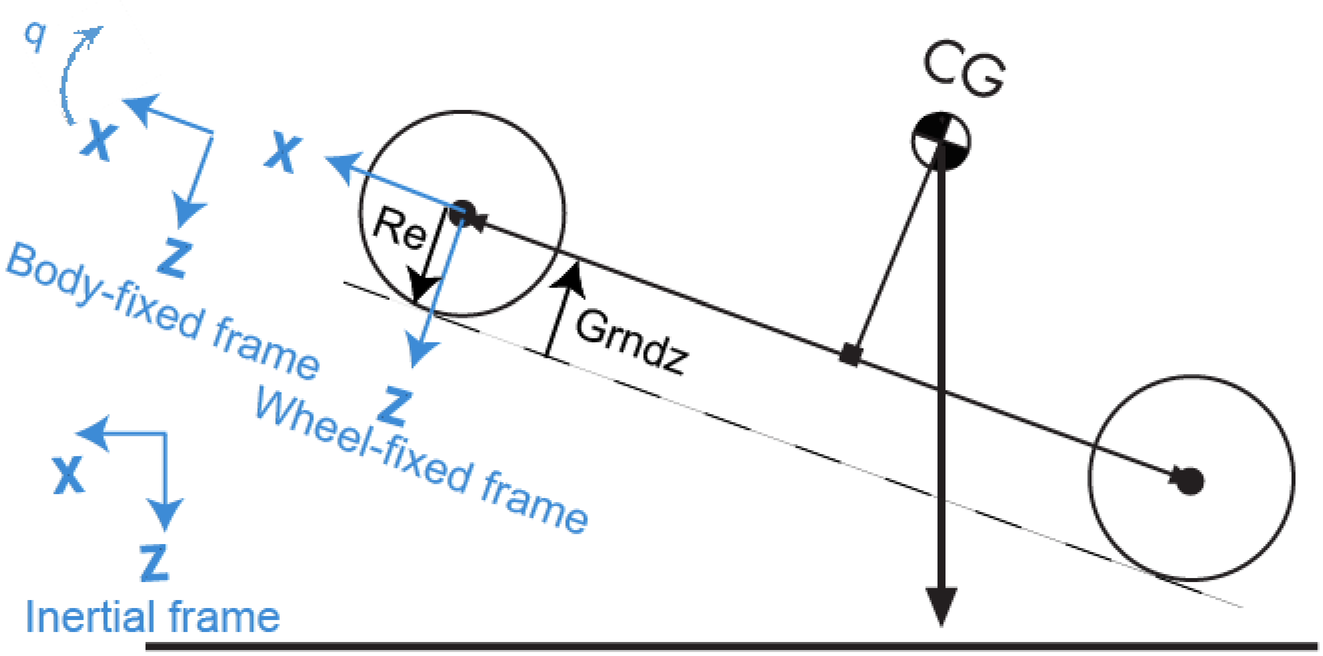
Initial angular velocity of wheel, along body-fixed *y*-axis, in rad/s.

`Relaxation length, Lrel` — Relaxation length
`0.5` (default) | `scalar`

Wheel relaxation length, in m.

`Loaded radius, Re` — Loaded radius
`0.3` (default) | `scalar`

Loaded wheel radius, Re, in m.



`Unloaded radius, UNLOADED_RADIUS` — Unloaded radius
`0.4` (default) | `scalar`

Unloaded wheel radius, in m.

Dependencies

To create this parameter, set **Rolling Resistance** to `Pressure and velocity` or `Magic Formula`.

`Nominal longitudinal speed, LONGVL` — Speed
`16` (default) | `scalar`

Nominal longitudinal speed along body-fixed *x*-axis, in m/s.

Dependencies

To enable this parameter, set **Longitudinal Force** to `Magic Formula pure longitudinal slip`.

`Nominal camber angle, gamma` — Camber
`0` (default) | `scalar`

Nominal camber angle, in rad.

Dependencies

To enable this parameter, set either:

- **Longitudinal Force** to `Magic Formula pure longitudinal slip`.
- **Rolling Resistance** to `Magic Formula`.

Nominal pressure, NOMPRES — Pressure
220000 (default) | scalar

Nominal pressure, in Pa.

Dependencies

To enable this parameter, set either:

- **Longitudinal Force** to `Magic Formula pure longitudinal slip`.
- **Rolling Resistance** to `Magic Formula`.

Pressure, press — Pressure
220000 (default) | scalar

Pressure, in Pa.

Dependencies

To enable this parameter:

- Set one of these:
  - **Longitudinal Force** to `Magic Formula pure longitudinal slip`.
  - **Rolling Resistance** to `Pressure and velocity` or `Magic Formula`.
  - **Vertical Motion** to `Mapped stiffness and damping`.
- On the **Wheel Dynamics** pane, clear **Input tire pressure**.

Longitudinal

Magic Formula Constant Value

Pure longitudinal peak factor, Dx — Factor
1 (default) | scalar

Pure longitudinal peak factor, dimensionless.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula constant value`.

Pure longitudinal shape factor, Cx — Factor
1.65 (default) | scalar

Pure longitudinal shape factor, dimensionless.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula constant value`.

`Pure longitudinal stiffness factor, Bx` — Factor
`10` (default) | `scalar`

Pure longitudinal stiffness factor, dimensionless.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula constant value`.

`Pure longitudinal curvature factor, Ex` — Factor
`0.01` (default) | `scalar`

Pure longitudinal curvature factor, dimensionless.

The coefficients are based on empirical tire data. These values are typical sets of constant Magic Formula coefficients for common road conditions.

Surface	B	C	D	E
Dry tarmac	10	1.9	1	0.97
Wet tarmac	12	2.3	0.82	1
Snow	5	2	0.3	1
Ice	4	2	0.1	1

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula constant value`.

Magic Formula Pure Longitudinal Slip

`Cfx shape factor, PCX1` — Factor
`1.6` (default) | `scalar`

Cfx shape factor, PCX1, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Longitudinal friction at nominal normal load, PDX1` — Factor
`1` (default) | `scalar`

Longitudinal friction at nominal normal load, PDX1, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Frictional variation with load, PDX2` — Factor
`-0.08` (default) | `scalar`

Frictional variation with load, PDX2, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Frictional variation with camber, PDX3` — Factor
`0` (default) | `scalar`

Frictional variation with camber, PDX3, 1/rad^2.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Longitudinal curvature at nominal normal load, PEX1` — Factor
`0.112` (default) | `scalar`

Longitudinal curvature at nominal normal load, PEX1, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Variation of curvature factor with load, PEX2` — Factor
`0.313` (default) | `scalar`

Variation of curvature factor with load, PEX2, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Variation of curvature factor with square of load, PEX3` — Factor
`0` (default) | `scalar`

Variation of curvature factor with square of load, PEX3, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Longitudinal curvature factor with slip, PEX4` — Factor
`0.0016` (default) | `scalar`

Longitudinal curvature factor with slip, PEX4, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Longitudinal slip stiffness at nominal normal load, PKX1` — Factor
`21.7` (default) | `scalar`

Longitudinal slip stiffness at nominal normal load, PKX1, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Variation of slip stiffness with load, PKX2` — Factor
`13.77` (default) | `scalar`

Variation of slip stiffness with load, PKX2, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

`Slip stiffness exponent factor, PKX3` — Factor
`-0.412` (default) | `scalar`

Slip stiffness exponent factor, PKX3, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Horizontal shift in slip ratio at nominal normal load, PHX1 — Factor
2.1585E-4 (default) | scalar

Horizontal shift in slip ratio at nominal normal load, PHX1, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Variation of horizontal slip ratio with load, PHX2 — Factor
0.00115 (default) | scalar

Variation of horizontal slip ratio with load, PHX2, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Vertical shift in load at nominal normal load, PVX1 — Factor
1.5973E-5 (default) | scalar

Vertical shift in load at nominal normal load, PVX1, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Variation of vertical shift with load, PVX2 — Factor
1.043E-4 (default) | scalar

Variation of vertical shift with load, PVX2, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Linear variation of longitudinal slip stiffness with tire pressure, PPX1 — Factor
-0.3489 (default) | scalar

Linear variation of longitudinal slip stiffness with tire pressure, PPX1, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Quadratic variation of longitudinal slip stiffness with tire pressure, PPX2 — Factor
0.382 (default) | scalar

Quadratic variation of longitudinal slip stiffness with tire pressure, PPX2, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Linear variation of peak longitudinal friction with tire pressure, PPX3 — Factor
`-0.09634` (default) | `scalar`

Linear variation of peak longitudinal friction with tire pressure, PPX3, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Quadratic variation of peak longitudinal friction with tire pressure, PPX4 — Factor
`0.06447` (default) | `scalar`

Quadratic variation of peak longitudinal friction with tire pressure, PPX4, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Slip speed decay function scaling factor, lam_muV — Factor
`1` (default) | `scalar`

Slip speed decay function scaling factor, lam_muV, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Brake slip stiffness scaling factor, lam_Kxkappa — Factor
`1` (default) | `scalar`

Brake slip stiffness scaling factor, lam_Kxkappa, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Longitudinal shape scaling factor, lam_Cx — Factor
`1` (default) | `scalar`

Longitudinal shape scaling factor, lam_Cx, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Longitudinal curvature scaling factor, lam_Ex — Factor
0 (default) | scalar

Longitudinal curvature scaling factor, lam_Ex, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Longitudinal horizontal shift scaling factor, lam_Hx — Factor
1 (default) | scalar

Longitudinal horizontal shift scaling factor, lam_Hx, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Longitudinal vertical shift scaling factor, lam_Vx — Factor
1 (default) | scalar

Longitudinal vertical shift scaling factor, lam_Vx, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Magic Formula pure longitudinal slip`.

Mapped Force

Slip ratio breakpoints, kappaFx — Breakpoints
vector

Slip ratio breakpoints, dimensionless.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Mapped force`.

Normal force breakpoints, FzFx — Breakpoints
vector

Normal force breakpoints, N.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Mapped force`.

Longitudinal force map, FxMap — Lookup table
array

Longitudinal force versus slip ratio and normal force, N.

Dependencies

To create this parameter, select the **Longitudinal Force** parameter `Mapped force`.

Rolling Resistance

Pressure and Velocity

`Velocity independent force coefficient, aMy` — Force coefficient
`8e-4` (default) | `scalar`

Velocity-independent force coefficient, *a*, in s/m.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Pressure and velocity`.

`Linear velocity force component, bMy` — Force component
`.001` (default) | `scalar`

Linear velocity force component, *b*, in s/m.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Pressure and velocity`.

`Quadratic velocity force component, cMy` — Force component
`1.6e-4` (default) | `scalar`

Quadratic velocity force component, *c*, in s^2/m^2.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Pressure and velocity`.

`Tire pressure exponent, alphaMy` — Pressure exponent
`-0.003` (default) | `scalar`

Tire pressure exponent, α, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Pressure and velocity`.

`Normal force exponent, betaMy` — Force exponent
`0.97` (default) | `scalar`

Normal force exponent, β, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Pressure and velocity`.

ISO 28580

`Parasitic losses force, Fpl` — Force loss
`10` (default) | `scalar`

Parasitic force loss, F_{pl}, in N.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `ISO 28580`.

Rolling resistance constant, Cr — Constant
1e-3 (default) | scalar

Rolling resistance constant, C_r, in N/kN. ISO 28580 specifies the rolling resistance unit as one newton of tractive resistance for every kilonewtons of normal load.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Thermal correction factor, Kt — Correction factor
.008 (default) | scalar

Thermal correction factor, K_t, in 1/degC.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Measured temperature, Tmeas — Temperature
298.15 (default) | scalar

Measured temperature, T_{meas}, in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Ambient temperature, Tamb — Temperature
298.15 (default) | scalar

Measured temperature, T_{amb}, in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Input ambient temperature — Selection
off (default) | on

Select to create input port Tamb.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter ISO 28580.

Magic Formula

Rolling resistance torque coefficient, QSY1 — Torque coefficient
0.007 (default) | scalar

Rolling resistance torque coefficient, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

`Longitudinal force rolling resistance coefficient, QSY2` — Force resistance coefficient
`0` (default) | `scalar`

Longitudinal force rolling resistance coefficient, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Magic Formula`.

`Linear rotational speed rolling resistance coefficient, QSY3` — Linear speed coefficient
`0.0015` (default) | `scalar`

Linear rotational speed rolling resistance coefficient, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Magic Formula`.

`Quartic rotational speed rolling resistance coefficient, QSY4` — Quartic speed coefficient
`8.5e-05` (default) | `scalar`

Quartic rotational speed rolling resistance coefficient, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Magic Formula`.

`Camber squared rolling resistance torque, QSY5` — Camber resistance torque
`0` (default) | `scalar`

Camber squared rolling resistance torque, in 1/rad^2.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Magic Formula`.

`Load based camber squared rolling resistance torque, QSY6` — Load resistance torque
`0` (default) | `scalar`

Load based camber squared rolling resistance torque, in 1/rad^2.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Magic Formula`.

`Normal load rolling resistance coefficient, QSY7` — Normal resistance coefficient
`0.9` (default) | `scalar`

Normal load rolling resistance coefficient, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `Magic Formula`.

Pressure load rolling resistance coefficient, QSY8 — Pressure resistance coefficient
-0.4 (default) | scalar

Pressure load rolling resistance coefficient, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

Rolling resistance scaling factor, lam_My — Scale
1 (default) | scalar

Rolling resistance scaling factor, dimensionless.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Magic Formula.

Mapped

Spin axis velocity breakpoints, VxMy — Breakpoints
-20:1:20 (default) | vector

Spin axis velocity breakpoints, in m/s.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Mapped torque.

Normal force breakpoints, FzMy — Breakpoints
0:200:1e4 (default) | vector

Normal force breakpoints, in N.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Mapped torque.

Rolling resistance torque map, MyMap — Lookup table
array

Rolling resistance torque versus axle speed and normal force, in N·m.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter Mapped torque.

Brake

Static friction coefficient, mu_static — Static friction
.3 (default) | scalar

Static friction coefficient, dimensionless.

Dependencies

To enable this parameter, for the **Brake Type** parameter, specify one of these types:

- `Disc`
- `Drum`
- `Mapped`

`Kinetic friction coefficient, mu_kinetic` — Kinetic friction
`.2` (default) | `scalar`

Kinematic friction coefficient, dimensionless.

Dependencies

To enable this parameter, for the **Brake Type** parameter, specify one of these types:

- `Disc`
- `Drum`
- `Mapped`

Disc

`Disc brake actuator bore, disc_abore` — Bore distance
`.05` (default) | `scalar`

Disc brake actuator bore, in m.

Dependencies

To enable the disc brake parameters, select `Disc` for the **Brake Type** parameter.

`Brake pad mean radius, Rm` — Radius
`.177` (default) | `scalar`

Brake pad mean radius, in m.

Dependencies

To enable the disc brake parameters, select `Disc` for the **Brake Type** parameter.

`Number of brake pads, num_pads` — Count
`2` (default) | `scalar`

Number of brake pads.

Dependencies

To enable the disc brake parameters, select `Disc` for the **Brake Type** parameter.

Drum

`Drum brake actuator bore, disc_abore` — Bore distance
`0.0508` (default) | `scalar`

Drum brake actuator bore, in m.

Dependencies

To enable the drum brake parameters, select `Drum` for the **Brake Type** parameter.

Shoe pin to drum center distance, drum_a — Distance
0.123 (default) | scalar

Shoe pin to drum center distance, in m.

Dependencies

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

Shoe pin center to force application point distance, drum_c — Distance
0.212 (default) | scalar

Shoe pin center to force application point distance, in m.

Dependencies

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

Drum internal radius, drum_r — Radius
0.15 (default) | scalar

Drum internal radius, in m.

Dependencies

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

Shoe pin to pad start angle, drum_theta1 — Angle
0 (default) | scalar

Shoe pin to pad start angle, in deg.

Dependencies

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

Shoe pin to pad end angle, drum_theta2 — Angle
126 (default) | scalar

Shoe pin to pad end angle, in deg.

Dependencies

To enable the drum brake parameters, select Drum for the **Brake Type** parameter.

Mapped

Brake actuator pressure breakpoints, brake_p_bpt — Breakpoints
vector

Brake actuator pressure breakpoints, in bar.

Dependencies

To enable the mapped brake parameters, select Mapped for the **Brake Type** parameter.

Wheel speed breakpoints, brake_n_bpt — Breakpoints
vector

Wheel speed breakpoints, in rpm.

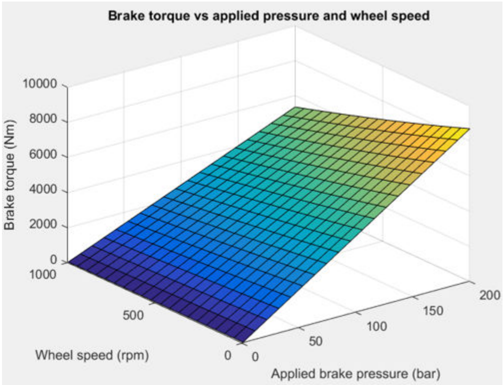
Dependencies

To enable the mapped brake parameters, select `Mapped` for the **Brake Type** parameter.

`Brake torque map, f_brake_t` — Lookup table
`array`

The lookup table for the brake torque, $f_{brake}(P, N)$, is a function of applied brake pressure and wheel speed, where:

- T is brake torque, in N·m.
- P is applied brake pressure, in bar.
- N is wheel speed, in rpm.



Dependencies

To enable the mapped brake parameters, select `Mapped` for the **Brake Type** parameter.

Vertical

`Nominal normal force, FNOMIN` — Force
`2000` (default) | `scalar`

Nominal rated wheel load along wheel-fixed *z*-axis, in N.

Dependencies

To enable this parameter, set either:

- **Longitudinal Force** to `Magic Formula pure longitudinal slip`.
- **Rolling Resistance** to `Magic Formula`.

`Nominal rated load scaling factor, lam_Fzo` — Factor
`1` (default) | `scalar`

Nominal rated load scaling factor, dimensionless. Used to scale the normal for specific applications and load conditions.

Dependencies

To enable this parameter, set **Longitudinal Force** to `Magic Formula pure longitudinal slip`.

`Wheel and unsprung mass, m` — Mass
`10` (default) | `scalar`

Wheel and unsprung mass, in kg. Used in the vertical motion calculations.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

`Initial deflection, zo` — Deflection
`0` (default) | `scalar`

Initial axle displacement along wheel-fixed *z*-axis, in m.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

`Initial velocity, zdoto` — Velocity
`0` (default) | `scalar`

Initial axle velocity along wheel-fixed *z*-axis, in m.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

`Gravitational acceleration, g` — Gravity
`9.81` (default) | `scalar`

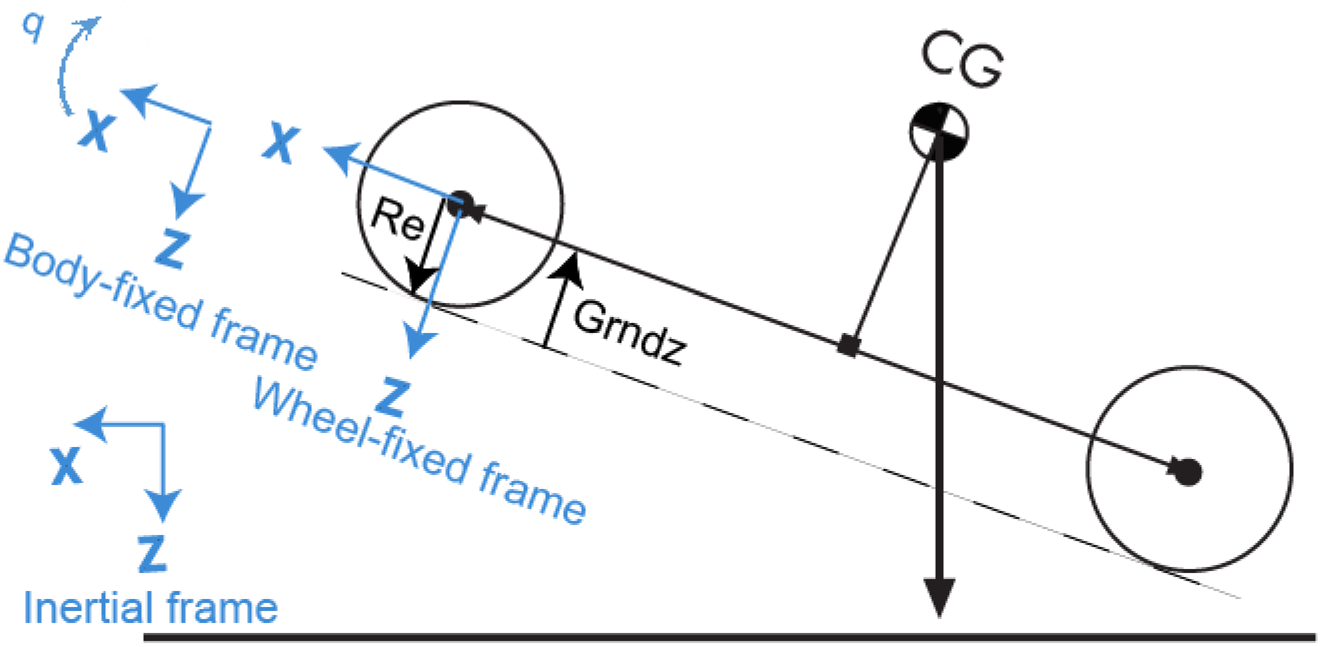
Gravitational acceleration, in m/s^2.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

`Ground displacement, Gndz` — Displacement
`0` (default) | `scalar`

Ground displacement, `Grndz`, along negative wheel-fixed *z*-axis, in m.



Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

Mapped Stiffness and Damping

`Vertical deflection breakpoints, zFz` — Breakpoints
`[0 .01 .1]` (default) | `vector`

Vector of sidewall deflection breakpoints corresponding to the force table, in m.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

`Pressure breakpoints, pFz` — Breakpoints
`[10000 1000000]` (default) | `vector`

Vector of pressure data points corresponding to the force table, in Pa.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

`Force due to deflection, Fzz` — Force
`[0 1e3 1e4; 0 1e4 1e5]` (default) | `vector`

Force due to sidewall deflection and pressure along wheel-fixed *z*-axis, in N.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

`Vertical velocity breakpoints, zdotFz` — Breakpoints
`[-20 0 20]` (default) | `scalar`

Vector of sidewall velocity breakpoints corresponding to the force due to velocity table, in m.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

`Force due to velocity, Fzzdot` — Force
`[500 0 -500;250 0 -250]` (default) | `array`

Force due to sidewall velocity and pressure along wheel-fixed *z*-axis, in N.

Dependencies

To enable this parameter, set **Vertical Motion** to `Mapped stiffness and damping`.

Simulation Setup

`Minimum normal force, FZMIN` — Force
`0` (default) | `scalar`

Minimum normal force, in N. Used with all vertical force calculations.

`Maximum normal force, FZMAX` — Force
`10000` (default) | `scalar`

Maximum normal force, in N. Used with all vertical force calculations.

`Max allowable slip ratio (absolute), kappamax` — Ratio
`1.5` (default) | `scalar`

Maximum allowable absolute slip ratio, dimensionless.

`Velocity tolerance used to handle low velocity situations, VXLOW` — Tolerance
`1` (default) | `scalar`

Velocity tolerance used to handle low-velocity situations, in m/s.

`Minimum ambient temperature, TMIN` — Tmin
`0` (default) | `scalar`

Minimum ambient temperature, T_{MIN}, in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `ISO 28580`.

`Maximum ambient temperature, TMAX` — Tmax
`400` (default) | `scalar`

Maximum ambient temperature, T_{MAX}, in K.

Dependencies

To create this parameter, select the **Rolling Resistance** parameter `ISO 28580`.

References

[1] Highway Tire Committee. *Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance*. Standard J2452_199906. Warrendale, PA: SAE International, June 1999.

[2] Pacejka, H. B. *Tire and Vehicle Dynamics*. 3rd ed. Oxford, United Kingdom: SAE and Butterworth-Heinemann, 2012.

[3] Schmid, Steven R., Bernard J. Hamrock, and Bo O. Jacobson. "Chapter 18: Brakes and Clutches." *Fundamentals of Machine Elements, SI Version*. 3rd ed. Boca Raton, FL: CRC Press, 2014.

[4] Shigley, Joseph E., and Larry Mitchel. *Mechanical Engineering Design*. 4th ed. New York, NY: McGraw Hill, 1983.

[5] ISO 28580:2018. *Passenger car, truck and bus tyre rolling resistance measurement method -- Single point test and correlation of measurement results*. ISO (International Organization for Standardization), 2018.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

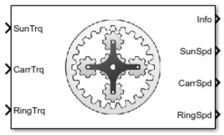
See Also

Drive Cycle Source | Longitudinal Driver

Introduced in R2017a

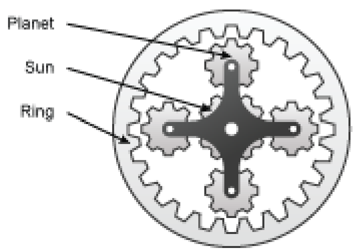
Planetary Gear

Ideal planetary gear with sun, ring, and carrier
Library: Powertrain Blockset / Drivetrain / Couplings



Description

The Planetary Gear block implements an ideal planetary gear coupling consisting of a rigidly coupled sun, ring, and carrier gears. The block calculates the dynamic response to the sun, carrier, and ring input torques.



In fuel economy and powertrain studies, you can use the Planetary Gear block as a power-split device by coupling it to common driveline elements such as transmissions, engines, clutches, and differentials.

These equations of motion represent the dynamic response of the planetary gear.

$$\dot{\omega}_s J_s = \dot{\omega}_s b_s + T_s + T_{ps}$$
$$\dot{\omega}_c J_c = \dot{\omega}_c b_c + T_c + T_{pc}$$
$$\dot{\omega}_s J_r = \dot{\omega}_r b_r + T_r + T_{pr}$$
$$\dot{\omega}_p J_p = \omega_p b_p + T_{rp} + T_{sp} + T_{cp}$$

To reduce the equations of motion, the block uses these kinematic and geometric constraints.

$$\omega_c r_c = r_s \omega_s + r_p \omega_p$$
$$\omega_r r_r = r_c \omega_c + r_p \omega_p$$
$$r_c = r_s + r_p$$
$$r_r = r_c + r_p$$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrSun	Sun gear applied power	$\omega_s T_s$
		PwrCarr	Carrier gear applied power	$\omega_c T_c$
		PwrRing	Ring gear applied power	$\omega_r T_r$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrDampLoss	Mechanical damping loss	$-\left(b_s\omega_s^2 + b_c\omega_c^2 + b_r\omega_r^2 + b_p\omega_p^2\right)$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredPlntry	Rate change in rotational kinetic energy	$\dot{\omega}_s\omega_s J_s + \dot{\omega}_c\omega_c J_c + \dot{\omega}_r\omega_r J_r + \dot{\omega}_p\omega_p J_p$

The equations use these variables.

ω_c, ω_p, ω_r, ω_s	Carrier, planet, ring, and sun gear angular speed
r_c, r_p, r_r, r_s	Carrier, planet, ring, and sun gear angular radius
J_c, J_p, J_r, J_s	Carrier, planet, ring, and sun gear inertia
b_c, b_p, b_r, b_s	Carrier, planet, ring, and sun gear damping
T_c, T_p, T_r, T_s	Applied carrier, planet, ring, and sun gear torque

T_{ps}	Torque applied from planet gear on sun gear
T_{pc}	Torque applied from planet gear on carrier gear
T_{pr}	Torque applied from planet gear on ring gear
T_{rp}	Torque applied from ring gear on planet gear
T_{sp}	Torque applied from sun gear on planet gear
T_{cp}	Torque applied from carrier gear on planet gear

Ports

Input

`SunTrq` — Sun gear applied torque
`scalar`

Sun gear input torque, T_s, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

`CarrTrq` — Carrier gear applied torque
`scalar`

Carrier gear input torque, T_c, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

`RingTrq` — Ring gear applied torque
`scalar`

Ring gear applied torque, T_r, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

`C` — Carrier gear angular speed and torque
two-way connector port

Carrier gear angular speed, ω_c, in rad/s. Carrier gear applied torque, T_c, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Two-way connection`.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
Sun	SunTrq		Sun gear applied torque	N·m
	SunSpd		Sun gear angular speed	rad/s
Carr	CarrTrq		Carrier gear applied torque	N·m
	CarrSpd		Carrier gear angular speed	rad/s
Ring	RingTrq		Ring gear applied torque	N·m
PwrInfo	PwrTrnsfrd	PwrSun	Sun gear applied power	W
		PwrCarr	Carrier gear applied power	W
		PwrRing	Ring gear applied power	W
	PwrNotTrnsfrd	PwrDampLoss	Mechanical damping loss	W
	PwrStored	PwrStoredPlntry	Rate change in rotational kinetic energy	W

SunSpd — Sun gear angular speed
`scalar`

Sun gear angular speed, ω_s, in rad/s.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

`CarrSpd` — Carrier gear angular speed
`scalar`

Carrier gear angular speed, ω_c, in rad/s.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

RingSpd — Ring gear angular speed
`scalar`

Ring gear angular speed, ω_r, in rad/s.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

S — Sun gear angular speed and torque
two-way connector port

Sun gear angular speed, ω_s, in rad/s. Sun gear applied torque, T_s, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Two-way connection`.

R — Ring gear angular speed and torque
two-way connector port

Ring gear angular speed, ω_r, in rad/s. Ring gear applied torque, T_r, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Two-way connection`.

Parameters

Block Options

`Port Configuration` — Specify configuration
`Simulink` (default) | `Two-way connection`

Specify the port configuration.

Dependencies

Specifying `Simulink` creates these ports:

- `SunTrq`
- `CarrTrq`
- `RingTrq`
- `SunSpd`
- `CarrSpd`
- `RingSpd`

Specifying `Two-way connection` creates these ports:

- `C`
- `S`
- `R`

`Sun to planet ratio, Nsp` — Ratio
`30/23` (default) | `scalar`

Sun-to-planet gear ratio, dimensionless.

`Sun to ring ratio, Nsr` — Ratio
`30/78` (default) | `scalar`

Sun-to-ring gear ratio, dimensionless.

`Sun inertia, Js` — Inertia
`.003` (default) | `scalar`

Sun gear inertia, J_s, in kg·m^2.

`Planet inertia, Jp` — Inertia
`.001` (default) | `scalar`

Planet gear inertia, J_p, in kg·m^2.

`Ring inertia, Jr` — Inertia
`.01` (default) | `scalar`

Ring gear inertia, J_r, in kg·m^2.

Carrier inertia, Jc — Inertia
.002 (default) | scalar

Carrier gear inertia, J_c, in kg·m^2.

Sun viscous damping, bs — Damping
.001 (default) | scalar

Sun gear viscous damping, b_s, N·m· s/rad.

Ring viscous damping, br — Damping
.001 (default) | scalar

Ring gear viscous damping, b_r, N·m· s/rad.

Planet viscous damping, bp — Damping
.001 (default) | scalar

Planet gear viscous damping, b_p, N·m· s/rad.

Carrier viscous damping, bc — Damping
.001 (default) | scalar

Carrier gear viscous damping, b_c, N·m· s/rad.

Initial sun velocity, ws_o — Angular speed
0 (default) | scalar

Initial sun gear angular speed, in rad/s.

Initial carrier velocity, wc_o — Angular speed
0 (default) | scalar

Initial carrier gear angular speed, in rad/s.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

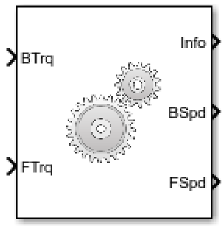
See Also

Disc Clutch | Gearbox | Rotational Inertia | Torque Converter | Torsional Compliance

Introduced in R2017a

Gearbox

Ideal rotational gearbox
Library: Powertrain Blockset / Drivetrain / Couplings



Description

The Gearbox block implements an ideal rotational gearbox. The block uses the gear inertias and damping to calculate the velocity response to the base and follower gear pair input torques.

In fuel economy and powertrain efficiency studies, you can use the Gearbox block to model ideal gear coupling and the power transfer between common driveline elements such as transmissions, engines, clutches, and differentials.

The Gearbox block uses these equations to approximate the transmission dynamics.

$$\dot{\omega}_B J_B = \omega_B b_B + \eta N T_F$$

$$\dot{\omega}_F J_F = \omega_F b_F + \eta T_F$$

This constraint equation reduces the system to a one DOF system.

$$\omega_B = N\omega_F$$

To express the ideal torque transfer, the block uses this relationship.

$$\eta N T_B + T_F = 0$$

Efficiency

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
`Constant`	Constant efficiency that you can set with the **Constant efficiency factor, eta** parameter.

Setting	Implementation
`Driveshaft torque, temperature and speed`	Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints: • **Efficiency lookup table, eta_tbl** • **Efficiency torque breakpoints, Trq_bpts** • **Efficiency speed breakpoints, omega_bpts** • **Efficiency temperature breakpoints, Temp_bpts** For the air temperature, you can either: • Select **Input temperature** to create an input port. • Set a **Ambient temperature, Tamb** parameter value. To select the interpolation method, use the **Interpolation method** parameter. For more information, see “Interpolation Methods”.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrBase`	Mechanical power from base shaft	P_{Base}	$P_{Base} = \eta T_B \omega_B$
		`PwrFlwr`	Mechanical power from follower shaft	P_{Flwr}	$P_{Flwr} = \eta T_F \omega_F$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrMechLoss`	Total power loss	P_{ng}	$P_{ng} = -(P_t + P_d) + P$ $P_t = \eta T_B \omega_B + \eta T_F \omega_F$
		`PwrDampLoss`	Power loss due to damping	P_d	$P_d = -\left(b_F \lvert\omega_F\rvert^2 + b_B \lvert\omega_B\rvert^2\right)$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredShft`	Rate change of stored internal kinetic energy	P_s	$P_s = (\omega_B \dot{\omega}_B J_B + \omega_F \dot{\omega}_F J_F)$

The equations use these variables.

T_B	Base gear input torque
T_F	Follower gear output torque
ω_B	Base gear angular velocity
ω_F	Follower gear angular velocity
J_B	Base gear rotational inertia
J_F	Follower gear rotational inertia
b_B	Base gear rotational viscous damping
b_F	Follower gear rotational viscous damping
N	Torque transmission gear ratio
η	Gear efficiency
P_t	Total power
P_d	Power loss due to damping
P_s	Rate change of stored internal kinetic energy

Ports

Input

`BTrq` — Base gear input torque
`scalar`

Base gear input torque, T_B, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

`FTrq` — Follower gear output torque
`scalar`

Follower gear output torque, T_F, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

`B` — Base gear angular velocity and torque
two-way connector port

Base gear angular velocity, ω_B, in rad/s. Base gear torque, T_B, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Two-way connection`.

`AirTemp` — Ambient air temperature
`scalar`

Ambient air temperature, T_{air}, in K.

Dependencies

To enable this port:

- Set **Efficiency factors** to `Driveshaft torque, speed and temperature`.
- Select **Input ambient temperature**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

<table>
<tr><th colspan="3">Signal</th><th>Description</th><th>Variable</th><th>Units</th></tr>
<tr><td rowspan="2">Base</td><td colspan="2"><code>BaseTrq</code></td><td>Base gear input torque</td><td>T_B</td><td>N·m</td></tr>
<tr><td colspan="2"><code>BaseSpd</code></td><td>Base gear angular velocity</td><td>ω_B</td><td>rad/s</td></tr>
<tr><td rowspan="2">Flwr</td><td colspan="2"><code>FlwrTrq</code></td><td>Follower gear torque</td><td>T_F</td><td>N·m</td></tr>
<tr><td colspan="2"><code>FlwrSpd</code></td><td>Follower gear angular velocity</td><td>ω_F</td><td>rad/s</td></tr>
<tr><td rowspan="5">PwrInfo</td><td rowspan="2"><code>PwrTrnsfrd</code></td><td><code>PwrBase</code></td><td>Mechanical power from base shaft</td><td>P_{Base}</td><td>W</td></tr>
<tr><td><code>PwrFlwr</code></td><td>Mechanical power from follower shaft</td><td>P_{Flwr}</td><td>W</td></tr>
<tr><td rowspan="2"><code>PwrNotTrnsfrd</code></td><td><code>PwrMechLoss</code></td><td>Total gear power loss</td><td>P_{ng}</td><td>W</td></tr>
<tr><td><code>PwrDampLoss</code></td><td>Power loss due to damping</td><td>P_d</td><td>W</td></tr>
<tr><td><code>PwrStored</code></td><td><code>PwrStoredShft</code></td><td>Rate change of stored internal kinetic energy</td><td>P_s</td><td>W</td></tr>
</table>

BSpd — Input gear angular velocity
`scalar`

Base gear angular velocity, ω_B, in rad/s.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

FSpd — Output gear angular velocity
`scalar`

Follower gear angular velocity, ω_F, in rad/s.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

F — Output gear angular velocity and torque
two-way connector port

Follower gear angular velocity, ω_F, in rad/s. Follower gear torque, T_F, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Two-way connection`.

Parameters

Block Options

`Port Configuration` — Specify configuration
`Simulink` (default) | `Two-way connection`

Specify the port configuration.

Dependencies

Specifying `Simulink` creates these ports:

- `BSpd`
- `FSpd`
- `BTrq`
- `FTrq`

Specifying `Two-way connection` creates these ports:

- `B`
- `F`

`Efficiency factors` — Specify configuration
`Constant` (default) | `Driveshaft torque, speed and temperature`

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
`Constant`	Constant efficiency that you can set with the **Constant efficiency factor, eta** parameter.

Setting	Implementation
`Driveshaft torque, temperature and speed`	Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints: • **Efficiency lookup table, eta_tbl** • **Efficiency torque breakpoints, Trq_bpts** • **Efficiency speed breakpoints, omega_bpts** • **Efficiency temperature breakpoints, Temp_bpts** For the air temperature, you can either: • Select **Input temperature** to create an input port. • Set a **Ambient temperature, Tamb** parameter value. To select the interpolation method, use the **Interpolation method** parameter. For more information, see "Interpolation Methods".

Interpolation method — Method
`Flat` | `Nearest` | `Linear point-slope` | `Linear Lagrange` | `Cubic spline`

For more information, see "Interpolation Methods".

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

Output shaft rotates in same direction as input — Rotation
`off` (default) | `on`

Select to specify that the output shaft rotates in the same direction as the input.

Input ambient temperature — Create input port
`off` (default) | `on`

Select to create input port `AirTemp` for the ambient air temperature.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

Input to output gear ratio, N — Ratio
`2` (default) | `scalar`

Base-to-follower gear ratio, dimensionless.

Input shaft inertia, J1 — Inertia
`.01` (default) | `scalar`

Base shaft inertia, in kg·m^2.

Output shaft inertia, J2 — Inertia
`.01` (default) | `scalar`

Follower shaft inertia, in kg·m^2.

Input shaft damping, b1 — Damping
.001 (default) | scalar

Base viscous shaft damping, in N·m· s/rad.

Output shaft damping, b2 — Damping
.001 (default) | scalar

Follower viscous shaft damping, in N·m· s/rad.

Input shaft initial velocity, w1_o — Initial velocity
0 (default) | scalar

Base shaft initial velocity, in rad/s.

Efficiency

Constant efficiency factor, eta — Efficiency
1 (default) | scalar

Constant efficiency, η.

Dependencies

To enable this parameter, set **Efficiency factors** to `Constant`.

Efficiency lookup table, eta_tbl — Lookup table
M-by-N-by-L array

Dimensionless array of values for efficiency as a function of:

- M input torques
- N input speed
- L air temperatures

Each value specifies the efficiency for a specific combination of torque, speed, and temperature. The array size must match the dimensions defined by the torque, speed, and temperature breakpoint vectors.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

Efficiency torque breakpoints, Trq_bpts — Torque breakpoints
[25, 50, 75, 100, 150, 200, 250] (default) | 1-by-M vector

Vector of input torque, breakpoints for efficiency, in N·m.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency speed breakpoints, omega_bpts` — Speed breakpoints
`[52.4 78.5 105 131 157 183 209 262 314 419 524]` (default) | 1-by-N vector

Vector of speed, breakpoints for efficiency, in rad/s.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency temperature breakpoints, Temp_bpts` — Temperature breakpoints
`[290 358]` (default) | 1-by-L vector

Vector of ambient temperature breakpoints for efficiency, in K.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Air temperature, Tair` — Ambient air temperature
`297.15` (default) | `scalar`

Ambient air temperature, T_{air}, in K.

Dependencies

To enable this parameter:

- Set **Efficiency factors** to `Driveshaft torque, speed and temperature`.
- Clear **Input ambient temperature**.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

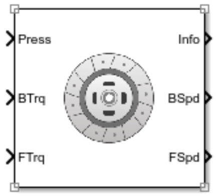
Disc Clutch | Planetary Gear | Rotational Inertia | Torque Converter | Torsional Compliance

Introduced in R2017a

Disc Clutch

Idealized disc clutch coupler

Library: Powertrain Blockset / Drivetrain / Couplings



Description

The Disc Clutch block implements an idealized disc clutch coupler. The block couples the rotary input and output shafts through an idealized friction model. To determine the output torque, the block uses friction parameters, relative slip velocity, and applied input pressure.

In fuel economy and powertrain efficiency studies, you can use the Disc Clutch block to model the mechanical power transfer between common driveline elements such as transmissions, engines, and differentials.

To approximate the torque response, the Disc Clutch block implements friction and dynamic models that depend on the clutch lockup condition. The block determines the locked or unlocked condition based on an idealized dry clutch friction model. This table summarizes the logic the block uses to determine the clutch condition.

Clutch Condition	When
Unlocked	$\omega_i \neq \omega_o$ or $T_{fmax} < \left\lvert \frac{J_o T_i - (J_o b_i - J_i b_o)\omega_{i/o}}{J_o + J_i} \right\rvert$
Locked	$\omega_i = \omega_o$ and $T_{fmax} < \left\lvert T_i - \frac{J_i(b_i + b_o)\omega_i}{J_o + J_i} + b_o\omega_i \right\rvert$

This table summarizes the friction and dynamic models that the block uses for locked or unlocked clutch conditions.

Clutch Condition	Friction Model	Dynamic Model
Unlocked	$T_{fmax} = T_k$ where, $T_k = N_{disc} P_c A_{eff} R_{eff} \mu_k \tanh[4(\omega_i - \omega_o)]$ $R_{eff} = \frac{2(R_o 3 - R_i 3)}{3(R_o 2 - R_i 2)}$ and$P_c = \max(P_c - P_{eng}, 0)$	$\dot{\omega}_i J_i = T_i - T_f - \omega_i b_i$ $\dot{\omega}_o J_o = T_f + T_o - \omega_o b_o$
Locked	$T_{fmax} = T_s$ where, $T_s = N_{disc} P_c A_{eff} R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o 3 - R_i 3)}{3(R_o 2 - R_i 2)}$	$\dot{\omega}_i (J_o + J_i) = T_o - \omega_i (b_i + b_o) + T_i$ $\omega_i = \omega_o$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrBase	Applied base power	$\omega_i T_i$
		PwrFlwr	Applied follower output power	$\omega_o T_o$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrDampLoss	Damping power loss	$-b_o \omega_o^2 - b_i \omega_i^2$
		PwrCltchSlipLoss	Clutch slip power loss	$-T_k(\omega_i - \omega_o)$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredBase	Rate change in base rotational kinetic energy	$\dot{\omega}_i \omega_i J_i$
		PwrStoredFlwr	Rate change in follower rotational kinetic energy	$\dot{\omega}_o \omega_o J_o$

The equations use these variables.

ω_i	Input shaft angular speed
ω_o	Output shaft angular speed

b_i	Input shaft viscous damping
b_o	Output shaft viscous damping
J_i	Input shaft moment of inertia
J_o	Output shaft moment of inertia
T_f	Frictional torque
T_i	Net input torque
T_k	Kinetic frictional torque
T_o	Net output torque
T_s	Static frictional torque
T_{fmax}	Maximum frictional torque before slipping
P_c	Applied clutch pressure
P_{eng}	Engagement pressure
A_{eff}	Effective area
N_{disc}	Number of frictional discs
R_{eff}	Effective clutch radius
R_o	Annular disk outer radius
R_i	Annular disk inner radius
R_e	Effective tire radius while under load and for a given pressure
μ_s	Coefficient of static friction
μ_k	Coefficient of kinetic friction

Ports

Input

`Press` — Applied clutch pressure
`scalar`

Base gear input torque, P_c, in N·m^2.

`BTrq` — Applied input torque
`scalar`

Applied input torque, T_i, typically from the engine crankshaft or dual mass flywheel damper, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

`FTrq` — Applied load torque
`scalar`

Applied load torque, T_o, typically from the differential or drive shaft, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

B — Applied drive shaft angular speed and torque
two-way connector port

Applied drive shaft angular speed, ω_i, in rad/s. Applied drive shaft torque, T_i, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Two-way connection`.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
`Base`	`BTrq`		Applied input torque, typically from the engine crankshaft or dual mass flywheel damper	N·m
	`BSpd`		Applied drive shaft angular speed input	rad/s
`Flwr`	`FTrq`		Applied load torque, typically from the differential	N·m
	`FSpd`		Drive shaft angular speed output	rad/s
`Cltch`	`CltchForce`		Applied clutch force	N
	`CltchLocked`		Clutch lock status	NA
	`CltchSpdRatio`		Clutch speed ratio	NA
	`CltchEta`		Clutch power transmission efficiency	NA
`PwrInfo`	`PwrTrnsfrd`	`PwrBase`	Applied base power	W
		`PwrFlwr`	Applied follower output power	W
	`PwrNotTrnsfrd`	`PwrDampLoss`	Damping power loss	W
		`PwrCltchSlipLoss`	Clutch slip power loss	W
	`PwrStored`	`PwrStoredBase`	Rate change in base rotational kinetic energy	W
		`PwrStoredFlwr`	Rate change in follower rotational kinetic energy	W

BSpd — Angular speed
`scalar`

Applied drive shaft angular speed input, ω_i, in rad/s.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

FSpd — Angular speed
`scalar`

Drive shaft angular speed output, ω_o, in rad/s.

Dependencies

To create this port, for **Port Configuration**, select `Simulink`.

F — Output velocity and torque
two-way connector port

Output drive shaft angular speed, ω_{oi}, in rad/s. Output drive shaft torque, T_o, in N·m.

Dependencies

To create this port, for **Port Configuration**, select `Two-way connection`.

Parameters

Block Options

`Port Configuration` — Specify configuration
`Simulink` (default) | `Two-way connection`

Specify the port configuration.

Dependencies

Specifying `Simulink` creates these ports:

- `BSpd`
- `FSpd`
- `BTrq`
- `FTrq`

Specifying `Two-way connection` creates these ports:

- `B`
- `F`

`Clutch force equivalent net radius, Reff` — Radius
`1` (default) | `scalar`

Clutch force equivalent net radius, in m.

`Number of disks, Ndisk` — Ratio
`1` (default) | `scalar`

Number of disks, dimensionless.

Effective applied pressure area, Aeff — Pressure area
.01 (default) | scalar

Effective applied pressure area, in m^2.

Engagement pressure threshold, Peng — Pressure threshold
0 (default) | scalar

Pressure to engage clutch, in Pa.

Input shaft inertia, Jin — Inertia
.1 (default) | scalar

Input shaft inertia, in kg·m^2.

Output shaft inertia, Jout — Inertia
.1 (default) | scalar

Output shaft inertia, in kg·m^2.

Kinetic friction coefficient, muk — Coefficient
.3 (default) | scalar

Kinetic friction coefficient, dimensionless.

Static friction coefficient, mus — Coefficient
.5 (default) | scalar

Static friction coefficient, dimensionless.

Input shaft viscous damping, bin — Damping
.001 (default) | scalar

Input shaft viscous damping, in N·m· s/rad.

Output shaft viscous damping, bout — Damping
.001 (default) | scalar

Output shaft viscous damping, in N·m· s/rad.

Initial input shaft velocity, win_o — Initial velocity
0 (default) | scalar

Input shaft initial velocity, in rad/s.

Initial output shaft velocity, wout_o — Initial velocity
0 (default) | scalar

Input shaft initial velocity, in rad/s.

Clutch actuation time constant, tauC — Constant
.01 (default) | scalar

Clutch actuation time constant, in s.

`Clutch initially locked` — Select to initially lock clutch
`off` (default) | `on`

Select to lock clutch initially.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

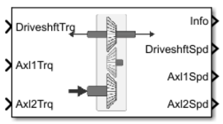
Planetary Gear | Rotational Inertia | Torque Converter | Torsional Compliance

Introduced in R2017a

Transfer Case

Differential as a planetary bevel gear

Library: Powertrain Blockset / Drivetrain / Final Drive Unit
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Final Drive Unit



Description

The Transfer Case block implements a differential as a planetary bevel gear train. The block matches the driveshaft bevel gear to the crown (ring) bevel gear. You can specify:

- Carrier-to-driveshaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier

Use the Transfer Case block to:

- Dynamically couple the post-transmission driveshaft to the wheel axles or universal joints
- Model simplified or older drivetrains when optimal traction control does not require passive or active torque vectoring
- Model mechanical power splitting in generic gearbox and drive line scenarios

The block is suitable for use in hardware-in-the-loop (HIL) and optimization workflows. All the parameters are tunable.

Efficiency

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
`Constant`	Constant efficiency that you can set with the **Constant efficiency factor, eta** parameter.

Setting	Implementation
`Driveshaft torque, temperature and speed`	Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints: • **Efficiency lookup table, eta_tbl** • **Efficiency torque breakpoints, Trq_bpts** • **Efficiency speed breakpoints, omega_bpts** • **Efficiency temperature breakpoints, Temp_bpts** For the air temperature, you can either: • Select **Input temperature** to create an input port. • Set a **Ambient temperature, Tamb** parameter value. To select the interpolation method, use the **Interpolation method** parameter. For more information, see “Interpolation Methods”.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrDriveshft`	Mechanical power from driveshaft	$\eta T_d \omega_d$
		`PwrAxl1`	Mechanical power from axle 1	$\eta T_1 \omega_1$
		`PwrAxl2`	Mechanical power from axle 2	$\eta T_2 \omega_2$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrMechLoss`	Total power loss	$\dot{W}_{loss} = -(P_t + P_d) + P_s$ $P_t = \eta T_d \omega_d + \eta T_1 \omega_1 + \eta T_2 \omega_2$
		`PwrDampLoss`	Power loss due to damping	$P_d = -(b_1\|\omega_1\| + b_2\|\omega_2\| + b_d\|\omega_d\|)$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredShft`	Rate change of stored internal energy	$P_s = -(\omega_1 \dot{\omega}_1 J_1 + \omega_2 \dot{\omega}_2 J_2 + \omega_d \dot{\omega}_d J_d)$

Dynamics

The Transfer Case block implements these differential equations to represent the mechanical dynamic response for the crown gear, front axle, and rear axle.

Mechanical Dynamic Response	Differential Equation
Crown Gear	$\dot{\omega}_d J_d = \eta T_d - \omega_d b_d - T_i$
Front Axle	$\dot{\omega}_1 J_1 = \eta T_1 - \omega_1 b_1 - T_{i1}$
Rear Axle	$\dot{\omega}_2 J_2 = \eta T_2 - \omega_2 b_2 - T_{i2}$

The equations use these variables.

N	Carrier-to-driveshaft gear ratio
J_d	Rotational inertia of the crown gear assembly
b_d	Crown gear linear viscous damping
ω_d	Driveshaft angular speed
η	Differential efficiency
J_1	Axle 1 rotational inertia
b_1	Axle 1 linear viscous damping
ω_1	Axle 1 speed
J_2	Axle 2 rotational inertia
b_2	Axle 2 linear viscous damping
ω_2	Axle 2 angular speed
T_d	Driveshaft torque
T_1	Axle 1 torque
T_2	Axle 2 torque
T_i	Driveshaft internal resistance torque
T_{i1}	Axle 1 internal resistance torque
T_{i2}	Axle 2 internal resistance torque

Ports

Inputs

`DriveshftTrq` — Torque
`scalar`

Applied input torque, typically from the engine crankshaft, in N·m.

`Axl1Trq` — Torque
`scalar`

Axle 1 torque, T_1, in N·m.

Axl2Trq — Torque
scalar

Axle 2 torque, T_2, in N·m.

Temp — Temperature
scalar

Temperature, in K.

Dependencies

To enable this port:

- Set **Efficiency factors** to `Driveshaft torque, speed and temperature`.
- Select **Input temperature**.

TrqSplitRatioConstant — Front axle torque split ratio
scalar

Front axle torque split ratio.

Dependencies

To enable this port, select **Input front axle torque split ratio, TrqSplitRatio**.

SpdLockConstant — Axle speed lock
scalar

Axle speed lock.

Dependencies

To enable this port, select **Input axle speed lock, SpdLock**.

Output

Info — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
Driveshft	DriveshftTrq		Driveshaft torque	N·m
	DriveshftSpd		Driveshaft speed	rad/s
Axl1	Axl1Trq		Axle 1 torque	N·m
	Axl1Spd		Axle 1 speed	rad/s
Axl2	Axl2Trq		Axle 2 torque	N·m
	Axl2Spd		Axle 2 speed	rad/s
PwrInfo	PwrTrnsfrd	PwrDriveshft	Mechanical power from driveshaft	W

Signal			Description	Units
		PwrAxl1	Mechanical power from axle 1	W
		PwrAxl2	Mechanical power from axle 2	W
	PwrTrnsfrd	PwrMechLoss	Total power loss	W
		PwrDampLoss	Power loss due to damping	W
	PwrStored	PwrStoredShft	Rate change of stored internal energy	W

DriveshftSpd — Angular speed
scalar

Driveshaft angular speed, ω_d, in rad/s.

Axl1Spd — Angular speed
scalar

Axle 1 angular speed, ω_1, in rad/s.

Axl2Spd — Angular speed
scalar

Axle 2 angular speed, ω_2, in rad/s.

Parameters

Block Options

Efficiency factors — Specify configuration
Constant (default) | Driveshaft torque, speed and temperature

To account for the block efficiency, use the **Efficiency factors** parameter. This table summarizes the block implementation for each setting.

Setting	Implementation
Constant	Constant efficiency that you can set with the **Constant efficiency factor, eta** parameter.

Setting	Implementation
`Driveshaft torque, temperature and speed`	Efficiency as a function of base gear input torque, air temperature, and driveshaft speed. Use these parameters to specify the lookup table and breakpoints: • **Efficiency lookup table, eta_tbl** • **Efficiency torque breakpoints, Trq_bpts** • **Efficiency speed breakpoints, omega_bpts** • **Efficiency temperature breakpoints, Temp_bpts** For the air temperature, you can either: • Select **Input temperature** to create an input port. • Set a **Ambient temperature, Tamb** parameter value. To select the interpolation method, use the **Interpolation method** parameter. For more information, see “Interpolation Methods”.

Interpolation method — Method
`Flat` | `Nearest` | `Linear point-slope` | `Linear Lagrange` | `Cubic spline`

For more information, see “Interpolation Methods”.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

Input temperature — Create input port
`off` (default) | `on`

Select to create input port `Temp` for the temperature.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

Input front axle torque split ratio, TrqSplitRatio — Create input port
`off` (default) | `on`

Select to create input port `TrqSplitRatioConstant` for the front axle torque split ratio.

Input axle speed lock, SpdLock — Create input port
`off` (default) | `on`

Select to create input port `SpdLockConstant` for the axle speed lock.

Crown wheel (ring gear) located — Specify crown wheel connection
`To the left of center-line` (default) | `To the right of center-line`

Specify the crown wheel connection to the driveshaft.

Carrier to drive shaft ratio, Ndiff — Ratio
4 (default) | `scalar`

Carrier-to-driveshaft gear ratio, N, dimensionless.

`Carrier inertia, Jd` — Inertia
`.1` (default) | `scalar`

Rotational inertia of the crown gear assembly, J_d, in kg·m^2. You can include the driveshaft inertia.

`Carrier damping, bd` — Damping
`1e-3` (default) | `scalar`

Crown gear linear viscous damping, b_d, in N·m·s/rad.

`Axle 1 inertia, Jw1` — Inertia
`.1` (default) | `scalar`

Axle 1 rotational inertia, J_1, in kg·m^2.

`Axle 1 damping, bw1` — Damping
`1e-3` (default) | `scalar`

Axle 1 linear viscous damping, b_1, in N·m·s/rad.

`Axle 2 inertia, Jw2` — Inertia
`.1` (default) | `scalar`

Axle 2 rotational inertia, J_2, in kg·m^2.

`Axle 2 damping, bw2` — Damping
`1e-3` (default) | `scalar`

Axle 2 linear viscous damping, b_2, in N·m·s/rad.

`Axle 1 initial velocity, omegaw1o` — Angular velocity
`0` (default) | `scalar`

Axle 1 initial velocity, ω_{o1}, in rad/s.

`Axle 2 initial velocity, omegaw2o` — Angular velocity
`0` (default) | `scalar`

Axle 2 initial velocity, ω_{o2}, in rad/s.

Efficiency

`Constant efficiency factor, eta` — Efficiency
`1` (default) | `scalar`

Constant efficiency, η.

Dependencies

To enable this parameter, set **Efficiency factors** to `Constant`.

`Efficiency lookup table, eta_tbl` — Lookup table
`M`-by-`N`-by-`L` array

Dimensionless array of values for efficiency as a function of:

- `M` input torques
- `N` input speed
- `L` air temperatures

Each value specifies the efficiency for a specific combination of torque, speed, and temperature. The array size must match the dimensions defined by the torque, speed, and temperature breakpoint vectors.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency torque breakpoints, Trq_bpts` — Torque breakpoints
`[25, 50, 75, 100, 150, 200, 250]` (default) | 1-by-`M` vector

Vector of input torque, breakpoints for efficiency, in N·m.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency speed breakpoints, omega_bpts` — Speed breakpoints
`[52.4 78.5 105 131 157 183 209 262 314 419 524]` (default) | 1-by-`N` vector

Vector of speed, breakpoints for efficiency, in rad/s.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Efficiency temperature breakpoints, Temp_bpts` — Temperature breakpoints
`[290 358]` (default) | 1-by-`L` vector

Vector of ambient temperature breakpoints for efficiency, in K.

Dependencies

To enable this parameter, set **Efficiency factors** to `Driveshaft torque, speed and temperature`.

`Ambient temperature, Tamb` — Ambient temperature
`297.15` (default) | `scalar`

Ambient air temperature, T_{air}, in K.

Dependencies

To enable this parameter:

- Set **Efficiency factors** to `Driveshaft torque, speed and temperature`.
- Clear **Input temperature**.

`Front axle torque split ratio, TrqSplitRatio` — Front axle torque split ratio
`0.5` (default) | `scalar`

Front axle torque split ratio.

Dependencies

To enable this parameter, clear **Input front axle torque split ratio, TrqSplitRatio**.

`Axle speed lock, SpdLock` — Axle speed lock

`0` (default) | `scalar`

Axle speed lock. Set this value to 0 to make the front and rear axle rotational speed not fixed. Set this value to 1 to make the front and rear axle rotational speed fixed.

Dependencies

To enable this parameter, clear **Input axle speed lock, SpdLock**.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Limited Slip Differential

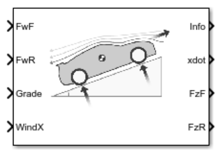
Introduced in R2021b

Vehicle Dynamics Blocks

Vehicle Body 1DOF Longitudinal

Two-axle vehicle in forward and reverse motion

Library: Powertrain Blockset / Vehicle Dynamics
Vehicle Dynamics Blockset / Vehicle Body



Description

The Vehicle Body 1DOF Longitudinal block implements a one degree-of-freedom (1DOF) rigid vehicle body with constant mass undergoing longitudinal (that is, forward and reverse) motion. Use the block:

- In powertrain and fuel economy studies to represent the vehicle inertial and drag loads when weight transfer from vertical and pitch motions are negligible.
- To determine the engine torque and power required for the vehicle to follow a specified drive cycle.

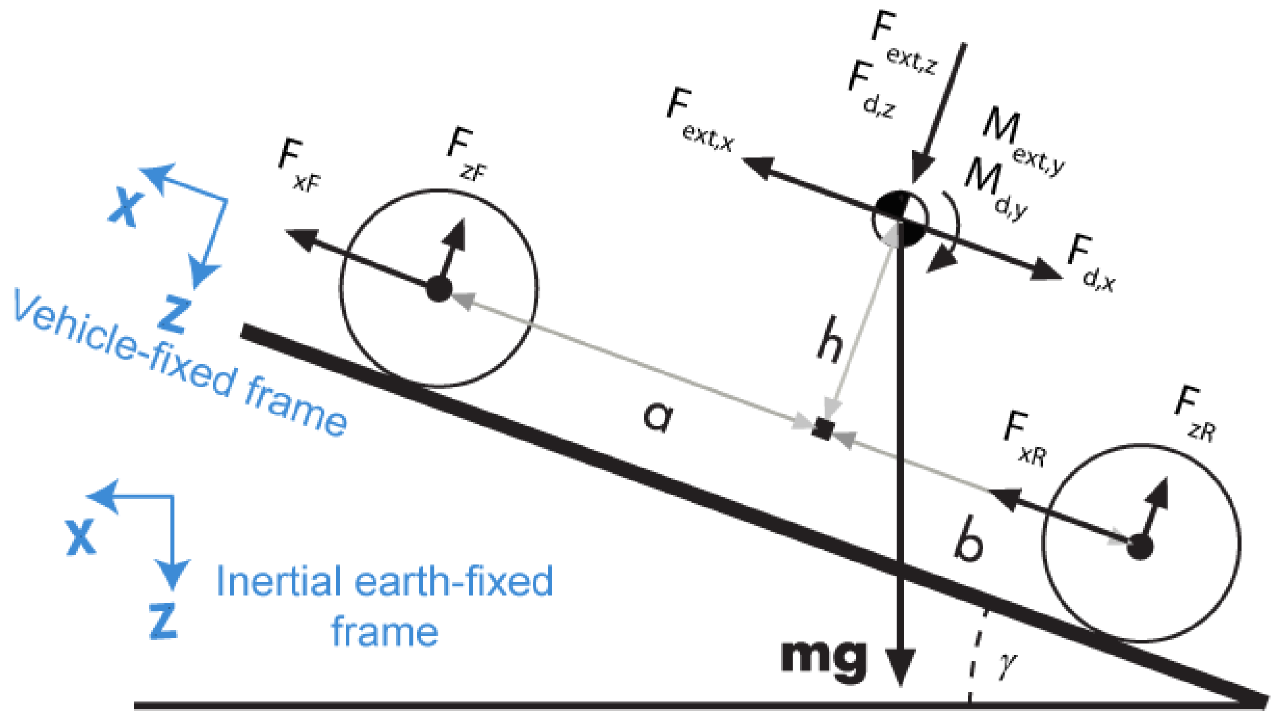
You can select block options to create input ports for external forces, moments, air temperature, and wind speed.

Block Option Setting	External Input Ports	Description
External forces	`FExt`	External force applied to vehicle CG in the vehicle-fixed frame.
External moments	`MExt`	External moment about vehicle CG in the vehicle-fixed frame.
Air temperature	`AirTemp`	Ambient air temperature. Consider this option if you want to vary the temperature during run-time.
Wind X,Y,Z	`WindXYZ`	Wind speed along earth-fixed *X*-, *Y*-, and *Z*-axes. If you do not select this option, the block implements input port `WindX` — Longitudinal wind speed along the earth-fixed *X*-axis.

Vehicle Body Model

The vehicle axles are parallel and form a plane. The longitudinal direction lies in this plane and is perpendicular to the axles. If the vehicle is traveling on an inclined slope, the normal direction is not parallel to gravity but is always perpendicular to the axle-longitudinal plane.

The block uses the net effect of all the forces and torques acting on it to determine the vehicle motion. The longitudinal tire forces push the vehicle forward or backward. The weight of the vehicle acts through its center of gravity (CG). The grade angle changes the direction of the resolved gravitational force acting on the vehicle CG. Similarly, the block resolves the resistive aerodynamic drag force on the vehicle CM.



The Vehicle Body 1DOF Longitudinal block implements these equations.

$$F_b = m\ddot{x}$$

$$F_b = F_{xF} + F_{xR} - F_{d,x} + F_{ext,x} - mg\sin\gamma$$

Zero normal acceleration and zero pitch torque determine the normal force on each front and rear axles.

$$F_{zF} = \frac{-M_{ext,y} - M_{d,y} + b(F_{d,z} + F_{ext,z} + mg\cos\gamma) - h(-F_{ext,x} + F_{d,x} + mg\sin\gamma + m\ddot{x})}{N_F(a + b)}$$

$$F_{zR} = \frac{M_{ext,y} + M_{d,y} + a(F_{d,z} + F_{ext,z} + mg\cos\gamma) + h(-F_{ext,x} + F_{d,x} + mg\sin\gamma + m\ddot{x})}{N_R(a + b)}$$

The wheel normal forces satisfy this equation.

$$N_F F_{zF} + N_R F_{zR} - F_{ext,z} = mg\cos\gamma$$

Wind and Drag Forces

The block subtracts the wind speeds from the vehicle velocity components to obtain a net relative airspeed. To calculate the drag force and moments acting on the vehicle, the block uses the net relative airspeed.

$$F_{d,x} = \frac{1}{2TR} C_d A_f P_{abs}(\dot{x}$$

$$F_{d,z} = \frac{1}{2TR} C_l A_f P_{abs}(\dot{x}$$

$$M_{d,y} = \frac{1}{2TR} C_{pm} A_f P_{abs}(\dot{x}(a + b)$$

By default, to calculate the wind speed along the vehicle-fixed *x*-axis, the block uses the longitudinal wind speed along the earth-fixed *X*-axis. If you select **WindX,Y,Z**, the block uses the wind speed along the earth-fixed *X*-, *Y*-, *Z*-axes.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrFxExt`	Externally applied force power	$P_{FxExt} = F_{xExt}\dot{x}$
		`PwrFwFx`	Longitudinal force power applied at the front axle	$P_{FwFx} = F_{wF}\dot{x}$
		`PwrFwRx`	Longitudinal force power applied at the rear axle	$P_{FwRx} = F_{wR}\dot{x}$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFxDrag`	Drag force power	$P_d = -\frac{0.5C_dA_fP_{abs}\left(\dot{x}^2 - w_x\right)^2}{287.058T}\dot{x}$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`wrStoredGrvty`	Rate change in gravitational potential energy	$P_g = -mg\dot{Z}$
		`PwrStoredxdot`	Rate in change of longitudinal kinetic energy	$P_{\dot{x}} = m\ddot{x}\dot{x}$

The equations use these variables.

F_{xf}, F_{xr}	Longitudinal forces on each wheel at the front and rear ground contact points, respectively

F_{zf}, F_{zr}	Normal load forces on each wheel at the front and rear ground contact points, respectively
F_{wF}, F_{wR}	Longitudinal force on front and rear axles along vehicle-fixed x-axis
F_{xExt}, F_{wR}	External force along the vehicle-fixed x-axis
$F_{d,x}$, $F_{d,z}$	Longitudinal and normal drag force on vehicle CG
$M_{d,y}$	Torque due to drag on vehicle about the vehicle-fixed y-axis
F_d	Aerodynamic drag force
V_x	Velocity of the vehicle. When $V_x > 0$, the vehicle moves forward. When $V_x < 0$, the vehicle moves backward.
N_f, N_r	Number of wheels on front and rear axle, respectively
γ	Angle of road grade
m	Vehicle body mass
a,b	Distance of front and rear axles, respectively, from the normal projection point of vehicle CG onto the common axle plane
h	Height of vehicle CG above the axle plane
C_d	Frontal air drag coefficient
A_f	Frontal area
P_{abs}	Absolute pressure
ρ	Mass density of air
x, $\dot{x}$, $\ddot{x}$	Vehicle longitudinal position, velocity, and acceleration along the vehicle-fixed x-axis
w_x	Wind speed along the vehicle-fixed x-axis
$\dot{Z}$	Vehicle vertical velocity along the vehicle-fixed z-axis

Limitations

The Vehicle Body 1DOF Longitudinal block lets you model only longitudinal dynamics, parallel to the ground and oriented along the direction of motion. The vehicle is assumed to be in pitch and normal equilibrium. The block does not model pitch or vertical movement. To model a vehicle with three degrees-of-freedom (DOF), use the Vehicle Body 3DOF Longitudinal.

Ports

Input

`FExt` — External force on vehicle CG

`array`

External forces applied to vehicle CG, F_{xext}, F_{yext}, F_{zext}, in vehicle-fixed frame, in N. Signal vector dimensions are `[1x3]` or `[3x1]`.

Dependencies

To enable this port, select **External forces**.

`MExt` — External moment about vehicle CG
`array`

External moment about vehicle CG, M_x, M_y, M_z, in the vehicle-fixed frame, in N·m. Signal vector dimensions are `[1x3]` or `[3x1]`.

Dependencies

To enable this port, select **External moments**.

`FwF` — Total longitudinal force on front axle
`scalar`

Longitudinal force on the front axle, F_{xf}, along vehicle-fixed `x`-axis, in N.

`FwR` — Total longitudinal force on rear axle
`scalar`

Longitudinal force on the rear axle, Fw_R, along vehicle-fixed `x`-axis, in N.

`Grade` — Road grade angle
`scalar`

Road grade angle, γ, in deg.

`WindX` — Longitudinal wind speed
`scalar`

Longitudinal wind speed, W_w, along earth-fixed `X`-axis, in m/s.

Dependencies

To enable this port, clear **Wind X,Y,Z components**.

`WindXYZ` — Wind speed
`array`

Wind speed, W_w, W_{wY}, W_{wZ} along inertial X-, Y-, and Z-axes, in m/s. Signal vector dimensions are `[1x3]` or `[3x1]`.

Dependencies

To enable this port, select **Wind X,Y,Z components**.

`AirTemp` — Ambient air temperature
`scalar`

Ambient air temperature, T_{air}, in K. Considering this option if you want to vary the temperature during run-time.

Dependencies

To enable this port, select **Air temperature**.

Output

`Info` — Bus signal
bus

Bus signal containing these block values.

Signal				Description	Value	Units
InertFrm	Cg	Disp	X	Vehicle CG displacement along earth-fixed X-axis	Computed	m
			Y	Vehicle CG displacement along earth-fixed Y-axis	0	m
			Z	Vehicle CG displacement along earth-fixed Z-axis	Computed	m
		Vel	Xdot	Vehicle CG velocity along earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CG velocity along earth-fixed Y-axis	0	m/s
			Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s
		Ang	phi	Rotation of vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about the earth-fixed Y-axis (pitch)	Computed (input - grade angle)	rad
			psi	Rotation of vehicle-fixed frame about the earth-fixed Z-axis (yaw)	0	rad
	FrntAxl	Disp	X	Front axle displacement along the earth-fixed X-axis	Computed	m
			Y	Front axle displacement along the earth-fixed Y-axis	0	m
			Z	Front axle displacement along the earth-fixed Z-axis	Computed	m
		Vel	Xdot	Front axle velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Front axle velocity along the earth-fixed Y-axis	0	m/s
			Zdot	Front axle velocity along the earth-fixed Z-axis	Computed	m/s
	RearAxl	Disp	X	Rear axle displacement along the earth-fixed X-axis	Computed	m
			Y	Rear axle displacement along the earth-fixed Y-axis	0	m
			Z	Rear axle displacement along the earth-fixed Z-axis	Computed	m

Signal				Description	Value	Units
		Vel	Xdot	Rear axle velocity along the earth-fixed X-axis	Computed	m/s
			Ydot	Rear axle velocity along the earth-fixed Y-axis	0	m/s
			Zdot	Rear axle velocity along the earth-fixed Z-axis	Computed	m/s
BdyFrm	Cg	Disp	x	Vehicle CG displacement along the vehicle-fixed x-axis	Computed	m
			y	Vehicle CG displacement along the vehicle-fixed y-axis	0	m
			z	Vehicle CG displacement along the vehicle-fixed z-axis	0	m
		Vel	xdot	Vehicle CG velocity along the vehicle-fixed x-axis	Computed	m/s
			ydot	Vehicle CG velocity along the vehicle-fixed y-axis	0	m/s
			zdot	Vehicle CG velocity along the vehicle-fixed z-axis	0	m/s
		AngVel	p	Vehicle angular velocity about the vehicle-fixed x-axis (roll rate)	0	rad/s
			q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	0	rad/s
			r	Vehicle angular velocity about the vehicle-fixed z-axis (yaw rate)	0	rad/s
		Accel	ax	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CG acceleration along the vehicle-fixed y-axis	0	gn
			az	Vehicle CG acceleration along the vehicle-fixed z-axis	0	gn
	Forces	Body	Fx	Net force on vehicle CG along the vehicle-fixed x-axis	0	N

Signal					Description	Value	Units
			Fy		Net force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz		Net force on vehicle CG along the vehicle-fixed z-axis	0	N
		Ext	Fx		External force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy		External force on vehicle CG along the vehicle-fixed y-axis	Computed	N
			Fz		External force on vehicle CG along the vehicle-fixed z-axis	Computed	N
		FrntAxl	Fx		Longitudinal force on front axle, along the vehicle-fixed x-axis	0	N
			Fy		Lateral force on front axle, along the vehicle-fixed y-axis	0	N
			Fz		Normal force on front axle, along the vehicle-fixed z-axis	Computed	N
		RearAxl	Fx		Longitudinal force on rear axle, along the vehicle-fixed x-axis	0	N
			Fy		Lateral force on rear axle, along the vehicle-fixed y-axis	0	N
			Fz		Normal force on rear axle, along the vehicle-fixed z-axis	Computed	N
		Tires	FrntTire	Fx	Front tire force, along the vehicle-fixed x-axis	0	N
				Fy	Front tire force, along the vehicle-fixed y-axis	0	N
				Fz	Front tire force, along the vehicle-fixed z-axis	Computed	N
			RearTire	Fx	Rear tire force, along the vehicle-fixed x-axis	0	N
				Fy	Rear tire force, along the vehicle-fixed y-axis	0	N

Signal					Description	Value	Units
				Fz	Rear tire force, along the vehicle-fixed z-axis	Computed	N
		Drag	Fx		Drag force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy		Drag force on vehicle CG along the vehicle-fixed y-axis	Computed	N
			Fz		Drag force on vehicle CG along the vehicle-fixed z-axis	Computed	N
		Grvty	Fx		Gravity force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy		Gravity force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz		Gravity force on vehicle CG along the vehicle-fixed z-axis	Computed	N
	Moments	Body	Mx		Net moment on vehicle CG about the vehicle-fixed x-axis	0	N·m
			My		Net moment on vehicle CG about the vehicle-fixed y-axis	0	N·m
			Mz		Net moment on vehicle CG about the vehicle-fixed z-axis	0	N·m
		Drag	Mx		Drag moment on vehicle CG about the vehicle-fixed x-axis	Computed	N·m
			My		Drag moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m
			Mz		Drag moment on vehicle CG about the vehicle-fixed z-axis	Computed	N·m
		Ext	Fx		External moment on vehicle CG about the vehicle-fixed x-axis	Computed	N·m
			Fy		External moment on vehicle CG about the vehicle-fixed y-axis	Computed	N·m

Signal				Description	Value	Units
			Fz	External moment on vehicle CG about the vehicle-fixed z-axis	Computed	N·m
	FrntAxl	Disp	x	Front axle displacement along the vehicle-fixed x-axis	Computed	m
			y	Front axle displacement along the vehicle-fixed y-axis	0	m
			z	Front axle displacement along the vehicle-fixed z-axis	Computed	m
		Vel	xdot	Front axle velocity along the vehicle-fixed x-axis	Computed	m/s
			ydot	Front axle velocity along the vehicle-fixed y-axis	0	m/s
			zdot	Front axle velocity along the vehicle-fixed z-axis	Computed	m/s
		Steer	WhlAngFL	Front left wheel steering angle	Computed	rad
			WhlAngFR	Front right wheel steering angle	Computed	rad
	RearAxl	Disp	x	Rear axle displacement along the vehicle-fixed x-axis	Computed	m
			y	Rear axle displacement along the vehicle-fixed y-axis	0	m
			z	Rear axle displacement along the vehicle-fixed z-axis	Computed	m
		Vel	xdot	Rear axle velocity along the vehicle-fixed x-axis	Computed	m/s
			ydot	Rear axle velocity along the vehicle-fixed y-axis	0	m/s
			zdot	Rear axle velocity along the vehicle-fixed z-axis	Computed	m/s
		Steer	WhlAngRL	Rear left wheel steering angle	Computed	rad
			WhlAngRR	Rear right wheel steering angle	Computed	rad
	Pwr	PwrExt		Applied external power	Computed	W
		Drag		Power loss due to drag	Computed	W

Signal			Description	Value	Units
PwrInfo	PwrTrnsfrd	PwrFxExt	Externally applied force power	Computed	W
		PwrFwFx	Longitudinal force power applied at the front axle	Computed	W
		PwrFwRx	Longitudinal force power applied at the rear axle	Computed	W
	PwrNotTrnsfrd	PwrFxDrag	Drag force power	Computed	W
	PwrStored	wrStoredGrvty	Rate change in gravitational potential energy	Computed	W
		PwrStoredxdot	Rate in change of longitudinal kinetic energy	Computed	W

xdot — Vehicle body longitudinal velocity
scalar

Vehicle body longitudinal velocity along the vehicle-fixed reference frame x-axis, in m/s.

FzF — Front axle normal force
scalar

Normal load force on the front axle, F_{zf}, along vehicle-fixed z-axis, in N.

FzR — Rear axle normal force
scalar

Normal force on rear axle, F_{zr}, along the vehicle-fixed z-axis, in N.

Parameters

Options

External forces — FExt input port
off (default) | on

Specify to create input port FExt.

External moments — MExt input port
off (default) | on

Specify to create input port MExt.

Air temperature — AirTemp input port
off (default) | on

Specify to create input port AirTemp.

Wind X,Y,Z components — WindXYZ input port
off (default) | on

Specify to create input port `WindXYZ`.

Longitudinal

`Number of wheels on front axle, NF` — Front wheel count
`2` (default) | `scalar`

Number of wheels on front axle, N_F. The value is dimensionless.

`Number of wheels on rear axle, NR` — Rear wheel count
`2` (default) | `scalar`

Number of wheels on rear axle, N_R. The value is dimensionless.

`Mass, m` — Vehicle mass
`1500` (default) | `scalar`

Vehicle mass, M, in kg.

`Horizontal distance from CG to front axle, a` — Front axle distance
`1.4` (default) | `scalar`

Horizontal distance a from the vehicle CG to the front wheel axle, in m.

`Horizontal distance from CG to rear axle, b` — Rear axle distance
`1.8` (default) | `scalar`

Horizontal distance b from the vehicle CG to the rear wheel axle, in m.

`CG height above axles, h` — Height
`.35` (default) | `scalar`

Height of vehicle CG above the ground, h, in m.

`Longitudinal drag coefficient, Cd` — Drag
`.3` (default) | `scalar`

Air drag coefficient, C_d. The value is dimensionless.

`Longitudinal lift coefficient, Cl` — Lift
`0` (default) | `scalar`

Air lift coefficient, C_l. The value is dimensionless.

`Longitudinal drag pitch moment, Cpm` — Pitch drag
`0` (default) | `scalar`

Pitch drag moment coefficient, C_{pm}. The value is dimensionless.

`Frontal area, Af` — Area
`4` (default) | `scalar`

Effective vehicle cross-sectional area, A, to calculate the aerodynamic drag force on the vehicle, in m^2.

`Initial position, x_o` — Position
`0` (default) | `scalar`

Vehicle body longitudinal initial position along the vehicle-fixed x-axis, x_o, in m.

Initial velocity, xdot_o — Velocity
0 (default) | scalar

Vehicle body longitudinal initial velocity along the vehicle-fixed x-axis, $\dot{x}_0$, in m/s.

Environment

Absolute air pressure, Pabs — Pressure
101325 (default) | scalar

Environmental air absolute pressure, P_{abs}, in Pa.

Air temperature, T — Ambient air temperature
273 (default) | scalar

Ambient air temperature, T_{air}, in K.

Dependencies

To enable this parameter, clear **Air temperature**.

Gravitational acceleration, g — Gravity
9.81 (default) | scalar

Gravitational acceleration, g, in m/s^2.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

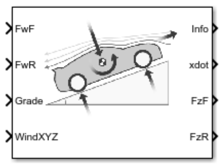
See Also
Vehicle Body 3DOF Longitudinal | Vehicle Body Total Road Load

Introduced in R2017a

Vehicle Body 3DOF Longitudinal

3DOF rigid vehicle body to calculate longitudinal, vertical, and pitch motion

Library: Powertrain Blockset / Vehicle Dynamics
Vehicle Dynamics Blockset / Vehicle Body



Description

The Vehicle Body 3DOF Longitudinal block implements a three degrees-of-freedom (3DOF) rigid vehicle body model with configurable axle stiffness to calculate longitudinal, vertical, and pitch motion. The block accounts for body mass, aerodynamic drag, road incline, and weight distribution between the axles due to acceleration and the road profile.

You can specify the type of axle attachment to the vehicle:

- Grade angle — Vertical axle displacement from road surface to axles remains constant. The block uses tabular stiffness and damping parameters to model the suspension forces acting between the vehicle body and axles.
- Axle displacement — Axles have input-provided vertical displacement and velocity with respect to the road grade. The block uses tabular stiffness and damping parameters to model the suspension forces acting between the vehicle body and axle.
- External suspension — Axles have externally applied forces for coupling the vehicle body to custom suspension models.

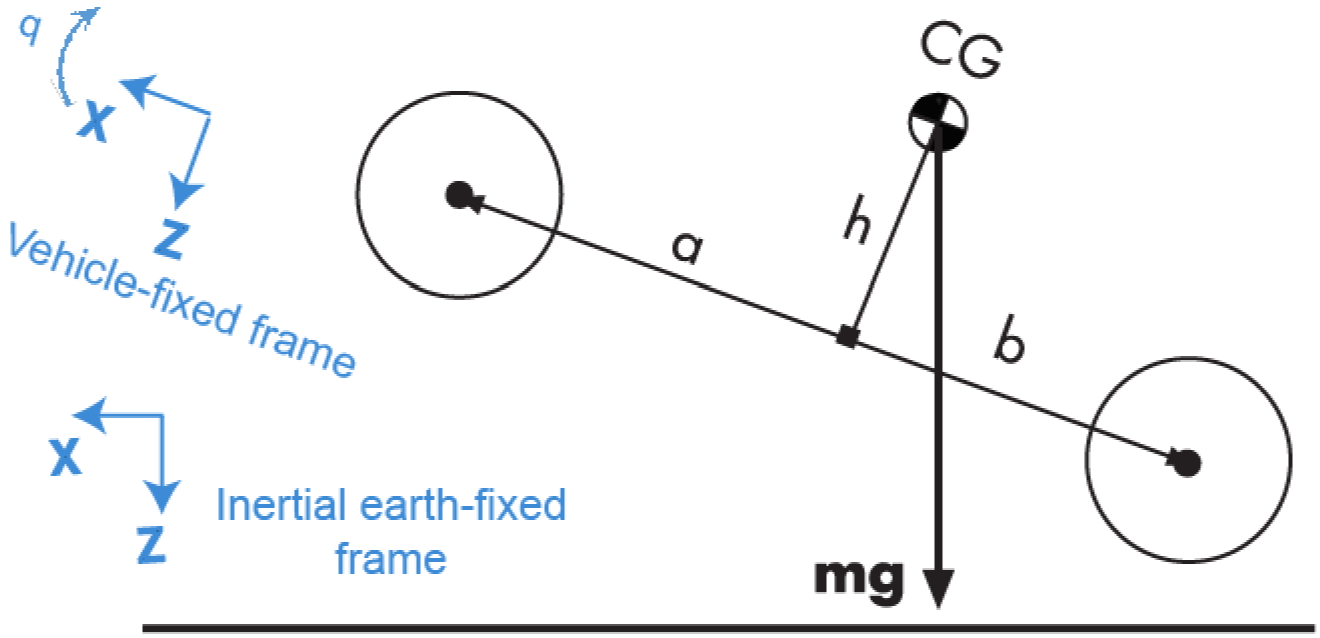
If the weight transfer from vertical and pitch motions are not negligible, consider using this block to represent vehicle motion in powertrain and fuel economy studies. For example, in studies with heavy breaking or acceleration or road profiles that contain larger vertical changes.

The block uses rigid-body vehicle motion, suspension system forces, and wind and drag forces to calculate the normal forces on the front and rear axles. The block resolves the force components and moments on the rigid vehicle body frame:

$$F_x = F_{wF} + F_{wR} - F_{d,x} - F_{sx,F} - F_{sx,R} + F_{g,x}$$

$$F_z = F_{d,z} - F_{sz,F} - F_{sz,R} + F_{g,z}$$

$$M_y = aF_{sz,F} - bF_{sz,R} + h(F_{wF} + F_{wR} + F_{sx,F} + F_{sx,R}) - M_{d,y}$$



Rigid-Body Vehicle Motion

The vehicle axles are parallel and form a plane. The longitudinal direction lies in this plane and is perpendicular to the axles. If the vehicle is traveling on an inclined slope, the normal direction is not parallel to gravity but is always perpendicular to the axle-longitudinal plane.

The block uses the net effect of all the forces and torques acting on it to determine the vehicle motion. The longitudinal tire forces push the vehicle forward or backward. The weight of the vehicle acts through its center of gravity (CG). Depending on the inclined angle, the weight pulls the vehicle to the ground and either forward or backward. Whether the vehicle travels forward or backward, aerodynamic drag slows it down. For simplicity, the drag is assumed to act through the CG.

The Vehicle Body 3DOF Longitudinal implements these equations.

$$\ddot{x} = \frac{F_x}{m} - qz$$

$$\ddot{z} = \frac{F_z}{m} - qx$$

$$\dot{q} = \frac{M_y}{I_{yy}}$$

$$\dot{\theta} = q$$

Suspension System Forces

If you configure the block with the **Ground interaction type** parameter `Grade angle` or `Axle displacement, velocity`, the block uses nonlinear stiffness and damping parameters to model the suspension system.

The front and rear axle suspension forces are given by:

$$Fs_F = N_F[Fk_F + Fb_F]$$
$$Fs_R = N_R[Fk_R + Fb_R]$$

The block uses lookup tables to implement the front and rear suspension stiffness. To account for kinematic and material nonlinearities, including collisions with end-stops, the tables are functions of the stroke.

$$Fk_F = f(dZ_F)$$
$$Fk_R = f(dZ_R)$$

The block uses lookup tables to implement the front and rear suspension damping. To account for nonlinearities, compression, and rebound, the tables are functions of the stroke rate.

$$Fb_F = f(d\dot{Z}_F)$$
$$Fb_R = f(d\dot{Z}_R)$$

The stroke is the difference in the vehicle vertical and axle positions. The stroke rate is the difference in the vertical and axle velocities.

$$dZ_F = Z_F - \bar{Z}_F$$
$$dZ_R = Z_R - \bar{Z}_R$$
$$d\dot{Z}_F = \dot{Z}_F - \dot{\bar{Z}}_F$$
$$d\dot{Z}_R = \dot{Z}_R - \dot{\bar{Z}}_R$$

When the **Ground interaction type** parameter is `Grade angle`, the axle vertical positions ($\bar{Z}_F, \bar{Z}_R$) and velocities ($\dot{\bar{Z}}_F, \dot{\bar{Z}}_R$) are set to `0`.

Wind and Drag Forces

The block subtracts the wind speeds from the vehicle velocity components to obtain a net relative airspeed. To calculate the drag force and moments acting on the vehicle, the block uses the net relative airspeed:

$$F_{d,x} = \frac{1}{2TR} C_d A_f P_{abs}(^{\dot{x}}$$
$$F_{d,z} = \frac{1}{2TR} C_l A_f P_{abs}(^{\dot{x}}$$
$$M_{d,y} = \frac{1}{2TR} C_{pm} A_f P_{abs}(^{\dot{x}}(a + b)$$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrFxExt	Externally applied longitudinal force power	$P_{FxExt} = F_{xExt}\dot{x}$
		PwrFzExt	Externally applied longitudinal force power	$P_{FzExt} = F_{zExt}\dot{z}$
		PwrMyExt	Externally applied pitch moment power	$P_{MzExt} = M_{zExt}\dot{\theta}$
		PwrFwFx	Longitudinal force applied at the front axle	$P_{FwFx} = F_{wF}\dot{x}$
		PwrFwRx	Longitudinal force applied at the rear axle	$P_{FwRx} = F_{wR}\dot{x}$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrFsF	Internal power transferred between suspension and vehicle body at the front axle	$P_{Fs,F} = -P_{FwFx} + P_{FsbF} + P_{Fsk,F} + F_{xF}\dot{x}_F + F_{zF}\dot{z}_F$
		PwrFsR	Internal power transferred between suspension and vehicle body at the rear axle	$P_{Fs,R} = -P_{FwRx} + P_{Fsb,R} + P_{Fsk,R} + F_{xF}\dot{x}_F + F_{zF}\dot{z}_F$
		PwrFxDrag	Longitudinal drag force power	$P_{d,x} = F_{d,x}\dot{x}$
		PwrFzDrag	Vertical drag force power	$P_{d,z} = F_{d,z}\dot{z}$
		PwrMyDrag	Drag pitch moment power	$P_{d,My} = M_{d,y}\dot{\theta}$
		PwrFsb	Total suspension damping power	$P_{Fsb} = \sum_{i=F,R} F_{sb,i}\dot{z}_i$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredGrvty	Rate change in gravitational potential energy	$P_g = -mg\dot{Z}$
		PwrStoredxdot	Rate of change of longitudinal kinetic energy	$P_{\dot{x}} = m\ddot{x}\dot{x}$
		PwrStoredzdot	Rate of change of longitudinal kinetic energy	$P_{\dot{z}} = m\ddot{z}\dot{z}$

Bus Signal			Description	Equations
		PwrStoredq	Rate of change of rotational pitch kinetic energy	$P_{\dot{\theta}} = I_{yy}\ddot{\theta}\dot{\theta}$
		PwrStoredFsFzSprng	Stored spring energy from front suspension	$P_{FskF} = F_{sk,F}\dot{z}_F$
		PwrStoredFsRzSprng	Stored spring energy from rear suspension	$P_{FskF} = F_{sk,R}\dot{z}_R$

The equations use these variables.

F_x	Longitudinal force on vehicle
F_z	Normal force on vehicle
M_y	Torque on vehicle about the vehicle-fixed *y*-axis
F_{wF}, F_{wR}	Longitudinal force on front and rear axles along vehicle-fixed *x*-axis
$F_{d,x}$, $F_{d,z}$	Longitudinal and normal drag force on vehicle CG
$F_{sx,F}$, $F_{sx,R}$	Longitudinal suspension force on front and rear axles
$F_{sz,F}$, $F_{sz,R}$	Normal suspension force on front and rear axles
$F_{g,x}$,$F_{g,z}$	Longitudinal and normal gravitational force on vehicle along the vehicle-fixed frame
$M_{d,y}$	Torque due to drag on vehicle about the vehicle-fixed *y*-axis
a,b	Distance of front and rear axles, respectively, from the normal projection point of vehicle CG onto the common axle plane
h	Height of vehicle CG above the axle plane along vehicle-fixed *z*-axis
Fs_F, Fs_R	Front and rear axle suspension force along vehicle-fixed *z*-axis
Z_{wF}, Z_{wR}	Front and rear vehicle normal position along earth-fixed *z*-axis
Θ	Vehicle pitch angle about the vehicle-fixed *y*-axis
m	Vehicle body mass
N_F, N_R	Number of front and rear wheels
I_{yy}	Vehicle body moment of inertia about the vehicle-fixed *y*-axis
x, $\dot{x}$, $\ddot{x}$	Vehicle longitudinal position, velocity, and acceleration along the vehicle-fixed *x*-axis
z, $\dot{z}$, $\ddot{z}$	Vehicle normal position, velocity, and acceleration along the vehicle-fixed *z*-axis
Fk_F, Fk_R	Front and rear wheel suspension stiffness force along vehicle-fixed *z*-axis
Fb_F, Fb_R	Front and rear wheel suspension damping force along vehicle-fixed *z*-axis
Z_F, Z_R	Front and rear vehicle vertical position along earth-fixed *Z*-axis
$\dot{Z}_F, \dot{Z}_R$	Front and rear vehicle vertical velocity along vehicle-fixed *z*-axis
$\bar{Z}_F, \bar{Z}_R$	Front and rear wheel axle vertical position along vehicle-fixed *z*-axis
$\dot{\bar{Z}}_F, \dot{\bar{Z}}_R$	Front and rear wheel axle vertical velocity along earth-fixed *z*-axis

dZ_F, dZ_R	Front and rear axle suspension deflection along vehicle-fixed *z*-axis
$d\dot{Z}_F, d\dot{Z}_R$	Front and rear axle suspension deflection rate along vehicle-fixed *z*-axis
C_d	Frontal air drag coefficient acting along the vehicle-fixed *x*-axis
C_l	Lateral air drag coefficient acting along the vehicle-fixed *z*-axis
C_{pm}	Air drag pitch moment acting about the vehicle-fixed *y*-axis
A_f	Frontal area
P_{abs}	Environmental absolute pressure
R	Atmospheric specific gas constant
T	Environmental air temperature
w_x	Wind speed along the vehicle-fixed *x*-axis

Ports

Input

`FExt` — External force on vehicle CG

`array`

External forces applied to vehicle CG, F_{xext}, F_{yext}, F_{zext}, in vehicle-fixed frame, in N. Signal vector dimensions are `[1x3]` or `[3x1]`.

Dependencies

To enable this port, select **External forces**.

`MExt` — External moment about vehicle CG

`array`

External moment about vehicle CG, M_x, M_y, M_z, in the vehicle-fixed frame, in N·m. Signal vector dimensions are `[1x3]` or `[3x1]`.

Dependencies

To enable this port, select **External moments**.

`FwF` — Total longitudinal force on the front axle

`scalar`

Longitudinal force on the front axle, Fw_F, along vehicle-fixed *x*-axis, in N.

`FwR` — Total longitudinal force on the rear axle

`scalar`

Longitudinal force on the rear axle, Fw_R, along vehicle-fixed *x*-axis, in N.

`Grade` — Road grade angle

`scalar`

Road grade angle, γ, in deg.

`FsF` — Suspension force on front axle per wheel

`vector`

Suspension force on front axle, Fs_F, along the vehicle-fixed *z*-axis, in N.

Dependencies

To enable this port, for the **Ground interaction type** parameter, select `External suspension`.

`FsR` — Suspension force on rear axle per wheel
`vector`

Suspension force on rear axle, Fs_R, along the vehicle-fixed *z*-axis, in N.

Dependencies

To enable this port, for the **Ground interaction type** parameter, select `External suspension`.

`WindXYZ` — Wind speed
`array`

Wind speed, W_X, W_Y, W_Z along earth-fixed *X*-, *Y*-, and *Z*-axes, in m/s. Signal vector dimensions are `[1x3]` or `[3x1]`.

`AirTemp` — Ambient air temperature
`scalar`

Ambient air temperature, T_{air}, in K. Considering this option if you want to vary the temperature during run-time.

Dependencies

To enable this port, select **Air temperature**.

`zF,R` — Forward and rear axle positions
`vector`

Forward and rear axle positions along the vehicle-fixed *z*-axis, $\bar{Z}_F$, $\bar{Z}_R$, in m.

Dependencies

To enable this port, for the **Ground interaction type** parameter, select `Axle displacement, velocity`.

`zdotF,R` — Forward and rear axle velocities
`vector`

Forward and rear axle velocities along the vehicle-fixed *z*-axis, $\dot{\bar{Z}}_F$, $\dot{\bar{Z}}_R$, in m/s.

Dependencies

To enable this port, for the **Ground interaction type** parameter, select `Axle displacement, velocity`.

Output

`Info` — Bus signal
bus

Bus signal containing these block values.

Signal				Description	Value	Units
InertFrm	Cg	Disp	X	Vehicle CG displacement along earth-fixed *X*-axis	Computed	m
			Y	Vehicle CG displacement along earth-fixed *Y*-axis	0	m
			Z	Vehicle CG displacement along earth-fixed *Z*-axis	Computed	m
		Vel	Xdot	Vehicle CG velocity along earth-fixed *X*-axis	Computed	m/s
			Ydot	Vehicle CG velocity along earth-fixed *Y*-axis	0	m/s
			Zdot	Vehicle CG velocity along earth-fixed *Z*-axis	Computed	m/s
		Ang	phi	Rotation of vehicle-fixed frame about the earth-fixed *X*-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about the earth-fixed *Y*-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about the earth-fixed *Z*-axis (yaw)	0	rad
	FrntAxl	Disp	X	Front axle displacement along the earth-fixed *X*-axis	Computed	m
			Y	Front axle displacement along the earth-fixed *Y*-axis	0	m
			Z	Front axle displacement along the earth-fixed *Z*-axis	Computed	m
		Vel	Xdot	Front axle velocity along the earth-fixed *X*-axis	Computed	m/s
			Ydot	Front axle velocity along the earth-fixed *Y*-axis	0	m/s
			Zdot	Front axle velocity along the earth-fixed *Z*-axis	Computed	m/s
	RearAxl	Disp	X	Rear axle displacement along the earth-fixed *X*-axis	Computed	m
			Y	Rear axle displacement along the earth-fixed *Y*-axis	0	m
			Z	Rear axle displacement along the earth-fixed *Z*-axis	Computed	m
		Vel	Xdot	Rear axle velocity along the earth-fixed *X*-axis	Computed	m/s
			Ydot	Rear axle velocity along the earth-fixed *Y*-axis	0	m/s

Signal				Description	Value	Units
			Zdot	Rear axle velocity along the earth-fixed *Z*-axis	Computed	m/s
BdyFrm	Cg	Disp	x	Vehicle CG displacement along the vehicle-fixed *x*-axis	Computed	m
			y	Vehicle CG displacement along the vehicle-fixed *y*-axis	0	m
			z	Vehicle CG displacement along the vehicle-fixed *z*-axis	Computed	m
		Vel	xdot	Vehicle CG velocity along the vehicle-fixed *x*-axis	Computed	m/s
			ydot	Vehicle CG velocity along the vehicle-fixed *y*-axis	0	m/s
			zdot	Vehicle CG velocity along the vehicle-fixed *z*-axis	Computed	m/s
		AngVel	p	Vehicle angular velocity about the vehicle-fixed *x*-axis (roll rate)	0	rad/s
			q	Vehicle angular velocity about the vehicle-fixed y-axis (pitch rate)	Computed	rad/s
			r	Vehicle angular velocity about the vehicle-fixed *z*-axis (yaw rate)	0	rad/s
		Accel	ax	Vehicle CG acceleration along the vehicle-fixed *x*-axis	Computed	gn
			ay	Vehicle CG acceleration along the vehicle-fixed *y*-axis	0	gn
			az	Vehicle CG acceleration along the vehicle-fixed *z*-axis	Computed	gn
	Forces	Body	Fx	Net force on vehicle CG along the vehicle-fixed *x*-axis	Computed	N
			Fy	Net force on vehicle CG along the vehicle-fixed *y*-axis	0	N
			Fz	Net force on vehicle CG along the vehicle-fixed *z*-axis	Computed	N

Signal					Description	Value	Units
		Ext	Fx		External force on vehicle CG along the vehicle-fixed *x*-axis	Computed	N
			Fy		External force on vehicle CG along the vehicle-fixed *y*-axis	Computed	N
			Fz		External force on vehicle CG along the vehicle-fixed *z*-axis	Computed	N
		FrntAxl	Fx		Longitudinal force on front axle, along the vehicle-fixed *x*-axis	Computed	N
			Fy		Lateral force on front axle, along the vehicle-fixed *y*-axis	0	N
			Fz		Normal force on front axle, along the vehicle-fixed *z*-axis	Computed	N
		RearAxl	Fx		Longitudinal force on rear axle, along the vehicle-fixed *x*-axis	Computed	N
			Fy		Lateral force on rear axle, along the vehicle-fixed *y*-axis	0	N
			Fz		Normal force on rear axle, along the vehicle-fixed *z*-axis	Computed	N
		Tires	FrntTire	Fx	Front tire force, along the vehicle-fixed *x*-axis	0	N
				Fy	Front tire force, along the vehicle-fixed *y*-axis	0	N
				Fz	Front tire force, along the vehicle-fixed *z*-axis	Computed	N
			RearTire	Fx	Rear tire force, along the vehicle-fixed *x*-axis	0	N
				Fy	Rear tire force, along the vehicle-fixed *y*-axis	0	N
				Fz	Rear tire force, along the vehicle-fixed *z*-axis	Computed	N
		Drag	Fx		Drag force on vehicle CG along the vehicle-fixed *x*-axis	Computed	N

Signal				Description	Value	Units
			Fy	Drag force on vehicle CG along the vehicle-fixed *y*-axis	Computed	N
			Fz	Drag force on vehicle CG along the vehicle-fixed *z*-axis	Computed	N
		Grvty	Fx	Gravity force on vehicle CG along the vehicle-fixed *x*-axis	Computed	N
			Fy	Gravity force on vehicle CG along the vehicle-fixed *y*-axis	0	N
			Fz	Gravity force on vehicle CG along the vehicle-fixed *z*-axis	Computed	N
	Moments	Body	Mx	Body moment on vehicle CG about the vehicle-fixed *x*-axis	0	N·m
			My	Body moment on vehicle CG about the vehicle-fixed *y*-axis	Computed	N·m
			Mz	Body moment on vehicle CG about the vehicle-fixed *z*-axis	0	N·m
		Drag	Mx	Drag moment on vehicle CG about the vehicle-fixed *x*-axis	0	N·m
			My	Drag moment on vehicle CG about the vehicle-fixed *y*-axis	Computed	N·m
			Mz	Drag moment on vehicle CG about the vehicle-fixed *z*-axis	0	N·m
		Ext	Fx	External moment on vehicle CG about the vehicle-fixed *x*-axis	Computed	N·m
			Fy	External moment on vehicle CG about the vehicle-fixed *y*-axis	Computed	N·m
			Fz	External moment on vehicle CG about the vehicle-fixed *z*-axis	Computed	N·m
	FrntAxl	Disp	x	Front axle displacement along the vehicle-fixed *x*-axis	Computed	m

Signal				Description	Value	Units
			y	Front axle displacement along the vehicle-fixed *y*-axis	0	m
			z	Front axle displacement along the vehicle-fixed *z*-axis	Computed	m
		Vel	xdot	Front axle velocity along the vehicle-fixed *x*-axis	Computed	m/s
			ydot	Front axle velocity along the vehicle-fixed *y*-axis	0	m/s
			zdot	Front axle velocity along the vehicle-fixed *z*-axis	Computed	m/s
		Steer	WhlAngFL	Front left wheel steering angle	Computed	rad
			WhlAngFR	Front right wheel steering angle	Computed	rad
	RearAxl	Disp	x	Rear axle displacement along the vehicle-fixed *x*-axis	Computed	m
			y	Rear axle displacement along the vehicle-fixed *y*-axis	0	m
			z	Rear axle displacement along the vehicle-fixed *z*-axis	Computed	m
		Vel	xdot	Rear axle velocity along the vehicle-fixed *x*-axis	Computed	m/s
			ydot	Rear axle velocity along the vehicle-fixed *y*-axis	0	m/s
			zdot	Rear axle velocity along the vehicle-fixed *z*-axis	Computed	m/s
		Steer	WhlAngRL	Rear left wheel steering angle	Computed	rad
			WhlAngRR	Rear right wheel steering angle	Computed	rad
	Pwr	PwrExt		Applied external power	Computed	W
		Drag		Power loss due to drag	Computed	W
PwrInfo	PwrTrnsfrd	PwrFxExt		Externally applied longitudinal force power	Computed	W
		PwrFzExt		Externally applied longitudinal force power	Computed	W
		PwrMyExt		Externally applied pitch moment power	Computed	W

Signal			Description	Value	Units
		PwrFwFx	Longitudinal force applied at the front axle	Computed	W
		PwrFwRx	Longitudinal force applied at the rear axle	Computed	W
	PwrNotTrnsfrd	PwrFsF	Internal power transferred between suspension and vehicle body at the front axle	Computed	W
		PwrFsR	Internal power transferred between suspension and vehicle body at the rear axle	Computed	W
		PwrFxDrag	Longitudinal drag force power	Computed	W
		PwrFzDrag	Vertical drag force power	Computed	W
		PwrMyDrag	Drag pitch moment power	Computed	W
		PwrFsb	Total suspension damping power	Computed	W
	PwrStored	PwrStoredGrvty	Rate change in gravitational potential energy	Computed	W
		PwrStoredxdot	Rate of change of longitudinal kinetic energy	Computed	W
		PwrStoredzdot	Rate of change of longitudinal kinetic energy	Computed	W
		PwrStoredq	Rate of change of rotational pitch kinetic energy	Computed	W
		PwrStoredFsFzSprng	Stored spring energy from front suspension	Computed	W
		PwrStoredFsRzSprng	Stored spring energy from rear suspension	Computed	W

xdot — Vehicle longitudinal velocity
scalar

Vehicle CG velocity along the vehicle-fixed *x*-axis, in m/s.

FzF — Front axle normal force
scalar

Normal force on front axle, Fz_F, along the vehicle-fixed *z*-axis, in N.

FzR — Rear axle normal force
scalar

Normal force on rear axle, Fz_R, along the vehicle-fixed *z*-axis, in N.

Parameters

Options

External forces — FExt input port
off (default) | on

Specify to create input port FExt.

External moments — MExt input port
off (default) | on

Specify to create input port MExt.

Air temperature — AirTemp input port
off (default) | on

Specify to create input port AirTemp.

Longitudinal

Number of wheels on front axle, NF — Front wheel count
2 (default) | scalar

Number of wheels on front axle, N_F. The value is dimensionless.

Number of wheels on rear axle, NR — Rear wheel count
2 (default) | scalar

Number of wheels on rear axle, N_R. The value is dimensionless.

Mass, m — Vehicle mass
1200 (default) | scalar

Vehicle mass, *m*, in kg.

Horizontal distance from CG to front axle, a — Front axle distance
1.4 (default) | scalar

Horizontal distance *a* from the vehicle CG to the front wheel axle, in m.

Horizontal distance from CG to rear axle, b — Rear axle distance
1.8 (default) | scalar

Horizontal distance *b* from the vehicle CG to the rear wheel axle, in m.

CG height above axles, h — Height
0.35 (default) | scalar

Height of vehicle CG above the axles, *h*, in m.

Longitudinal drag coefficient, Cd — Drag
.3 (default) | scalar

Air drag coefficient, C_d. The value is dimensionless.

Frontal area, Af — Area
2 (default) | scalar

Effective vehicle cross-sectional area, A_f to calculate the aerodynamic drag force on the vehicle, in m^2.

Initial position, x_o — Position
0 (default) | scalar

Vehicle body longitudinal initial position along earth-fixed *x*-axis, x_o, in m.

Initial velocity, xdot_o — Velocity
0 (default) | scalar

Vehicle body longitudinal initial velocity along earth-fixed *x*-axis, $\dot{x}_0$, in m/s.

Vertical

Longitudinal lift coefficient, Cl — Lift
.1 (default) | scalar

Lift coefficient, C_l. The value is dimensionless.

Initial vertical position, z_o — Position
-.35 (default) | scalar

Initial vertical CG position, z_o, along the vehicle-fixed *z*-axis, in m.

Initial vertical velocity, zdot_o — Velocity
0 (default) | scalar

Initial vertical CG velocity, $zdot_o$, along the vehicle-fixed *z*-axis, in m.

Pitch

Inertia, Iyy — About body y-axis
3500 (default) | scalar

Vehicle body moment of inertia about body *z*-axis.

Longitudinal drag pitch moment, Cpm — Drag coefficient
.1 (default) | scalar

Pitch drag moment coefficient. The value is dimensionless.

Initial pitch angle, theta_o — Pitch
0 (default) | scalar

Initial pitch angle about body *z*-axis, in rad.

Initial angular velocity, q_o — Pitch velocity
0 (default) | scalar

Initial vehicle body angular velocity about body *z*-axis, in rad/s.

Suspension

`Front axle stiffness force data, FskF` — Force
`[-50, -1, 0, 2, 3, 52].*1.5e4` (default) | `vector`

Front axle stiffness force data, Fk_F, in N.

Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

`Front axle displacement data, dzsF` — Displacement
`[-5e-3, -1e-4, 0, .2, .2001, .2051]` (default) | `vector`

Front axle displacement data, in m.

Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

`Front axle damping force data, FsbF` — Damping force
`[-10000 -100 -10 0 10 100 10000]` (default) | `vector`

Front axle damping force, in N.

Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

`Front axle velocity data, dzdotsF` — Velocity
`[-10 -1 -.1 0 .1 1 10]` (default) | `vector`

Front axle velocity data, in m/s.

Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

`Rear axle stiffness force data, FskR` — Force
`[-50, -1, 0, 2, 3, 52].*1e4` (default) | `vector`

Rear axle stiffness force data, in N.

Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

`Rear axle displacement data, dzsR` — Displacement
`[-5e-3, -1e-4, 0, .2, .2001, .2051]` (default) | `vector`

Rear axle displacement data, in m.

Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

`Rear axle damping force data, FsbR` — Damping force
`[-10000 -100 -10 0 10 100 10000]` (default) | `vector`

Rear axle damping force, in N.

Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

`Rear axle velocity data, dzdotsR` — Velocity
`[-10 -1 -.1 0 .1 1 10]` (default) | `vector`

Rear axle velocity data, in m/s.

Dependencies

To enable this parameter, for the **Ground interaction type** parameter, select `Grade angle` or `Axle displacement, velocity`.

Environment

`Absolute air pressure, Pabs` — Pressure
`101325` (default) | `scalar`

Environmental air absolute pressure, P_{abs}, in Pa.

`Air temperature, Tair` — Ambient air temperature
`273` (default) | `scalar`

Ambient air temperature, T_{air}, in K.

Dependencies

To enable this parameter, clear **Air temperature**.

`Gravitational acceleration, g` — Gravity
`9.81` (default)

Gravitational acceleration, g, in m/s^2.

References

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers, 1992.

[2] Vehicle Dynamics Standards Committee. *Vehicle Dynamics Terminology*. SAE J670. Warrendale, PA: Society of Automotive Engineers, 2008.

[3] Technical Committee. *Road vehicles — Vehicle dynamics and road-holding ability — Vocabulary*. ISO 8855:2011. Geneva, Switzerland: International Organization for Standardization, 2011.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

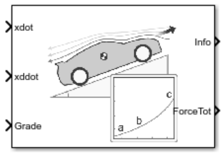
Vehicle Body 1DOF Longitudinal | Vehicle Body Total Road Load

Introduced in R2017a

Vehicle Body Total Road Load

Vehicle motion using coast-down testing coefficients

Library: Powertrain Blockset / Vehicle Dynamics
Vehicle Dynamics Blockset / Vehicle Body



Description

The Vehicle Body Total Road Load block implements a one degree-of-freedom (1DOF) rigid vehicle model using coast-down testing coefficients. You can use this block in a vehicle model to represent the load that the driveline and chassis applies to a transmission or engine. It is suitable for system-level performance, component sizing, fuel economy, or drive cycle tracking studies. The block calculates the dynamic powertrain load with minimal parameterization or computational cost.

You can configure the block for kinematic, force, or total power input.

- Kinematic — Block uses the vehicle longitudinal velocity and acceleration to calculate the tractive force and power.
- Force — Block uses the tractive force to calculate the vehicle longitudinal displacement and velocity.
- Power — Block uses the engine or transmission power to calculate the vehicle longitudinal displacement and velocity.

Dynamics

To calculate the total road load acting on the vehicle, the block implements this equation.

$$F_{road} = a + b\dot{x} + c\dot{x}^2 + mg\sin(\theta)$$

To determine the coefficients *a*, *b*, and *c*, you can use a test procedure similar to the one described in *Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques*. You can also use Simulink® Design Optimization™ to fit the coefficients to measured data.

To calculate the vehicle motion, the block uses Newton’s law for rigid bodies.

$$F_{total} = m\ddot{x} + F_{road}$$

Total power input is a product of the total force and longitudinal velocity. Power due to road and gravitational forces is a product of the road force and longitudinal velocity.

$$P_{total} = F_{total}\dot{x}$$
$$P_{road} = F_{road}\dot{x}$$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			**Description**	**Variable**	**Equations**
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrFxExt`	Externally applied force power	P_{FxExt}	$P_{FxExt} = F_{total}\dot{x}$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFxDrag`	Drag force power	P_D	$P_d = -(a + b\dot{x} + c\dot{x}^2)\dot{x}$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`wrStoredGrvty`	Rate change in gravitational potential energy	P_g	$P_g = -mg\dot{Z}$
		`PwrStoredxdot`	Rate in change of longitudinal kinetic energy	P_{xdot}	$P_{\dot{x}} = m\ddot{x}\dot{x}$

The equations use these variables.

a	Steady-state rolling resistance coefficient
b	Viscous driveline and rolling resistance coefficient
c	Aerodynamic drag coefficient
g	Gravitational acceleration
x	Vehicle longitudinal displacement with respect to ground, in the vehicle-fixed frame
$\dot{x}$	Vehicle longitudinal velocity with respect to ground, in the vehicle-fixed frame
$\ddot{x}$	Vehicle longitudinal acceleration with respect to ground, vehicle-fixed frame
m	Vehicle body mass
Θ	Road grade angle
F_{total}	Total force acting on vehicle
F_{road}	Resistive road load due to losses and gravitational load
P_{total}	Total tractive input power
P_{road}	Total power due to losses and gravitational load
$\dot{Z}$	Vehicle vertical velocity along the vehicle-fixed `z`-axis

Ports

Input

xdot — Vehicle longitudinal velocity
scalar

Vehicle total longitudinal velocity, $\dot{x}$, in m/s.

Dependencies

To enable this port, for the **Input Mode** parameter, select `Kinematic`.

xddot — Vehicle longitudinal acceleration
scalar

Vehicle total longitudinal acceleration, $\ddot{x}$, in m/s^2.

Dependencies

To enable this port, for the **Input Mode** parameter, select `Kinematic`.

PwrTot — Tractive input power
scalar

Tractive input power, P_{total}, in W.

Dependencies

To enable this port, for the **Input Mode** parameter, select `Power`.

ForceTot — Tractive input force
scalar

Tractive input force, F_{total}, in N.

Dependencies

To enable this port, for the **Input Mode** parameter, select `Force`.

Grade — Road grade angle
scalar

Road grade angle, Θ, in deg.

Output

Info — Bus signal
bus

Bus signal containing these block calculations.

Signal				Description	Value	Units
InerCg	Cg	Disp	X	Vehicle CG displacement along earth-fixed X-axis	Computed	m

Signal				Description	Value	Units
tF rm			Y	Vehicle CG displacement along earth-fixed Y-axis	0	m
			Z	Vehicle CG displacement along earth-fixed Z-axis	Computed	m
		Vel	Xdot	Vehicle CG velocity along earth-fixed X-axis	Computed	m/s
			Ydot	Vehicle CG velocity along earth-fixed Y-axis	0	m/s
			Zdot	Vehicle CG velocity along earth-fixed Z-axis	Computed	m/s
		Ang	phi	Rotation of vehicle-fixed frame about the earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about the earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about the earth-fixed Z-axis (yaw)	0	rad
Bd yF rm	Cg	Disp	x	Vehicle CG displacement along the vehicle-fixed x-axis	Computed	m
			y	Vehicle CG displacement along the vehicle-fixed y-axis	0	m
			z	Vehicle CG displacement along the vehicle-fixed z-axis	0	m
		Vel	xdot	Vehicle CG velocity along the vehicle-fixed x-axis	Computed	m/s
			ydot	Vehicle CG velocity along the vehicle-fixed y-axis	0	m/s
			zdot	Vehicle CG velocity along the vehicle-fixed z-axis	0	m/s
		Acc	ax	Vehicle CG acceleration along the vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CG acceleration along the vehicle-fixed y-axis	0	gn
			az	Vehicle CG acceleration along the vehicle-fixed z-axis	0	gn
	Forc es	Body	Fx	Net force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz	Net force on vehicle CG along the vehicle-fixed z-axis	0	N
		Ext	Fx	External force on vehicle CG along the vehicle-fixed x-axis	Computed	N

Signal				Description	Value	Units
			Fy	External force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz	External force on vehicle CG along the vehicle-fixed z-axis	0	N
		Drag	Fx	Drag force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Drag force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz	Drag force on vehicle CG along the vehicle-fixed z-axis	0	N
		Grvty	Fx	Gravity force on vehicle CG along the vehicle-fixed x-axis	Computed	N
			Fy	Gravity force on vehicle CG along the vehicle-fixed y-axis	0	N
			Fz	Gravity force on vehicle CG along the vehicle-fixed z-axis	Computed	N
	Pwr	PwrExt		Applied external power	Computed	W
		Drag		Power loss due to drag	Computed	W
PwrInfo	PwrTrnsfrd	PwrFxExt		Externally applied force power	P_{FxExt}	W
	PwrNotTrnsfrd	PwrFxDrag		Drag force power	P_D	W
	PwrStored	wrStoredGrvty		Rate change in gravitational potential energy	P_g	W
		PwrStoredxdot		Rate in change of longitudinal kinetic energy	P_{xdot}	W

`xdot` — Vehicle longitudinal velocity

`scalar`

Vehicle total longitudinal velocity, $\dot{x}$, in m/s.

Dependencies

To enable this port, for the **Input Mode** parameter, select `Power` or `Force`.

`ForceTot` — Tractive input force

`scalar`

Tractive input force, F_{total}, in N.

Dependencies

To enable this port, for the **Input Mode** parameter, select `Kinematic`.

Parameters

Input Mode — Specify input mode
Kinematic (default) | Force | Power

Specify the input type.

- Kinematic — Block uses the vehicle longitudinal velocity and acceleration to calculate the tractive force and power. Use this configuration for powertrain, driveline, and braking system design, or component sizing.
- Force — Block uses the tractive force to calculate the vehicle longitudinal displacement and velocity. Use this configuration for system-level performance, fuel economy, or drive cycle tracking studies.
- Power — Block uses the engine or transmission power to calculate the vehicle longitudinal displacement and velocity. Use this configuration for system-level performance, fuel economy, or drive cycle tracking studies.

Dependencies

This table summarizes the port and input mode configurations.

Input Mode	Creates Ports
Kinematic	xdot xddot
Force	Force
Power	Power

Mass — Vehicle body mass
1200 (default) | scalar

Vehicle body mass, *m*, in kg.

Rolling resistance coefficient, a — Rolling
196 (default) | scalar

Steady-state rolling resistance coefficient, *a*, in N.

Rolling and driveline resistance coefficient, b — Rolling and driveline
2.232 (default) | scalar

Viscous driveline and rolling resistance coefficient, *b*, in N*s/m.

Aerodynamic drag coefficient, c — Drag
0.389 (default) | scalar

Aerodynamic drag coefficient, *c*, in N·s^2/m.

Gravitational acceleration, g — Gravity
9.81 (default) | scalar

Gravitational acceleration, *g*, in m/s^2.

`Initial position, x_o` — Position
`0` (default) | `scalar`

Vehicle longitudinal initial position, in m.

`Initial velocity, xdot_o` — Velocity
`0` (default) | `scalar`

Vehicle longitudinal initial velocity with respect to ground, in m/s.

References

[1] Gillespie, Thomas. *Fundamentals of Vehicle Dynamics*. Warrendale, PA: Society of Automotive Engineers (SAE), 1992.

[2] Light Duty Vehicle Performance And Economy Measure Committee. *Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques*. Standard J1263_201003. SAE International, March 2010.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

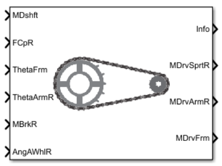
Drive Cycle Source | Vehicle Body 1DOF Longitudinal | Vehicle Body 3DOF Longitudinal

Introduced in R2017a

Motorcycle Chain

Implement motorcycle chain

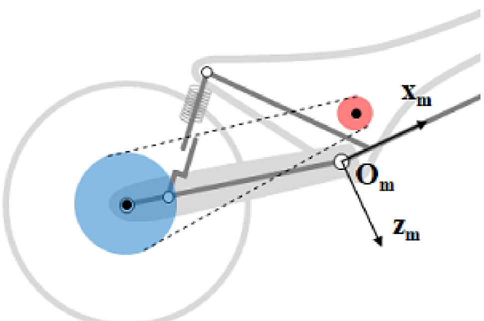
Library: Powertrain Blockset / Drivetrain / Couplings
Vehicle Dynamics Blockset / Powertrain / Drivetrain / Couplings



Description

The Motorcycle Chain block implements the dynamic effects of a motorcycle chain on the Motorcycle Body Longitudinal In-Plane block, including dynamic tension and moment drive coupling.

This figure shows how the chain relates geometrically to the motorcycle frame, rear arm, and rear wheel.



Frame	Variable in Figure	Description
Motorcycle main frame • x_m – Forward along vector pointing to front fork • z_m – Downward • y_m – Orthogonal to motorcycle plane	O_m	Main frame origin

Ports

Input

`MDshft` — Drive shaft moment on front sprocket
`scalar`

Drive shaft moment on front sprocket about y_m, in N·m.

`FCpR` — Longitudinal and vertical forces at rear wheel contact patch
`vector`

Longitudinal and vertical forces at rear wheel contact patch O_{CpR}, along i_{CpR} and k_{CpR}, in N. Signal vector dimensions are `[1x2]` or `[2x1]`.

`ThetaFrm` — Main frame pitch angle
`scalar`

Main frame pitch angle, Θ_{frm}, in rad.

`ThetaArmR` — Rear arm pitch angle
`scalar`

Rear arm pitch angle, Θ_{ra}, in rad.

`MBrkR` — Brake moment at rear wheel
`scalar`

Brake moment at the rear wheel G_{WhlRr}, about j_{WhlRr}, in N·m.

`AngAWhlR` — Rear wheel angular acceleration
`scalar`

Rear wheel angular acceleration, in rad/s^2.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
`FChn`	Chain force applied to rear arm	N
`AngVSprtR`	Angular velocity of rear sprocket	rad/s
`MDrvSprtR`	Wheel damper moment applied to rear sprocket	N·m
`WhlDmpAng`	Angle between rear sprocket and rear wheel	rad

`MDrvSprtR` — Wheel damper moment at rear sprocket
`scalar`

Wheel damper moment applied to rear sprocket, in N·m.

`MDrvArmR` — Drive chain moment at rear arm
`scalar`

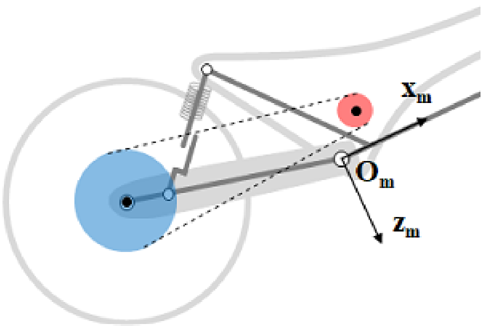
Drive chain moment at rear arm O_{ArmRr}, about j_{ArmRr}, in N·m.

`MDrvFrm` — Drive chain moment at frame
`scalar`

Drive chain moment at the frame O_{Frm}, about j_{Frm}, in N·m.

Parameters

This figure shows how the chain relates geometrically to the motorcycle frame, rear arm, and rear wheel.



Front Sprocket

`Coordinates, SprktFrPxz` — Front sprocket position
`[0.05 -0.05]` (default) | `vector`

Position of front sprocket, *SprktFrPxz*, along x_m z_m, respectively, in m.

`Mass moment of inertia, SprktFrIyy` — Front sprocket inertia
`0.005` (default) | `scalar`

Front sprocket mass moment of inertia, *SprktFrIyy*, in kg·m^2.

`Radius, SprktFrR` — Front sprocket radius
`0.04` (default) | `scalar`

Front sprocket radius, *SprktFrR*, in m.

Rear Sprocket

`Mass moment of inertia, SprktRrIyy` — Rear sprocket inertia
`0.01` (default) | `scalar`

Rear sprocket mass moment of inertia, *SprktRrIyy*, in kg·m^2.

`Radius, SprktRrR` — Rear sprocket radius
`0.12` (default) | `scalar`

Rear sprocket radius, *SprktRrR*, in m.

Rear Wheel

`Mass moment of inertia, WhlRrIyy` — Rear wheel inertia
`0.66` (default) | `scalar`

Rear wheel mass moment of inertia, *WhlRrIyy*, in kg·m^2.

Radius, WhlRrR — Rear wheel radius
0.33 (default) | scalar

Rear wheel radius, *WhlRrR*, in m.

Swing Arm

Arm length, ArmRrLen — Swing arm length
0.535 (default) | scalar

Arm length, *ArmRrLen*, in m.

Wheel Damper

Stiffness, WhlDmpK — Wheel damper stiffness
1e4 (default) | scalar

Wheel damper stiffness, *WhlDmpK*, in N/rad.

Damping, WhlDmpC — Wheel damping
1e2 (default) | scalar

Wheel damper damping, *WhlDmpC*, in N·s/rad.

Equilibrium angle — Wheel damper equilibrium angle
-15e-3 (default) | scalar

Equilibrium angle, *WhlDmpAng0*, in rad.

Initial Conditions

Rear sprocket angular velocity, SprktRrAngV0 — Angular velocity
0 (default) | scalar

Rear sprocket angular velocity, *SprktRrAngV0*, in rad/s.

Rear wheel angular velocity, WhlRrAngV0 — Angular velocity
0 (default) | scalar

Rear wheel angular velocity, *WhlRrAngV0*, in rad/s.

References

[1] Giner, David Moreno. "Symbolic-Numeric Tools for the Analysis of Motorcycle Dynamics. Development of a Virtual Rider for Motorcycles Based on Model Predictive Control." PhD diss., Universidad Miguel Hernández de Elche, 2016.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

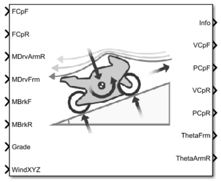
See Also
Motorcycle Body Longitudinal In-Plane

Introduced in R2021b

Motorcycle Body Longitudinal In-Plane

Longitudinal in-plane motorcycle vehicle motion

Library: Powertrain Blockset / Vehicle Dynamics
Vehicle Dynamics Blockset / Vehicle Body



Description

The Motorcycle Body Longitudinal In-Plane block implements a longitudinal in-plane motorcycle body model to calculate longitudinal, vertical, and pitch motion. The block accounts for:

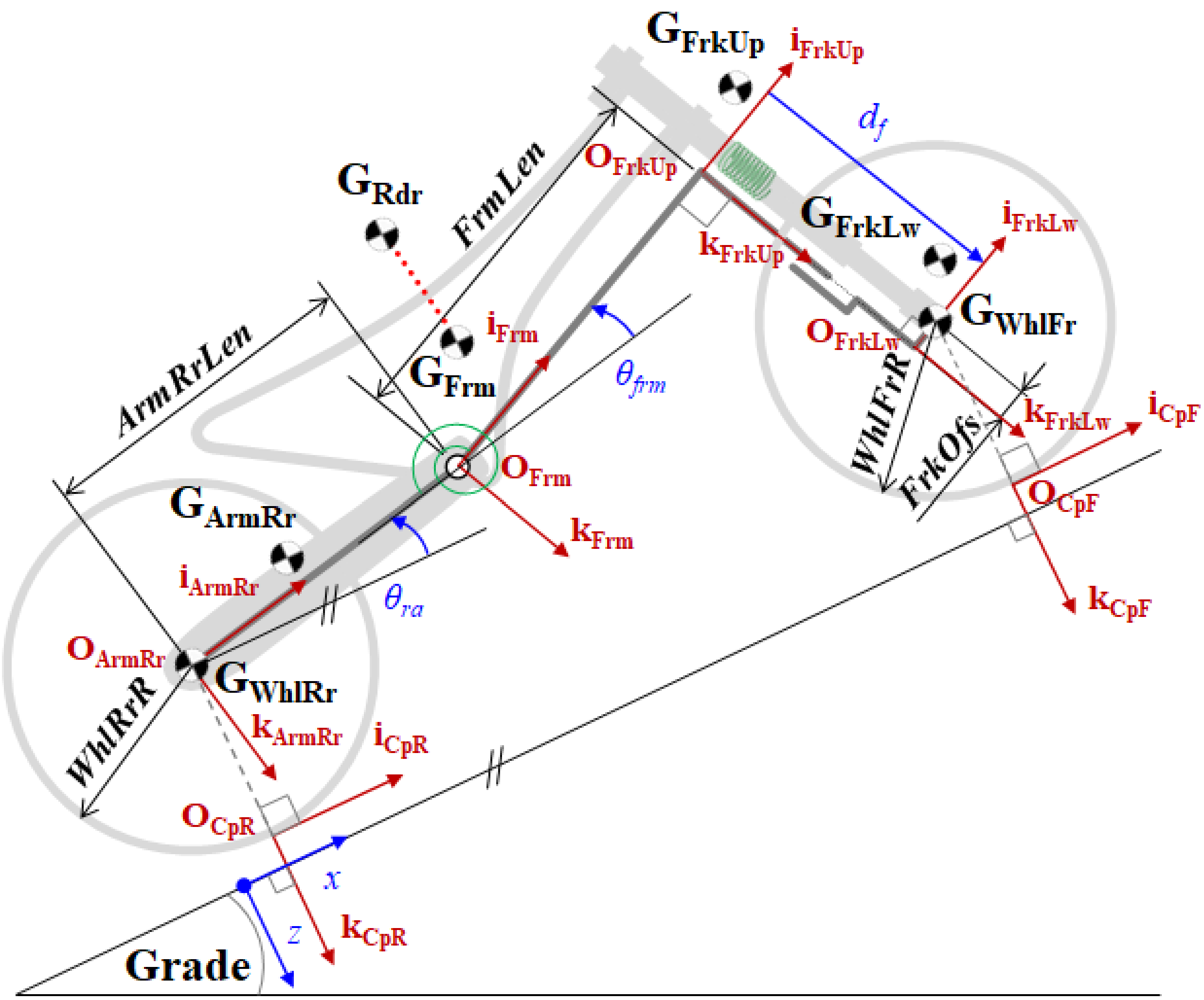
- Mass of the frame, rear arm, front upper fork, front lower fork, front wheel, and rear wheel
- In-plane dynamic effects of the frame, front lower fork, front wheel, rear wheel, rear suspension, front suspension, rear wheel damper, rear arm, and chain
- External forces, external moments, and aerodynamic drag
- Road incline
- Weight distribution between the axles due to acceleration

Consider using this block to represent motorcycle motion in powertrain and fuel economy studies, for example, in studies with heavy breaking or acceleration or road profiles that contain larger vertical changes.

The block uses rigid-body vehicle motion, suspension system forces, and wind and drag forces to calculate the forces on the motorcycle frames. The block then determines the position and velocity of motorcycle at the front and rear contact patches.

Layout

To determine the rigid-body motorcycle motion, the block uses right-handed (RH) *Cartesian* reference frames systems attached to the motorcycle. *i*, *j*, and *k* are orthogonal unit vectors attached to the frames.



Frame	Variable in Figure	Description
Road	x, z	Road-fixed coordinate system. x is along road grade, and z points downward.
Motorcycle main frame • i_{Frm} – Forward along vector given by θ_{frm} • k_{Frm} – Downward • j_{Frm} – Orthogonal to motorcycle plane	O_{Frm}	Main frame origin
	G_{Frm}	Center of mass (CM) of the main frame with respect to O_{Frm}, along i_{Frm} and k_{Frm}, respectively
	G_{Rdr}	CM of the rider with respect to O_{Frm}, along i_{Frm} and k_{Frm}, respectively
	Θ_{frm}	Main frame rotation about j_{Frm}
Upper fork • i_{FrkUp} – Forward along vector given by θ_{frm} • k_{FrkUp} – Downward	O_{FrkUp}	Upper fork origin

Frame	Variable in Figure	Description
• j_{FrkUp} – Orthogonal to motorcycle plane	G_{FrkUp}	CM of the upper fork with respect to O_{FrkUp}, along i_{FrkUp} and k_{FrkUp}, respectively
Lower fork • i_{FrkLw} – Forward along vector given by θ_{frm} • k_{FrkLw} – Downward • j_{FrkLw} – Orthogonal to motorcycle plane	O_{FrkLw}	Lower fork origin
	G_{FrkLw}	CM of the lower fork with respect to O_{FrkLw}, along i_{FrkLw} and k_{FrkLw}, respectively
Rear arm • i_{ArmRr} – Forward along vector given by θ_{ra} • k_{ArmRr} – Downward • j_{ArmRr} – Orthogonal to motorcycle plane	O_{ArmRr}	Rear arm origin
	G_{ArmRr}	CM of the rear arm with respect to O_{ArmRr}, along i_{ArmRr} and k_{ArmRr}, respectively
	Θ_{ra}	Rear arm rotation about j_{ArmRr}
Front wheel contact patch • i_{CpF} – Forward along vector given by road-fixed x- axis • k_{CpF} – Downward along vector given by road-fixed z- axis • j_{CpF} – Orthogonal to motorcycle plane	O_{CpF}	Front wheel contact patch origin
Rear wheel contact patch • i_{CpR} – Forward along vector given by road-fixed x- axis • k_{CpR} – Downward along vector given by road-fixed z- axis • j_{CpR} – Orthogonal to motorcycle plane	O_{CpR}	Rear wheel contact patch origin

Use the parameters in this table to specify the geometric layout of your motorcycle.

Parameter			Variable in Figure
Initial conditions	**Position**	**Rear contact patch longitudinal coordinate, CpRrX0**	O_{CpR} with respect to road-fixed coordinate system, along x
		Rear contact patch vertical coordinate, CpRrZ0	O_{CpR} with respect to road-fixed coordinate system, along z
		Pitch angle of rear arm, ArmRrAng0	θ_{ra}
		Pitch angle of main frame, FrmAng0	θ_{Frm}

Parameter			Variable in Figure
		Fork length, FrkFrL0	d_f
Frame		**Center of mass location, FrmCmPxz**	G_{Frm} with respect to O_{Frm}, along i_{Frm} and k_{Frm}, respectively
		Length, FrmLen	*FrmLen*
Rider		**Center of mass location, RdrCmPxz**	G_{Rdr} with respect to O_{Frm}, along i_{Frm} and k_{Frm}, respectively
Front Fork	**Upper**	**Position, FrkUpCmPxz**	G_{FrkUp} with respect to O_{FrkUp}, along i_{FrkUp} and k_{FrkUp}, respectively
		Offset, FrkOfs	*FrkOfs*
	Lower	**Position, FrkLwCmPxz**	G_{FrkLw} with respect to O_{FrkLw}, along i_{FrkLw} and k_{FrkLw}, respectively
Rear Arm		**Position, ArmRrCmPxz**	G_{ArmRr} with respect to O_{ArmRr}, along i_{ArmRr} and k_{ArmRr}, respectively
		Length, ArmRrLen	*ArmRrLen*
Wheels	**Front**	**Radius, WhlFrR**	*WhlFrR*
	Rear	**Radius, WhlRrR**	*WhlRrR*
Suspension	**Front**	**Equilibrium length, FrkLwL0**	d_f
	Rear	**Equilibrium angle, ShkRrAng0**	θ_{Frm}

Input Signals

You can use these block parameters to create additional input ports. This table summarizes the settings.

Input Signals Pane Parameter	Input Port	Description
External forces	`FExt`	External longitudinal and vertical forces applied at equivalent rider and motorcycle center of mass (CM).
External moments	`MExt`	External moment about equivalent rider and motorcycle CM, for example, moment due to rider physical motion.
External front wheel moment	`MWhlF`	External moment at the front wheel G_{WhlFr}, for example, wheel motors and external intermittent friction-related disturbances.
External rear wheel moment	`MWhlR`	External moment at the rear wheel G_{WhlRr}, for example, wheel motors and external intermittent friction-related disturbances.
Grade angle	`Grade`	Road grade angle.
Wind velocity	`WindXYZ`	Wind speed.
Ambient temperature	`Temp`	Ambient air temperature. Consider this option if you want to vary the temperature during run-time.

Suspension System

Use the **Suspension type** parameter to specify the type of suspension.

Setting	Description
`Simple`	Block models the suspension force and moment as a spring-damper system: • Suspension force at the upper fork • Suspension moment at the rear arm
`User-defined`	Input the suspension force and moment: • `FSuspF` – Suspension force at the upper fork • `MSuspR` – Suspension moment at the rear arm

Wind and Drag Forces

The block subtracts the wind speeds from the vehicle velocity components to obtain a net relative airspeed. To calculate the drag force and moments acting on the motorcycle, the block uses the net relative airspeed.

Power Accounting

The block accounts for the power transferred, not transferred, and stored.

Bus Signal			Description
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrFxExt`	Mechanical power from longitudinal external force
		`PwrFzExt`	Mechanical power from vertical external force
		`PwrMyExt`	Mechanical power from external pitch moment
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFxDrag`	Mechanical power loss from longitudinal drag force
		`PwrFzDrag`	Mechanical power loss from vertical lift
		`PwrMyDrag`	Mechanical power loss from pitch moment drag
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredGrvty`	Rate change in gravitational potential energy
		`PwrStoredxdot`	Rate of change of longitudinal kinetic energy
		`PwrStoredzdot`	Rate of change of vertical kinetic energy

Bus Signal			Description
		PwrStoredq	Rate of change of rotational pitch kinetic energy
		PwrStoredFsFzSprng	Stored spring energy from front suspension
		PwrStoredFsRzSprng	Stored spring energy from rear suspension

Ports

Input

FCpF — Longitudinal and vertical forces at front wheel contact patch
vector

Longitudinal and vertical forces at front wheel contact patch O_{CpF}, along i_{CpF} and k_{CpF}, in N. Signal vector dimensions are [1x2] or [2x1].

FCpR — Longitudinal and vertical forces at rear wheel contact patch
vector

Longitudinal and vertical forces at rear wheel contact patch O_{CpR}, along i_{CpR} and k_{CpR}, in N. Signal vector dimensions are [1x2] or [2x1].

MDrvArmR — Drive chain moment at rear arm
scalar

Drive chain moment at rear arm O_{ArmRr}, about j_{ArmRr}, in N·m.

MDrvFrm — Drive chain moment at frame
scalar

Drive chain moment at the frame O_{Frm}, about j_{Frm}, in N·m.

FExt — External longitudinal and vertical forces at frame
vector

External longitudinal and vertical forces applied at equivalent rider and motorcycle center of mass (CM), along i_{Frm} and k_{Frm}, in N. Signal vector dimensions are [1x2] or [2x1].

Dependencies

To create this port, select **External forces**.

MExt — External moment about frame
scalar

External moment about equivalent rider and motorcycle CM, j_{Frm}, for example, moment due to rider physical motion, in N·m.

Dependencies

To create this port, select **External moments**.

`MBrkF` — Brake moment at front wheel
`scalar`

Brake moment at the front wheel G_{WhlFr}, about j_{WhlFr}, in N·m.

`MBrkR` — Brake moment at rear wheel
`scalar`

Brake moment at the rear wheel G_{WhlRr}, about j_{WhlRr}, in N·m.

`MWhlF` — External moment at front wheel
`scalar`

External moment at the front wheel G_{WhlFr}, in N·m.

Dependencies

To create this port, select **External front wheel moment**.

`MWhlR` — External moment at rear wheel
`scalar`

External moment at the rear wheel G_{WhlRr}, in N·m.

Dependencies

To create this port, select **External rear wheel moment**.

`FSuspF` — External suspension force at upper fork
`scalar`

External suspension force at upper fork O_{FrkUp}, along k_{FrkUp}, in N.

Dependencies

To create this port, set **Suspension type** to `User-defined`.

`MSuspR` — External suspension moment at rear arm
`scalar`

External suspension force at upper fork O_{ArmRr}, about j_{ArmRr}, in N·m.

Dependencies

To create this port, set **Suspension type** to `User-defined`.

`Grade` — Road grade angle
`scalar`

Road grade angle, γ, in deg.

Dependencies

To create this port, select **Grade angle**.

`WindXYZ` — Wind speed
`array`

Wind speed, W_X, W_Y, W_Z along earth-fixed *X*-, *Y*-, and *Z*-axes, in m/s. Signal vector dimensions are `[1x3]` or `[3x1]`.

Dependencies

To create this port, select **Wind velocity**.

`Temp` — Ambient air temperature
`scalar`

Ambient air temperature, T_{air}, in K. Considering this option if you want to vary the temperature during run-time.

Dependencies

To create this port, select **Ambient temperature**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal					Signal	Units
`Geom`				`PosOrgInert`	Main frame position along the earth-fixed axes	m
				`PosFwBdy`	Front wheel center position relative to initial vehicle-fixed wheel position, along the vehicle Z-down *X*-, *Y*-, and *Z*-axes	m
				`PosRwBdy`	Rear wheel center position relative to initial vehicle-fixed wheel position, along the vehicle Z-down *X*-, *Y*-, and *Z*-axes	m
				`AngOrgInert`	Main frame rotation about the earth-fixed axes	rad
`Frame`	`Inert`	`Cg`	`Disp`	`X`	Vehicle CM displacement along the earth-fixed *X*-axis	m
				`Y`	Vehicle CM displacement along the earth-fixed *Y*-axis	m
				`Z`	Vehicle CM displacement along the earth-fixed *Z*-axis	m
			`Vel`	`Xdot`	Vehicle CM velocity along the earth-fixed *X*-axis	m/s

Signal					Signal	Units
				Ydot	Vehicle CM velocity along the earth-fixed *Y*-axis	m/s
				Zdot	Vehicle CM velocity along the earth-fixed *Z*-axis	m/s
			Ang	phi	Rotation of the vehicle-fixed frame about the earth-fixed *X*-axis (roll)	rad
				theta	Rotation of the vehicle-fixed frame about the earth-fixed *Y*-axis (pitch)	rad
				psi	Rotation of the vehicle-fixed frame about the earth-fixed *Z*-axis (yaw)	rad
	BdyFrm	Cg	Disp	x	Vehicle CM position along the road-fixed *x*-axis	m
				y	Vehicle CM position along the road-fixed *y*-axis	m
				z	Vehicle CM position along the road-fixed *z*-axis	m
			Vel	xdot	Vehicle CM velocity along the road-fixed *x*-axis	m/s
				ydot	Vehicle CM velocity along the road-fixed *y*-axis	m/s
				zdot	Vehicle CM velocity along the road-fixed *z*-axis	m/s
			AngVel	p	Vehicle angular velocity about the road-fixed *x*-axis (roll rate)	rad/s
				q	Vehicle angular velocity about the road-fixed *y*-axis (pitch rate)	rad/s
				r	Vehicle angular velocity about the road-fixed *z*-axis (yaw rate)	rad/s
			Acc	ax	Vehicle CM acceleration along the road-fixed *x*-axis	m/s^2
				ay	Vehicle CM acceleration along the road-fixed *y*-axis	m/s^2
				az	Vehicle CM acceleration along the road-fixed *z*-axis	m/s^2
				xddot	Vehicle CM acceleration along the road-fixed *x*-axis	m/s^2

Signal					Signal	Units
				yddot	Vehicle CM acceleration along the road-fixed *y*-axis	m/s^2
				zddot	Vehicle CM acceleration along the road-fixed *z*-axis	m/s^2
			AngAcc	pdot	Vehicle angular acceleration about the road-fixed *x*-axis	rad/s^2
				qdot	Vehicle angular acceleration about the road-fixed *y*-axis	rad/s^2
				rdot	Vehicle angular acceleration about the road-fixed *z*-axis	rad/s^2
		Forces	Ext	Fx	External force on vehicle CM along the road-fixed *x*-axis	N
				Fy	External force on vehicle CM along the road-fixed *x*-axis	N
				Fz	External force on vehicle CM along the road-fixed *x*-axis	N
			Drag	Fx	Drag force on vehicle CM along the road-fixed *x*-axis	N
				Fy	Drag force on vehicle CM along the road-fixed *y*-axis	N
				Fz	Drag force on vehicle CM along the road-fixed *z*-axis	N
			Grvty	Fx	Gravity force on vehicle CM along the road-fixed *x*-axis	N
				Fy	Gravity force on vehicle CM along the road-fixed *y*-axis	N
				Fz	Gravity force on vehicle CM along the road-fixed *z*-axis	N
		Moments	Drag	Mx	Drag moment on vehicle CM about the road-fixed *x*-axis	N·m
				My	Drag moment on vehicle CM about the road-fixed *z*-axis	N·m

Signal					Signal	Units
				Mz	Drag moment on vehicle CM about the road-fixed *z*-axis	N·m
			Ext	Mx	External moment on vehicle CG about the road-fixed *x*-axis	N·m
				My	External moment on vehicle CG about the road-fixed *y*-axis	N·m
				Mz	External moment on vehicle CG about the road-fixed *z*-axis	N·m
		Pwr	PwrExt		Applied external power	W
			Drag		Power loss due to drag	W
	PwrInfo	Pwr Trnsfrd	PwrFxExt		Mechanical power from longitudinal external force	W
			PwrFzExt		Mechanical power from vertical external force	W
			PwrMyExt		Mechanical power from external pitch moment	W
		PwrNot Trnsfrd	PwrFxDrag		Mechanical power loss from longitudinal drag force	W
			PwrFzDrag		Mechanical power loss from vertical lift force	W
			PwrMyDrag		Mechanical power loss from pitch moment drag	W
		PwrStored	PwrStoredGrvty		Rate change in gravitational potential energy	W
			PwrStoredxdot		Rate of change of longitudinal kinetic energy	W
			PwrStoredzdot		Rate of change of vertical kinetic energy	W
			PwrStoredq		Rate of change of rotational pitch kinetic energy	W
	Genrl	Vel	xdot		Vehicle CM velocity along the road-fixed *x*-axis	m/s
			zdot		Vehicle CM velocity along the road-fixed *z*-axis	m/s
		Ang	thetafrm		Pitch angle of main frame	rad

Signal						Signal	Units
		AngVel	thetafrmdot			Main frame rotational velocity	rad/s
		AngAcc	thetafrmddot			Main frame rotational acceleration	rad/s^2
Whl	Genrl	Frnt	Cp	Disp	x	Front wheel contact patch position along the road-fixed *x*-axis	m
					z	Front wheel contact patch position along the road-fixed *z*-axis	m
				Vel	xdot	Front wheel contact patch velocity along the road-fixed *x*-axis	m/s
					zdot	Front wheel contact patch velocity along the road-fixed *z*-axis	m/s
				Acc	xddot	Front wheel contact patch acceleration along the road-fixed *x*-axis	m/s^2
					zddot	Front wheel contact patch acceleration along the road-fixed *z*-axis	m/s^2
			Axl	Vel	xdot	Front wheel axle velocity along the road-fixed *x*-axis	m/s
					zdot	Front wheel axle velocity along the road-fixed *z*-axis	m/s
		Rear	Cp	Disp	x	Rear wheel contact patch position along the road-fixed *x*-axis	m
					z	Rear wheel contact patch position along the road-fixed *z*-axis	m
				Vel	xdot	Rear wheel contact patch velocity along the road-fixed *x*-axis	m/s
					zdot	Rear wheel contact patch velocity along the road-fixed *z*-axis	m/s
				Acc	xddot	Rear wheel contact patch acceleration along the road-fixed *x*-axis	m/s^2
					zddot	Rear wheel contact patch acceleration along the road-fixed *z*-axis	m/s^2

Signal						Signal	Units
			Axl	Vel	xdot	Rear wheel axle velocity along the road-fixed *x*-axis	m/s
					zdot	Rear wheel axle velocity along the road-fixed *z*-axis	m/s
RearArm	Genrl	Vel	xdot			Rear arm velocity along the road-fixed *x*-axis	m/s
			zdot			Rear arm velocity along the road-fixed *z*-axis	m/s
		Ang	thetara			Pitch angle of rear arm	rad
		AngVel	thetaradot			Rear arm rotational velocity	rad/s
		AngAcc	thetaraddot			Rear arm rotational acceleration	rad/s^2
Fork	Genrl	Upr	Vel	xdot		Upper fork velocity along the road-fixed *x*-axis	m/s
				zdot		Upper fork velocity along the road-fixed *z*-axis	m/s
		Lwr	Disp	df		Fork length	m
			Vel	xdot		Lower fork velocity along the road-fixed *x*-axis	m/s
				zdot		Lower fork velocity along the road-fixed *z*-axis	m/s
				dfdot		Fork length velocity	m/s
			Acc	dfddot		Fork length acceleration	m/s^2
Susp	Genrl	Rear	Moments	Mthetafrm		Rear suspension moment at frame	N·m
		Frnt	Forces	Fdf		Suspensive force at upper fork	N

VCpF — Longitudinal, lateral, and vertical velocity at front wheel contact patch
vector

Longitudinal, lateral, and vertical velocity at front wheel contact patch O_{CpF}, along i_{CpF} and k_{CpF}, in m/s. Signal vector dimensions are `[1x3]` or `[3x1]`. The lateral component is set to 0.

PCpF — Longitudinal, lateral, and vertical position at front wheel contact patch
vector

Longitudinal, lateral, and vertical position at front wheel contact patch O_{CpF}, along i_{CpF} and k_{CpF}, in m. Signal vector dimensions are `[1x3]` or `[3x1]`. The lateral component is set to 0.

VCpR — Longitudinal, lateral, and vertical velocity at rear wheel contact patch
vector

Longitudinal,lateral, and vertical velocity at rear wheel contact patch O_{CpR}, along i_{CpR} and k_{CpR}, in m/s. Signal vector dimensions are `[1x3]` or `[3x1]`. The lateral component is set to 0.

PCpR — Longitudinal, lateral, and vertical position at rear wheel contact patch
vector

Longitudinal, lateral, and vertical position at rear wheel contact patch O_{CpR}, along i_{CpR}, and k_{CpR}, in m. Signal vector dimensions are [1x3] or [3x1]. The lateral component is set to 0.

ThetaFrm — Main frame pitch angle
scalar

Main frame pitch angle, Θ_{frm}, in rad.

ThetaArmR — Rear arm pitch angle
scalar

Rear arm pitch angle, Θ_{ra}, in rad.

Parameters

Options

Suspension type — Type of suspension
Simple (default) | User-defined

Use the **Suspension type** parameter to specify the type of suspension.

Setting	Description
Simple	Block models the suspension force and moment as a spring-damper system: • Suspension force at the upper fork • Suspension moment at the rear arm
User-defined	Input the suspension force and moment: • FSuspF – Suspension force at the upper fork • MSuspR – Suspension moment at the rear arm

Input signals

External forces — FExt input port
off (default) | on

Specify to create input port FExt.

External moments — MExt input port
off (default) | on

Specify to create input port MExt.

External front wheel moment — MWhlF input port
off (default) | on

Specify to create input port MWhlF. Consider using this port to input external moments such as wheel motors and external intermittent friction-related disturbances.

External rear wheel moment — MWhlR input port
off (default) | on

Specify to create input port MWhlR. Consider using this port to input external moments such as wheel motors and external intermittent friction-related disturbances.

Grade angle — Grade input port
on (default) | off

Specify to create input port Grade.

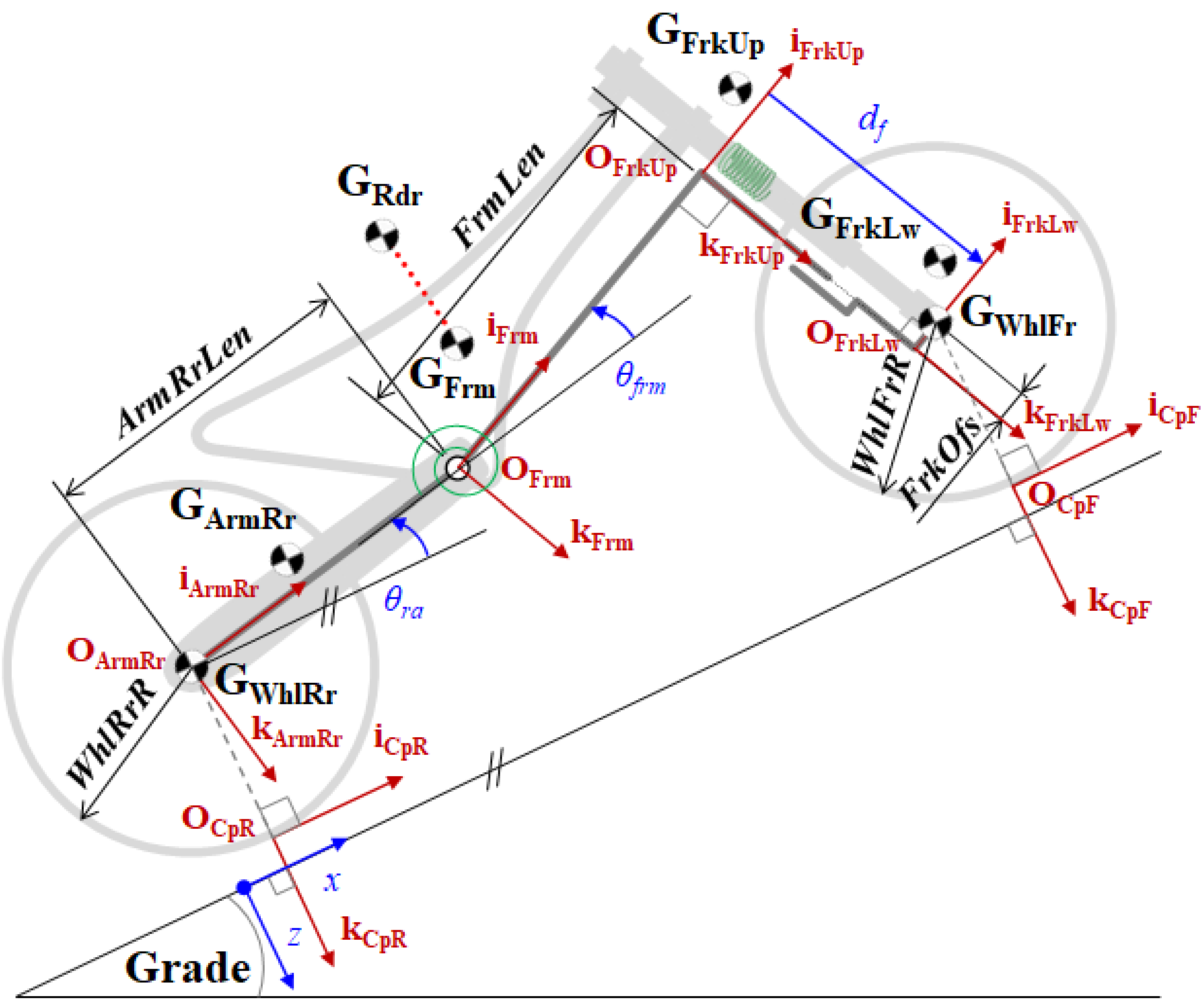
Wind velocity — WindXYZ input port
on (default) | off

Specify to create input port WindXYZ.

Ambient temperature — Temp input port
off (default) | on

Specify to create input port Temp.

Layout



Use the parameters in this table to specify the geometric layout of your motorcycle.

Parameter			Variable in Figure
Initial conditions	**Position**	**Rear contact patch longitudinal coordinate, CpRrX0**	O_{CpR} with respect to road-fixed coordinate system, along x
		Rear contact patch vertical coordinate, CpRrZ0	O_{CpR} with respect to road-fixed coordinate system, along z
		Pitch angle of rear arm, ArmRrAng0	θ_{ra}
		Pitch angle of main frame, FrmAng0	θ_{Frm}
		Fork length, FrkFrL0	d_f

Parameter			Variable in Figure
Frame		**Center of mass location, FrmCmPxz**	G_{Frm} with respect to O_{Frm}, along i_{Frm} and k_{Frm}, respectively
		Length, FrmLen	*FrmLen*
Rider		**Center of mass location, RdrCmPxz**	G_{Rdr} with respect to O_{Frm}, along i_{Frm} and k_{Frm}, respectively
Front Fork	**Upper**	**Position, FrkUpCmPxz**	G_{FrkUp} with respect to O_{FrkUp}, along i_{FrkUp} and k_{FrkUp}, respectively
		Offset, FrkOfs	*FrkOfs*
	Lower	**Position, FrkLwCmPxz**	G_{FrkLw} with respect to O_{FrkLw}, along i_{FrkLw} and k_{FrkLw}, respectively
Rear Arm		**Position, ArmRrCmPxz**	G_{ArmRr} with respect to O_{ArmRr}, along i_{ArmRr} and k_{ArmRr}, respectively
		Length, ArmRrLen	*ArmRrLen*
Wheels	**Front**	**Radius, WhlFrR**	*WhlFrR*
	Rear	**Radius, WhlRrR**	*WhlRrR*
Suspension	**Front**	**Equilibrium length, FrkLwL0**	d_f
	Rear	**Equilibrium angle, ShkRrAng0**	θ_{Frm}

Frame

`Center of mass location, FrmCmPxz` — Frame location
`[0.255, -0.02]` (default) | `vector`

Center of mass location of the frame, G_{Frm}. Specified as a vector with respect to O_{Frm}, along i_{Frm} and k_{Frm}, respectively.

`Mass, FrmMass` — Frame mass
`223` (default) | `scalar`

Frame mass, *FrmMass*, in kg.

`Mass moment of inertia, FrmIyy` — Frame inertia
`26.2` (default) | `scalar`

Mass moment of inertia, *FrmIyy*, in kg·m^2.

`Length, FrmLen` — Frame length
`0.730` (default) | `scalar`

Length of the frame, *FrmLen*, in m.

Rider

`Center of mass location, RdrCmPxz` — Rider location
`[0.275, -0.61]` (default) | `vector`

Center of mass location of the rider, G_{Rdr}. Specified as a vector with respect to O_{Frm}, along i_{Frm} and k_{Frm}, respectively.

`Mass, RdrMass` — Rider mass
`78` (default) | `scalar`

Rider mass, *RdrMass*, in kg.

`Mass moment of inertia, RdrIyy` — Rider inertia
`26.2` (default) | `scalar`

Rider mass moment of inertia, *RdrIyy*, in kg·m^2.

Front Fork - Upper

`Position, FrkUpCmPxz` — Upper fork location
`[0.023, -0.098]` (default) | `vector`

Center of mass location of the upper fork, G_{FrkUp}. Specified as a vector with respect to O_{FrkUp}, along i_{FrkUp} and k_{FrkUp}, respectively.

`Mass, FrkUpMass` — Upper fork mass
`8.8` (default) | `scalar`

Upper fork mass, *FrkUpMass*, in kg.

`Mass moment of inertia, FrmIyy` — Upper fork inertia
`0.14` (default) | `scalar`

Upper fork mass moment of inertia, *FrkUpIyy*, in kg·m^2.

`Offset, FrkOfs` — Upper fork offset
`0.034` (default) | `scalar`

Upper fork offset, *FrkOfs*, in m.

Front Fork - Lower

`Position, FrkLwCmPxz` — Lower fork location
`[-0.029, -0.189]` (default) | `vector`

Center of mass location of the lower fork, G_{FrkLw}. Specified as a vector with respect to O_{FrkLw}, along i_{FrkLw} and k_{FrkLw}, respectively.

`Mass, FrkLwMass` — Lower fork mass
`7.0` (default) | `scalar`

Lower fork mass, *FrkLwMass*, in kg.

`Mass moment of inertia, FrkLwIyy` — Lower fork inertia
`0.18` (default) | `scalar`

Lower fork mass moment of inertia, *FrkLwIyy*, in kg·m^2.

Rear Arm

`Position, ArmRrCmPxz` — Rear arm location
`[0.275, -0.052]` (default) | `vector`

Center of mass location of the rear arm, G_{ArmRr}. Specified as a vector with respect to O_{ArmRr}, along i_{ArmRr} and k_{ArmRr}, respectively.

`Mass, ArmRrMass` — Rear arm mass
`10` (default) | `scalar`

Rear arm mass, *ArmRrMass*, in kg.

`Mass moment of inertia, ArmRrIyy` — Rear arm inertia
`0.8` (default) | `scalar`

Rear arm mass moment of inertia, *ArmRrIyy*, in kg·m^2.

`Length, ArmRrLen` — Rear arm length
`0.535` (default) | `scalar`

Rear arm length, *ArmRrLen*, in m.

Wheels – Front

`Mass, WhlFrMass` — Front wheel mass
`12` (default) | `scalar`

Front wheel mass, *WhlFrMass*, in kg.

`Radius, WhlFrR` — Front wheel radius
`0.3` (default) | `scalar`

Front wheel radius, *WhlFrR*, in m.

Wheels – Rear

`Mass, WhlRrMass` — Rear wheel mass
`16.2` (default) | `scalar`

Rear wheel mass, *WhlRrMass*, in kg.

`Radius, WhlRrR` — Rear wheel radius
`0.33` (default) | `scalar`

Rear wheel radius, *WhlRrR*, in m.

Suspension – Front

`Stiffness, SuspFrK` — Front suspension stiffness
`25e3` (default) | `scalar`

Front suspension stiffness at O_{FrkUp}, along k_{FrkUp}, in N/m.

`Damping, SuspFrC` — Front suspension damping
`1250` (default) | `scalar`

Front suspension damping, at O_{FrkUp}, along k_{FrkUp}, in N·s/m.

`Equilibrium length, FrkLwL0` — Front suspension equilibrium length
`0.473` (default) | `scalar`

Front suspension equilibrium length, d_f, in m.

Suspension - Rear

`Stiffness, SuspRrK` — Rear arm suspension stiffness
`1500` (default) | `scalar`

Rear arm suspension stiffness at O_{ArmRr}, about j_{ArmRr}, in N/rad.

`Damping, SuspRrC` — Rear arm suspension damping
`150` (default) | `scalar`

Rear arm suspension damping at O_{ArmRr}, about j_{ArmRr}, in N·s/rad.

`Equilibrium angle, ShkRrAng0` — Rear suspension equilibrium angle
`0` (default) | `scalar`

Rear suspension equilibrium angle, θ_{Frm}, in rad.

Aerodynamic

`Longitudinal drag area, Af` — Area
`2` (default) | `scalar`

Effective vehicle cross-sectional area, A_f to calculate the aerodynamic drag force on the vehicle, in m^2.

`Longitudinal drag coefficient, Cd` — Drag
`.2` (default) | `scalar`

Air drag coefficient, C_d, dimensionless.

`Longitudinal lift coefficient, Cl` — Lift
`.1` (default) | `scalar`

Air lift coefficient, C_l, dimensionless.

`Longitudinal drag pitch moment, Cpm` — Pitch drag
`.1` (default) | `scalar`

Longitudinal drag pitch moment coefficient, C_{pm}, dimensionless.

`Pitch moment length, Lcpm` — Pitch drag
`2` (default) | `scalar`

Pitch moment length, *Lcpm*, in m.

Environment

`Gravitational acceleration, g` — Gravity
`9.80665` (default) | `scalar`

Gravitational acceleration, g, in m/s^2.

`Absolute air pressure, Pabs` — Pressure
`101325` (default) | `scalar`

Environmental air absolute pressure, P_{abs}, in Pa.

`Air temperature, Tair` — Ambient air temperature
`273` (default) | `scalar`

Ambient air temperature, T_{air}, in K.

Dependencies

To enable this parameter, clear **Ambient temperature**.

Initial conditions

Position

`Rear contact patch longitudinal coordinate, CpRrX0` — Longitudinal coordinate
`0` (default) | `scalar`

Rear contact patch longitudinal coordinate, O_{CpR}, with respect to road-fixed coordinate system, along `x`, in m.

`Rear contact patch vertical coordinate, CpRrZ0` — Vertical coordinate
`0` (default) | `scalar`

Rear contact patch vertical coordinate, O_{CpR}, with respect to road-fixed coordinate system, along `z`, in m.

`Pitch angle of rear arm, ArmRrAng0` — Rear arm angle
`0.0590379` (default) | `scalar`

Pitch angle of rear arm, θ_{ra}, in rad.

`Pitch angle of main frame, FrmAng0` — Angle length
`0.377024` (default) | `scalar`

Pitch angle of main frame, θ_{Frm}, in rad.

`Fork length, FrkFrL0` — Fork length
`0.4262193` (default) | `scalar`

Fork length, d_f, in m.

Velocity

`Longitudinal velocity of rear contact patch` — Longitudinal velocity
`0` (default) | `scalar`

Rear contact patch longitudinal coordinate, $\dot{O}_{CpR}$, with respect to road-fixed coordinate system, along `x`, in m/s.

`Vertical velocity of rear contact patch, CpRrVz0` — Vertical velocity
`0` (default) | `scalar`

Vertical velocity of rear contact patch, $\dot{O}_{CpR}$, with respect to road-fixed coordinate system, along `z`, in m/s.

Pitch rate of rear arm, `ArmRrAngV0` — Pitch rate
`0` (default) | `scalar`

Pitch rate of rear arm, $\dot{\theta}_{ra}$, in rad/s.

Pitch rate of main frame, `FrmAngV0` — Pitch rate
`0` (default) | `scalar`

Pitch rate of main frame, $\dot{\theta}_{Frm}$, in rad/s.

Lower fork deformation velocity, `FrkLwV0` — Deformation velocity
`0` (default) | `scalar`

Lower fork deformation velocity, $\dot{d}_f$, in m/s.

Coordinate Offsets

Longitudinal offset, `longOff` — Longitudinal offset
`0` (default) | `scalar`

Vehicle main frame offset along the earth-fixed *X*-axis, in m.

Lateral offset, `latOff` — Lateral offset
`0` (default) | `scalar`

Vehicle main frame offset along the earth-fixed *Y*-axis, in m.

Vertical offset, `vertOff` — Vertical offset
`0` (default) | `scalar`

Vehicle main frame offset along the earth-fixed *Z*-axis, in m.

Roll offset, `pitchOff` — Roll offset
`0` (default) | `scalar`

Vehicle main frame offset about the earth-fixed *X*-axis, in rad.

Pitch offset, `pitchOff` — Pitch offset
`0` (default) | `scalar`

Vehicle main frame offset about the earth-fixed *Y*-axis, in rad.

Yaw offset, `pitchOff` — Yaw offset
`0` (default) | `scalar`

Vehicle main frame offset about the earth-fixed *Z*-axis, in rad.

References

[1] Giner, David Moreno. “Symbolic-Numeric Tools for the Analysis of Motorcycle Dynamics. Development of a Virtual Rider for Motorcycles Based on Model Predictive Control.” PhD diss., Universidad Miguel Hernández de Elche, 2016.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Motorcycle Chain

Topics
“Conventional Vehicle Spark-Ignition Engine Fuel Economy and Emissions”

Introduced in R2021b

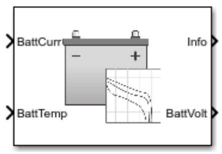
3

Energy Storage Blocks

Datasheet Battery

Lithium-ion, lithium-polymer, or lead-acid battery

Library: Powertrain Blockset / Energy Storage and Auxiliary Drive / Datasheet Battery



Description

The Datasheet Battery block implements a lithium-ion, lithium-polymer, or lead-acid battery that you can parameterize using manufacturer data. To create the open-circuit voltage and internal resistance parameters that you need for the block, use the manufacturer discharge characteristics by temperature data. For an example, see “Generate Parameter Data for Datasheet Battery Block”.

To determine the battery output voltage, the block uses lookup tables for the battery open-circuit voltage and the internal resistance. The lookup tables are functions of the state-of charge (SOC) and battery temperature, characterizing the battery performance at various operating points:

$$E_m = f(SOC)$$

$$R_{int} = f(T, SOC)$$

To calculate the voltage, the block implements these equations.

$$V_T = E_m + I_{batt}R_{int}$$

$$I_{batt} = \frac{I_{in}}{N_p}$$

$$V_{out} = \begin{cases} N_s V_T & \text{unfiltered} \\ \dfrac{V_{out}}{\tau s + 1} & \text{filtered} \end{cases}$$

$$SOC = \frac{1}{Cap_{batt}} \int_0^t I_{batt} dt$$

$$Ld_{AmpHr} = \int_0^t I_{batt} dt$$

Positive current indicates battery discharge. Negative current indicates battery charge.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrLdBatt	Battery network power	$V_{batt} = V_{out}$ OR $\frac{V_{out}}{\tau s + 1}$ $P_{batt} = -V_{batt}I_{batt}$ $P_{LdBatt} = -P_{batt}$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrLossBatt	Battery network power loss	$P_{LossBatt} = -N_pN_sI_{batt}{}^2R_{int}$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredBatt	Battery network power stored	$P_{StoredBatt} = P_{Batt} + P_{LossBatt}$

The equations use these variables.

SOC	State-of-charge
E_m	Battery open-circuit voltage
I_{batt}	Per module battery current
P_{LdBatt}	Battery network power
P_{batt}	Battery power
$P_{LossBatt}$	Battery network power loss
$P_{StoredBatt}$	Battery network power stored
I_{in}	Combined current flowing from the battery network
R_{int}	Battery internal resistance
N_s	Number of cells in series
N_p	Number of cells in parallel
V_{out}, V_{batt}	Combined voltage of the battery network
V_T	Per module battery voltage
Cap_{batt}	Battery capacity
Ld_{AmpHr}	Battery energy

Ports

Inputs

CapInit — Battery capacity
scalar

Rated battery capacity at the nominal temperature, Cap_{batt}, in Ah.

Dependencies

To create this port, select `External Input` for the **Initial battery capacity** parameter.

`BattCurr` — Battery load current
`scalar`

Combined current flowing from the battery network, I_{in}, in A.

`BattTemp` — Battery temperature
`scalar`

Temperature measured at the battery housing, T, in K.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Variable	Units
`BattCurr`			Combined current flowing from the battery network	I_{batt}	A
`BattAmpHr`			Battery energy	Ld_{AmpHr}	A*h
`BattSoc`			State-of-charge capacity	SOC	NA
`BattVolt`			Combined voltage of the battery network	V_{out}	V
`BattPwr`			Battery network power	P_{batt}	W
`PwrInfo`	`PwrTrnsfrd`	`PwrLdBatt`	Battery network power	P_{LdBatt}	W
	`PwrNotTrnsfrd`	`PwrLossBatt`	Battery network power loss	$P_{LossBatt}$	W
	`PwrStored`	`PwrStoredBatt`	Battery network power stored	$P_{StoredBatt}$	W

`BattVolt` — Battery output voltage
`scalar`

Combined voltage of the battery network, V_{out}, in V.

Parameters

Block Options

`Initial battery capacity` — Input or parameter
`Parameter` (default) | `External Input`

Initial battery capacity, Cap_{batt}, in Ah.

Dependencies

Block Parameter Initial battery capacity Option	Creates
`External Input`	Input port `CapInit`
`Parameter`	Parameter **Initial battery capacity, BattCapInit**

`Output battery voltage` — Unfiltered or Filter

`Unfiltered` (default) | `Filtered`

Select `Filtered` to apply a first-order filter to the output batter voltage.

Dependencies

Setting **Output battery voltage** parameter to `Filtered` creates these parameters:

- **Output battery voltage time constant, Tc**
- **Output battery voltage initial value, Vinit**

`Rated capacity at nominal temperature, BattChargeMax` — Constant

`100` (default) | `scalar`

Rated battery capacity at the nominal temperature, in Ah.

`Open circuit voltage table data, Em` — 1-D lookup table

1-by-P matrix

Open-circuit voltage data curve, E_m, as a function of the discharged capacity for `P` operating points, in V.

`Open circuit voltage breakpoints 1, CapLUTBp` — Breakpoints

1-by-P matrix

Discharge capacity breakpoints for `P` operating points, dimensionless.

Although this parameter is the same as the **Battery capacity breakpoints 2, CapSOCBp** parameter, the block uses unique parameters for calibration flexibility.

`Internal resistance table data, RInt` — 2-D lookup table

N-by-M matrix

Internal resistance map, R_{int}, as a function of `N` temperatures and `M` SOCs, in ohms.

`Battery temperature breakpoints 1, BattTempBp` — Breakpoints

`[243.1 253.1 263.1 273.1 283.1 298.1 313.1]` (default) | 1-by-N matrix

Battery temperature breakpoints for `N` temperatures, in K.

`Battery capacity breakpoints 2, CapSOCBp` — Breakpoints

`[0 0.2 0.4 0.6 0.8 1]` (default) | 1-by-M matrix

Battery capacity breakpoints for `M` SOCs, dimensionless.

Although this parameter is the same as the **Open circuit voltage breakpoints 1, CapLUTBp** parameter, the block uses unique parameters for calibration flexibility.

Number of cells in series, Ns — Integer
1 (default) | scalar

Number of cells in series, dimensionless, N_s.

Number of cells in parallel, Np — Integer
1 (default) | scalar

Number of cells in parallel, dimensionless, N_p.

Initial battery capacity, BattCapInit — Capacity
100 (default) | scalar

Initial battery capacity, Cap_{batt}, in Ah.

Dependencies

Block Parameter Initial battery capacity Option	Creates
External Input	Input port CapInit
Parameter	Parameter **Initial battery capacity, BattCapInit**

Output battery voltage time constant, Tc — Filter time constant
1/1000 (default) | scalar

Output battery voltage time constant, T_c, in s. Used in a first-order voltage filter.

Dependencies

Setting **Output battery voltage** parameter to `Filtered` creates these parameters:

- **Output battery voltage time constant, Tc**
- **Output battery voltage initial value, Vinit**

Output battery voltage initial value — Filter initial voltage
4.221 (default) | scalar

Output battery voltage initial value, V_{init}, in V. Used in a first-order voltage filter.

Dependencies

Setting **Output battery voltage** parameter to `Filtered` creates these parameters:

- **Output battery voltage time constant, Tc**
- **Output battery voltage initial value, Vinit**

References

[1] Arrhenius, S.A. “Über die Dissociationswärme und den Einflußß der Temperatur auf den Dissociationsgrad der Elektrolyte.” *Journal of Physical Chemistry*. 4 (1889): 96–116.

[2] Connors, K. *Chemical Kinetics*. New York: VCH Publishers, 1990.

[3] Ji, Yan, Yancheng Zhang, and Chao-Yang Wang. *Journal of the Electrochemical Society*. Volume 160, Issue 4 (2013), A636-A649.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Estimation Equivalent Circuit Battery | Equivalent Circuit Battery

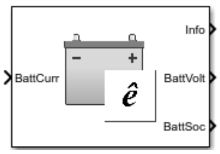
Topics
"Generate Parameter Data for Datasheet Battery Block"
Battery Modeling

Introduced in R2017a

Estimation Equivalent Circuit Battery

Resistor-capacitor (RC) circuit battery that creates lookup tables

Library: Powertrain Blockset / Energy Storage and Auxiliary Drive / Network Battery



Description

The Estimation Equivalent Circuit Battery block implements a resistor-capacitor (RC) circuit battery model that you can use to create lookup tables for the Equivalent Circuit Battery block. The lookup tables are functions of the state-of-charge (SOC).

The Estimation Equivalent Circuit Battery block calculates the combined voltage of the network battery using parameter lookup tables. The tables are functions of the SOC. To acquire the SOC, the block integrates the charge and discharge currents.

Specifically, the block implements these parameters as lookup tables that are functions of the SOC:

- Series resistance, R_o=f(SOC)
- Battery open-circuit voltage, E_m=f(SOC)
- Network resistance, R_n=f(SOC)
- Network capacitance, C_n=f(SOC)

To calculate the combined voltage of the battery network, the block uses these equations.

$$V_T = E_m - I_{batt}R_o - \sum_{1}^{n} V_n$$

$$V_n = \int_0^t \left[\frac{I_{batt}}{C_n} - \frac{V_n}{R_nC_n}\right]dt$$

$$SOC = \frac{-1}{C_{batt}}\int_0^t I_{batt}dt$$

$$I_{batt} = I_{in}$$

$$V_{out} = V_T$$

Positive current indicates battery discharge. Negative current indicates battery charge.

The equations use these variables.

SOC	State-of-charge
E_m	Battery open-circuit voltage

I_{batt}	Per module battery current
I_{in}	Combined current flowing from the battery network
R_o	Series resistance
n	Number of RC pairs in series
V_{out}, V_T	Combined voltage of the battery network
V_n	Voltage for *n*-th RC pair
R_n	Resistance for *n*-th RC pair
C_n	Capacitance for *n*-th RC pair
C_{batt}	Battery capacity

Ports

Inputs

`BattCurr` — Battery network current
`scalar`

Combined current flowing from the battery network, I_{in}, in A.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Variable	Units
`CapVolt`	Voltage for *n*-th RC pair	V_n	V

`BattVolt` — Battery output voltage
`scalar`

Combined voltage of the battery network, V_{out}, in V.

`BattSoc` — Battery SOC
`scalar`

Battery state-of-charge, *SOC*.

Parameters

Core Battery

`Number of series RC pairs` — RC pairs
1 (default) | 2 | 3 | 4 | 5

Number of series RC pairs. For lithium, typically 1 or 2.

`Open circuit voltage Em table data, Em` — Voltage table
`[3.8 3.8 3.8 3.8 3.8 3.8]` (default) | `array`

Open-circuit voltage table, E_m, in V. Function of SOC.

`Series resistance table data, R0` — Resistance
`[0.01 0.01 0.01 0.01 0.01 0.01]` (default) | `array`

Series resistance table, R_o, in ohms. Function of SOC.

`State of charge breakpoints, SOC_BP` — SOC breakpoints
`[0 .2 .4 .6 .8 1]` (default) | `vector`

State-of-charge (SOC) breakpoints, dimensionless.

`Battery capacity, BattCap` — Capacity
`27.6250` (default) | `scalar`

Battery capacity, C_{batt}, in Ah.

`Initial battery capacity, BattCapInit` — Capacity
`27.6250` (default) | `scalar`

Initial battery capacity, C_{batto}, in Ah.

`Initial capacitor voltage, InitialCapVoltage` — Voltage
`0` (default) | `vector`

Initial capacitor voltage, in V. Dimension of vector must equal the **Number of series RC pairs**.

R and C Table Data

`Network resistance table data, R`*n* — Lookup table
`[0.005 0.005 0.005 0.005 0.005 0.005]` (default) | `array`

Network resistance table data for *n*-th RC pair, as a function of SOC, in ohms.

`Network capacitance table data, C`*n* — Lookup table
`[10000 10000 10000 10000 10000 10000]` (default) | `array`

Network capacitance table data for *n*-th RC pair, as a function of SOC, in F.

Cell Limits

`Upper Integrator Voltage Limit, Vu` — Maximum
`Inf` (default) | `scalar`

Upper voltage limit, in V.

`Lower Integrator Voltage Limit, Vl` — Minimum
`Inf` (default) | `scalar`

Lower voltage limit, in V.

References

[1] Ahmed, R., J. Gazzarri, R. Jackey, S. Onori, S. Habibi, et al. "Model-Based Parameter Identification of Healthy and Aged Li-ion Batteries for Electric Vehicle Applications." *SAE International Journal of Alternative Powertrains*. doi:10.4271/2015-01-0252, 4(2):2015.

[2] Gazzarri, J., N. Shrivastava, R. Jackey, and C. Borghesani. "Battery Pack Modeling, Simulation, and Deployment on a Multicore Real Time Target." *SAE International Journal of Aerospace*. doi:10.4271/2014-01-2217, 7(2):2014.

[3] Huria, T., M. Ceraolo, J. Gazzarri, and R. Jackey. "High fidelity electrical model with thermal dependence for characterization and simulation of high power lithium battery cells." *IEEE® International Electric Vehicle Conference*. March 2012, pp. 1–8.

[4] Huria, T., M. Ceraolo, J. Gazzarri, and R. Jackey. "Simplified Extended Kalman Filter Observer for SOC Estimation of Commercial Power-Oriented LFP Lithium Battery Cells." *SAE Technical Paper 2013-01-1544*. doi:10.4271/2013-01-1544, 2013.

[5] Jackey, R. "A Simple, Effective Lead-Acid Battery Modeling Process for Electrical System Component Selection." *SAE Technical Paper 2007-01-0778*. doi:10.4271/2007-01-0778, 2007.

[6] Jackey, R., G. Plett, and M. Klein. "Parameterization of a Battery Simulation Model Using Numerical Optimization Methods." *SAE Technical Paper 2009-01-1381*. doi:10.4271/2009-01-1381, 2009.

[7] Jackey, R., M. Saginaw, T. Huria, M. Ceraolo, P. Sanghvi, and J. Gazzarri. "Battery Model Parameter Estimation Using a Layered Technique: An Example Using a Lithium Iron Phosphate Cell." *SAE Technical Paper 2013-01-1547*. Warrendale, PA: SAE International, 2013.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Datasheet Battery | Equivalent Circuit Battery

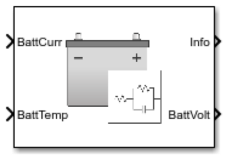
Topics
"Generate Parameter Data for Equivalent Circuit Battery Block"
Battery Modeling

Introduced in R2017a

Equivalent Circuit Battery

Resistor-capacitor (RC) circuit battery

Library: Powertrain Blockset / Energy Storage and Auxiliary Drive / Network Battery



Description

The Equivalent Circuit Battery block implements a resistor-capacitor (RC) circuit battery that you can parameterize using equivalent circuit modeling (ECM). To simulate the state-of-charge (SOC) and terminal voltage, the block uses load current and internal core temperature.

The Equivalent Circuit Battery block calculates the combined voltage of the network battery using parameter lookup tables. The tables are functions of the SOC and battery temperature. You can use the Estimation Equivalent Circuit Battery block to help create the lookup tables.

Specifically, the Equivalent Circuit Battery block implements these parameters as lookup tables that are functions of the SOC and battery temperature:

- Series resistance, $R_o = f(SOC,T)$
- Battery open-circuit voltage, $E_m = f(SOC,T)$
- Battery capacity, $C_{batt} = f(T)$
- Network resistance, $R_n = f(SOC,T)$
- Network capacitance, $C_n = f(SOC,T)$

To calculate the combined voltage of the battery network, the block uses these equations.

$$V_T = E_m - I_{batt}R_o - \sum_1^n V_n$$

$$V_n = \int_0^t \left[\frac{I_{batt}}{C_n} - \frac{V_n}{R_n C_n}\right] dt$$

$$SOC = \frac{-1}{C_{batt}} \int_0^t I_{batt} dt$$

$$I_{batt} = \frac{I_{in}}{N_p}$$

$$V_{out} = N_s V_T$$

$$P_{BattLoss} = I_{batt}2R_0 + \sum_1^n \frac{V_n2}{R_n}$$

$$Ld_{AmpHr} = \int_0^t I_{batt} dt$$

Positive current indicates battery discharge. Negative current indicates battery charge.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrLdBatt`	Battery network power	$V_{batt} = V_{out}$ OR $\frac{V_{out}}{\tau s + 1}$ $P_{batt} = -V_{batt} I_{batt}$ $P_{LdBatt} = -P_{batt}$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrLossBatt`	Battery network power loss	$P_{LossBatt} =$ $-\left(I_{batt}2R_0 + \sum_1^n \frac{V_n2}{R_n}\right)$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredBatt`	Battery network power stored	$P_{StoredBatt} = P_{Batt} + P_{LossBatt}$

The equations use these variables.

SOC	State-of-charge

E_m	Battery open-circuit voltage
I_{batt}	Per module battery current
I_{in}	Combined current flowing from the battery network
R_o	Series resistance
N_p	Number parallel branches
N_p	Number of RC pairs in series
V_{out}, V_T	Combined voltage of the battery network
V_n	Voltage for *n*-th RC pair
R_n	Resistance for *n*-th RC pair
C_n	Capacitance for *n*-th RC pair
C_{batt}	Battery capacity
P_{batt}	Battery power
$P_{LossBatt}$	Negative of battery network power loss
$P_{BattLoss}$	Battery network power loss
$P_{StoredBatt}$	Battery network power stored
P_{LdBatt}	Battery network power
T	Battery temperature

Ports

Inputs

`CapInit` — Battery capacity
`scalar`

Rated battery capacity at the nominal temperature, Cap_{batt}, in Ah.

Dependencies

To create this port, select `External Input` for the **Initial battery capacity** parameter.

`BattCurr` — Battery network current
`scalar`

Combined current flowing from the battery network, I_{in}, in A.

`BattTemp` — Battery temperature
`scalar`

Battery temperature, T, in K.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Variable	Units
BattCurr			Combined current flowing from the battery network	I_{batt}	A
BattAmpHr			Battery energy	Ld_{AmpHr}	A*h
BattSoc			State-of-charge capacity	SOC	NA
BattVolt			Combined voltage of the battery network	V_{out}	V
BattPwr			Battery power	P_{batt}	W
PwrInfo	PwrTrnsfrd	PwrLdBatt	Battery network power	P_{LdBatt}	W
	PwrNotTrnsfrd	PwrLossBatt	Battery network power loss	$P_{LossBatt}$	W
	PwrStored	PwrStoredBatt	Battery network power stored	$P_{StoredBatt}$	W

BattVolt — Battery output voltage
scalar

Combined voltage of the battery network, V_{out}, in V.

Parameters

Block Options

Initial battery capacity — Input or parameter
Parameter (default) | External Input

Initial battery capacity, Cap_{batt}, in Ah.

Dependencies

Block Parameter Initial battery capacity Option	Creates
External Input	Input port CapInit
Parameter	Parameter **Initial battery capacity, BattCapInit**

Output battery voltage — Unfiltered or Filter
Unfiltered (default) | Filtered

Select Filtered to apply a first-order filter to the output batter voltage.

Dependencies

Setting **Output battery voltage** parameter to Filtered creates these parameters:

- **Output battery voltage time constant, Tc**
- **Output battery voltage initial value, Vinit**

Core Battery

Number of series RC pairs — RC pairs
1 (default) | 2 | 3 | 4 | 5

Number of series RC pairs. For lithium, typically 1 or 2.

Open circuit voltage Em table data, Em — Voltage table
[3.5042 3.5136; 3.5573 3.5646; 3.6009 3.6153; 3.6393 3.6565; 3.6742 3.6889; 3.7121 3.7214; 3.7937 3.8078; 3.8753 3.8945; 3.97 3.9859; 4.0764 4.0821; 4.1924 4.193] (default) | array

Open circuit voltage table, E_m, in V. Function of SOC and battery temperature.

Series resistance table data, R0 — Resistance
array

Series resistance table, R_o, in ohms. Function of SOC and battery temperature.

State of charge breakpoints, SOC_BP — SOC breakpoints
[0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1] (default) | vector

State-of-charge (SOC) breakpoints, dimensionless.

Temperature breakpoints, Temperature_BP — Battery
[293.15 313.15] (default) | vector

Battery temperature breakpoints, K.

Battery capacity table, BattCap — Capacity
[28 28] (default) | array

Battery capacity, C_{batt}, in Ah. Function of battery temperature.

Initial battery capacity, BattCapInit — Capacity
28 (default) | scalar

Initial battery capacity, Cap_{batt}, in Ah.

Dependencies

Block Parameter Initial battery capacity Option	Creates
External Input	Input port CapInit
Parameter	Parameter **Initial battery capacity, BattCapInit**

Initial capacitor voltage, InitialCapVoltage — Voltage
0 (default) | array

Initial capacitor voltage, in V. Dimension of vector must equal the **Number of series RC pairs**.

Output battery voltage time constant, Tc — Filter time constant
1/1000 (default) | scalar

Output battery voltage time constant, T_c, in s. Used in a first-order voltage filter.

Dependencies

Setting **Output battery voltage** parameter to `Filtered` creates these parameters:

- **Output battery voltage time constant, Tc**
- **Output battery voltage initial value, Vinit**

`Output battery voltage initial value, Vinit` — Filter initial voltage

`4.193` (default) | `scalar`

Output battery voltage initial value, V_{init}, in V. Used in a first-order voltage filter.

Dependencies

Setting **Output battery voltage** parameter to `Filtered` creates these parameters:

- **Output battery voltage time constant, Tc**
- **Output battery voltage initial value, Vinit**

R and C Table Data

`Network resistance table data, R`*n* — Lookup table

`[0.010342 0.0012244; 0.0067316 0.0011396; 0.0051156 0.0012661; 0.0043447 0.0012265; 0.0038826 0.0011163; 0.0034226 0.0009968; 0.003346 0.0011458; 0.0033222 0.001345; 0.0033201 0.0013091; 0.0032886 0.0010986; 0.0028114 0.0010309]` (default) | `array`

Network resistance table data for *n*-th RC pair, in ohms, as a function of SOC and battery temperature.

`Network capacitance table data, C`*n* — Lookup table

`[2287.7 11897; 6122 24515; 18460 42098; 20975 44453; 15254 33098; 10440 24492; 13903 32975; 16694 40007; 15784 35937; 12165 26430; 9118 24795]` (default) | `array`

Network capacitance table data for *n*-th RC pair, in F, as a function of SOC and battery temperature.

Cell Limits

`Upper integrator voltage limit, Vu` — Maximum

`-Inf` (default) | `scalar`

Upper voltage limit, in V.

`Lower integrator voltage limit, Vl` — Minimum

`-Inf` (default) | `scalar`

Lower voltage limit, in V.

References

[1] Ahmed, R., J. Gazzarri, R. Jackey, S. Onori, S. Habibi, et al. "Model-Based Parameter Identification of Healthy and Aged Li-ion Batteries for Electric Vehicle Applications." *SAE International Journal of Alternative Powertrains*. doi:10.4271/2015-01-0252, 4(2):2015.

[2] Gazzarri, J., N. Shrivastava, R. Jackey, and C. Borghesani. "Battery Pack Modeling, Simulation, and Deployment on a Multicore Real Time Target." *SAE International Journal of Aerospace*. doi:10.4271/2014-01-2217, 7(2):2014.

[3] Huria, T., M. Ceraolo, J. Gazzarri, and R. Jackey. "High fidelity electrical model with thermal dependence for characterization and simulation of high power lithium battery cells." *IEEE International Electric Vehicle Conference*. March 2012, pp. 1–8.

[4] Huria, T., M. Ceraolo, J. Gazzarri, and R. Jackey. "Simplified Extended Kalman Filter Observer for SOC Estimation of Commercial Power-Oriented LFP Lithium Battery Cells." *SAE Technical Paper 2013-01-1544*. doi:10.4271/2013-01-1544, 2013.

[5] Jackey, R. "A Simple, Effective Lead-Acid Battery Modeling Process for Electrical System Component Selection." *SAE Technical Paper 2007-01-0778*. doi:10.4271/2007-01-0778, 2007.

[6] Jackey, R., G. Plett, and M. Klein. "Parameterization of a Battery Simulation Model Using Numerical Optimization Methods." *SAE Technical Paper 2009-01-1381*. doi:10.4271/2009-01-1381, 2009.

[7] Jackey, R., M. Saginaw, T. Huria, M. Ceraolo, P. Sanghvi, and J. Gazzarri. "Battery Model Parameter Estimation Using a Layered Technique: An Example Using a Lithium Iron Phosphate Cell." *SAE Technical Paper 2013-01-1547*. Warrendale, PA: SAE International, 2013.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Datasheet Battery | Estimation Equivalent Circuit Battery

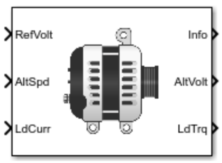
Topics
"Generate Parameter Data for Equivalent Circuit Battery Block"
Battery Modeling

Introduced in R2017a

Reduced Lundell Alternator

Reduced Lundell (claw-pole) alternator with an external voltage regulator

Library: Powertrain Blockset / Energy Storage and Auxiliary Drive / Alternator



Description

The Reduced Lundell Alternator block implements a reduced Lundell (claw-pole) alternator with an external voltage regulator. The back-electromotive force (EMF) voltage is proportional to the input velocity and field current. The motor operates as a source torque to the internal combustion engine.

Use the Reduced Lundell Alternator block:

- To model an automotive electrical system
- In an engine model with a front-end accessory drive (FEAD)

The calculated motor shaft torque is in the opposite direction of the engine speed. You can:

- Tune the external voltage regulator to a desired bandwidth. The stator current and two diode drops reduce the stator voltage.
- Filter the load current to desired bandwidth. The load current has a lower saturation of 0 A.

The Reduced Lundell Alternator block implements equations for the electrical, control, and mechanical systems that use these variables.

Electrical

To calculate voltages, the block uses these equations.

Calculation	Equations
Alternator output voltage	$v_s = K_v i_f \omega - R_s i_s - 2V_d$
Field winding voltage	$v_f = R_f i_f + L_f \frac{di_f}{dt}$

Control

The controller assumes no resistance or voltage drop.

Calculation	Equations
Field winding voltage transform	$V_f(s) = R_f I_f(s) + sL_f I_f(s)$
Field winding current transform	$I_f(s) = \frac{V_f(s)}{(R_f + sL_f)}$

Calculation	Equations
Open loop electrical transfer function	$G(s) = \frac{V_s(s)}{V_f(s)} = \frac{K_v\omega}{(R_f + sL_f)}$
Open loop voltage regulator transfer function	$G_C(s) = \frac{V_f(s)}{Vref(s)}$
Closed loop transfer function	$T(s) = \frac{G(s)Gc(s)}{1 + G(s)Gc(s)}$
Closed loop controller design	$T(s) = \frac{1}{\tau s + 1} \rightarrow \quad G(s)Gc(s) = \frac{1}{\tau s}$ $G_C(s) = K_g \quad (K_p + \frac{K_i}{s})$ $G(s)G_C(s) = \frac{K_v\omega}{(R_f + sL_f)}K_g \quad (K_p + \frac{K_i}{s})$ $K_p = L_f \ , K_i = R_f \ , and \quad K_g = \frac{2\pi f}{K_v\omega}$

Mechanical

To calculate torques, the block uses these equations.

Calculation	Equations
Electrical torque	$\tau_{elec} = (K_v i_f \omega) i_{load}$
Frictional torque	$\tau_{friction} = K_b\omega$
Windage torque	$\tau_{windage} = K_w\omega^2$
Torque at start	$\tau_{start} = K_c$ when $\omega = 0$
Motor shaft torque	$\tau_{mech} = \tau_{elec} + \tau_{friction} + \tau_{windage} + \tau_{start}$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrMtr`	Mechanical power	P_{mot}	$P_{mot} = \omega\tau_{mech}$
		`PwrBus`	Electrical power	P_{bus}	$P_{bus} = - v_s i_{load}$

Bus Signal			Description	Variable	Equations
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrLoss`	Motor power loss	P_{loss}	$P_{loss} = \quad -(P_{mot} + P_{bus} - P_{ind})$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrInd`	Electrical winding loss	P_{ind}	$P_{ind} = \quad L_f i_f \frac{di_f}{dt}$

The equations use these variables.

v_{ref}	Alternator output voltage command
v_f	Field winding voltage
i_f	Field winding current
i_s	Stator winding current
V_d	Diode voltage drop
R_f	Field winding resistance
R_s	Stator winding resistance
L_f	Field winding inductance
K_v	Voltage constant
F_v	Voltage regulator bandwidth
F_c	Input current filter bandwidth
V_{fmax}	Field control voltage upper saturation limit
V_{fmin}	Field control voltage lower saturation limit
K_c	Coulomb friction coefficient
K_b	Viscous friction coefficient
K_w	Windage coefficient
ω	Motor shaft angular speed
i_{load}	Alternator load current
v_s	Alternator output voltage
τ_{mech}, T_{mech}	Motor shaft torque

Ports

Inputs

`RefVolt` — Alternator output voltage command
`scalar`

Alternator output voltage command, in V.

`AltSpd` — Angular speed
`scalar`

Motor shaft input angular speed, in rad/s.

`LdCurr` — Alternator load current
`scalar`

Alternator load current, in A.

Do not connect the port to the alternator rated current, which is a constant value. The block uses the alternator load current as the stator winding current, i_s, to determine the alternator voltage and motor torque. If you connect the port to the rated alternator current, the block does not model the dynamic effect of load current changes on the voltage and motor torque.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

<table>
<tr><th colspan="3">Signal</th><th>Description</th><th>Units</th></tr>
<tr><td colspan="3">FldVolt</td><td>Field winding voltage</td><td>A</td></tr>
<tr><td colspan="3">FldFlux</td><td>Field flux</td><td>Wb</td></tr>
<tr><td rowspan="4">PwrInfo</td><td rowspan="2">PwrTrnsfrd</td><td>PwrMtr</td><td>Mechanical power</td><td>W</td></tr>
<tr><td>PwrBus</td><td>Electrical power</td><td>W</td></tr>
<tr><td>PwrNotTrnsfrd</td><td>PwrLoss</td><td>Motor power loss</td><td>W</td></tr>
<tr><td>PwrStored</td><td>PwrInd</td><td>Electrical winding loss</td><td>W</td></tr>
</table>

`AltVolt` — Alternator output voltage
`scalar`

Alternator output voltage, in V.

`LdTrq` — Motor shaft torque
`scalar`

Motor shaft torque, in N·m.

Parameters

Machine Configuration

Voltage constant, Kv — Constant
.1 (default) | scalar

Voltage constant, in V/rad/s.

Field winding resistance, Rf — Resistance
0.2 (default) | scalar

Field winding resistance, in ohm.

Field winding inductance, Lf — Inductance
0.002 (default) | scalar

Field winding inductance, in H.

Stator winding resistance, Rs — Resistance
0.01 (default) | scalar

Stator winding resistance, in ohm.

Diode voltage drop, Vd — Voltage
0.7 (default) | scalar

Diode voltage drop, in V.

Voltage Regulator

Regulator bandwidth, Fv — Bandwidth
2000 (default) | scalar

The regulator bandwidth, in Hz.

Current filter bandwidth, Fc — Bandwidth
1000 (default) | scalar

The current filter bandwidth, in Hz.

Field voltage max, Vfmax — Maximum field voltage
100 (default) | scalar

The maximum field voltage, in V.

Field voltage min, Vfmin — Minimum field voltage
-100 (default) | scalar

The minimum field voltage, in V.

Mechanical Losses

Coulomb friction, Kc — Friction
0 (default) | scalar

Coulomb friction, in N·m.

`Viscous friction, Kb` — Friction
`0` (default) | `scalar`

Viscous friction, in N·m/rad/s.

`Windage, Kw` — Windage
`0` (default) | `scalar`

Windage, in N·m/rad^2/s^2.

References

[1] Krause, P. C. *Analysis of Electric Machinery*. New York: McGraw-Hill, 1994.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

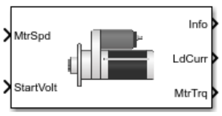
Starter

Introduced in R2017a

Starter

Starter as a DC motor

Library: Powertrain Blockset / Energy Storage and Auxiliary Drive / Starter



Description

The Starter block implements a starter assembly as a separately excited DC motor, permanent magnet DC motor, or series connection DC motor. The motor operates as a torque source to an internal combustion engine.

Use the Starter block:

- In an engine model with a front-end accessory drive (FEAD)
- To model engine start and stop scenarios

The Starter block supports only an angular speed input to the DC motor. A load torque input requires engine dynamics.

Separately Excited DC Motor

In a separately excited DC motor, the field winding is connected to a separate source of DC power.

The relationship between the field winding voltage, field resistance, and field inductance is given by:

$$V_f = L_f \frac{di_f}{dt} + R_f i_f$$

The counter-electromotive force is a product of the field resistance, mutual inductance, and motor shaft angular speed:

$$EMF = L_a i_f L_{af} \omega$$

The armature voltage is given by:

$$V_a = L_a \frac{di_a}{dt} + R_a i_a + \quad EMF$$

The starter motor current load is the sum of the field winding current and armature winding current:

$$i_{load} = \quad i_f + \quad i_a$$

The starter motor shaft torque is the product of the armature current, field current, and mutual inductance:

$$T_{mech} = \quad i_a i_f L_{af}$$

Permanent Magnet DC Motor

In a permanent magnet DC motor, the magnets establish the excitation flux, so there is no field current.

The counter-electromotive force is proportional to the motor shaft angular speed:

$$EMF = K_t \omega$$

The armature voltage is given by:

$$V_a = L_a \frac{di_a}{dt} + R_a i_a + EMF$$

The starter motor current load is equal to the armature winding current:

$$i_{load} = i_a$$

The starter motor shaft torque is proportional to the armature winding current:

$$T_{mech} = K_t i_a$$

Series Excited DC Motor

A series excited DC motor connects the armature and field windings in series with a common DC power source.

The counter-electromotive force is a product of the field and armature initial series current, field, and armature mutual inductance and motor shaft angular speed:

$$EMF = i_{af} L_{af} \omega$$

The field and armature winding voltage is given by:

$$V_{af} = L_{ser} \frac{di_{af}}{dt} + R_{ser} i_{af} + EMF$$

The starter motor current load is equal to the field and armature series current:

$$i_{load} = i_{af}$$

The starter motor shaft torque is the product of the squared field and armature series current and the field and armature mutual inductance:

$$T_{mech} = i_{af}^2 L_{af}$$

For motor stability, the motor shaft angular speed must be greater than the ratio of the series connected field and armature resistance to the mutual inductance:

$$\omega > -\frac{R_{ser}}{L_{af}}$$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrMtr`	Mechanical power	P_{mot}	$P_{mot} = -\omega T_{mech}$
		`PwrBus`	Electrical power	P_{bus}	Separately excited DC motor $P_{bus} = v_a i_a + v_f i_f$
					PM excited DC motor $P_{bus} = v_a i_a$
					Series excited DC motor $P_{bus} = v_{af} i_{af}$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrLoss`	Motor losses	P_{loss}	$P_{loss} = -(P_{mot} + P_{bus} - P_{ind})$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrInd`	Electrical inductance	P_{ind}	Separately excited DC motor $P_{ind} = L_f i_f \frac{di_f}{dt} + L_a i_a \frac{di_a}{dt}$
					PM excited DC motor $P_{ind} = L_a i_a \frac{di_a}{dt}$
					Series excited DC motor $P_{ind} = L_{ser} i_{af} \frac{di_{af}}{dt}$

The equations use these variables.

R_a	Armature winding resistance
L_a	Armature winding inductance
EMF	Counter-electromotive force
R_f	Field winding resistance
L_f	Field winding inductance
L_{af}	Field and armature mutual inductance

i_a	Armature winding current
i_f	Field winding current
K_t	Motor torque constant
ω	Motor shaft angular speed
V_a	Armature winding voltage
V_f	Field winding voltage
V_{af}	Field and armature winding voltage
i_{af}	Field and armature series current
R_{ser}	Series connected field and armature resistance
L_{ser}	Series connected field and armature inductance
i_{load}	Starter motor current load
T_{mech}	Starter motor shaft torque

Ports

Inputs

`MtrSpd` — Angular speed
`scalar`

Motor shaft angular speed, in rad/s.

`StartVolt` — Armature and field voltage
`scalar`

- Armature winding voltage V_a and field winding voltage V_f, in V.
- In series excited DC motor, armature and field winding voltage V_{af}.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
`ArmCurr`			Armature winding current	A
`FldCurr`			Field winding current	A
`PwrInfo`	`PwrTrnsfrd`	`PwrMtr`	Mechanical power	W
		`PwrBus`	Electrical power	W
	`PwrNotTrnsfrd`	`PwrLoss`	Motor power loss	W
	`PwrStored`	`PwrInd`	Electrical inductance	W

`LdCurr` — Starter motor load current
`scalar`

Starter motor load current, in A.

`MtrTrq` — Starter motor shaft torque
`scalar`

Starter motor shaft torque, in N·m.

Parameters

Configuration

`Motor Type` — Select motor type
`Separately Excited DC Motor` (default) | `Permanent Magnet Excited DC Motor` | `Series Connection DC Motor`

Select one of the three motor types.

Dependencies

The table summarizes the motor parameter dependencies.

Motor Type	Enables Motor Parameter
`Separately Excited DC Motor`	**Armature winding resistance, Ra**
	Armature winding inductance, La
	Field winding resistance Rf
	Field winding inductance, Lf
	Mutual inductance, Laf
	Initial armature and field current, Iaf
`Permanent Magnet Excited DC Motor`	**Armature winding resistance, Rapm**
	Armature winding inductance, Lapm
	Torque constant, Kt
	Initial armature current, Ia
`Series Connection DC Motor`	**Total resistance, Rser**
	Total inductance, Lser
	Initial current, Iafser
	Mutual inductance, Lafser

Separately Excited DC Motor

`Armature winding resistance, Ra` — Resistance
`1` (default) | `scalar`

Armature winding resistance, in ohm.

Dependencies

To enable this parameter, select `Separately Excited DC Motor` for the **Motor Type** parameter.

`Armature winding inductance, La` — Inductance
`.1` (default) | `scalar`

Armature winding inductance, in H.

Dependencies

To enable this parameter, select `Separately Excited DC Motor` for the **Motor Type** parameter.

`Field winding resistance, Rf` — Resistance
`.3` (default) | `scalar`

Field winding resistance, in ohm.

Dependencies

To enable this parameter, select `Separately Excited DC Motor` for the **Motor Type** parameter.

`Field winding inductance, Lf` — Inductance
`.2` (default) | `scalar`

Field winding inductance, in H.

Dependencies

To enable this parameter, select `Separately Excited DC Motor` for the **Motor Type** parameter.

`Mutual inductance, Laf` — Inductance
`.3` (default) | `scalar`

Mutual inductance, in H.

Dependencies

To enable this parameter, select `Separately Excited DC Motor` for the **Motor Type** parameter.

`Initial armature current and field current, Iaf` — Current
`[0 0]` (default) | `vector`

Initial armature and field current, in A.

Dependencies

To enable this parameter, select `Separately Excited DC Motor` for the **Motor Type** parameter.

Permanent Magnet Excited DC Motor

`Armature winding resistance, Rapm` — Resistance
`.5` (default) | `scalar`

Armature winding resistance, in ohm.

Dependencies

To enable this parameter, select `Permanent Magnet Excited DC Motor` for the **Motor Type** parameter.

`Armature winding inductance, Lapm` — Inductance
`.1` (default) | `scalar`

Armature winding inductance, in H.

Dependencies

To enable this parameter, select `Permanent Magnet Excited DC Motor` for the **Motor Type** parameter.

`Torque constant, Kt` — Motor torque constant

`.1` (default) | `scalar`

Motor torque constant, in N·m/A.

Dependencies

To enable this parameter, select `Permanent Magnet Excited DC Motor` for the **Motor Type** parameter.

`Initial armature current, Ia` — Current

`.1` (default) | `scalar`

Initial armature current, in A.

Dependencies

To enable this parameter, select `Permanent Magnet Excited DC Motor` for the **Motor Type** parameter.

Series Connection DC Motor

`Total resistance, Rser` — Resistance

`.1` (default) | `scalar`

Series connected field and armature resistance, in ohm.

Dependencies

To enable this parameter, select `Series Excited DC Motor` for the **Motor Type** parameter.

`Total inductance, Lser` — Inductance

`.1` (default) | `scalar`

Series connected field and armature inductance, in H.

Dependencies

To enable this parameter, select `Series Excited DC Motor` for the **Motor Type** parameter.

`Initial current, Iafser` — Current

`0` (default) | `scalar`

Initial series current, in A.

Dependencies

To enable this parameter, select `Series Excited DC Motor` for the **Motor Type** parameter.

`Mutual inductance, Lafser` — Inductance

`.3` (default) | `scalar`

Field and armature mutual inductance, in H.

Dependencies

To enable this parameter, select `Series Excited DC Motor` for the **Motor Type** parameter.

References

[1] Krause, P. C. *Analysis of Electric Machinery*. New York: McGraw-Hill, 1994.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

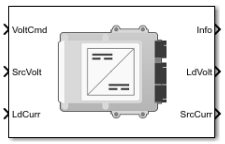
See Also
Reduced Lundell Alternator

Introduced in R2017a

Bidirectional DC-DC

DC-to-DC converter that supports bidirectional boost and buck

Library: Powertrain Blockset / Energy Storage and Auxiliary Drive / DC-DC



Description

The Bidirectional DC-DC block implements a DC-to-DC converter that supports bidirectional boost and buck (lower) operation. Unless the DC-to-DC conversion limits the power, the output voltage tracks the voltage command. You can specify electrical losses or measured efficiency.

Depending on your battery system configuration, the voltage might not be at a potential that is required by electrical system components such has inverters and motors. You can use the block to boost or buck the voltage. Connect the block to the battery and one of these blocks:

- Mapped Motor
- IM Controller
- Interior PM Controller
- Surface Mount PM Controller

To calculate the electrical loss during the DC-to-DC conversion, use **Parameterize losses by**.

Parameter Option	Description
`Single efficiency measurement`	Electrical loss calculated using a constant value for conversion efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of load current and voltage. DC-to-DC converter data sheets typically provide loss data in this format. When you use this option, provide data for all the operating quadrants in which the simulation will run. If you provide partial data, the block assumes the same loss pattern for other quadrants. The block does not extrapolate loss that is outside the range voltage and current that you provide. The block allows you to account for fixed losses that are still present for zero voltage or current.

Parameter Option	Description
`Tabulated efficiency data`	Electrical loss calculated using conversion efficiency that is a function of load current and voltage. When you use this option, provide data for all the operating quadrants in which the simulation will run. If you provide partial data, the block assumes the same efficiency pattern for other quadrants. The block: • Assumes zero loss when either the voltage or current is zero. • Uses linear interpolation to determine the loss. At lower power conditions, for calculation accuracy, provide efficiency at low voltage and low current.

Note The block does not support inversion. The polarity of the input voltage matches the polarity of the output voltage.

Theory

The Bidirectional DC-DC block uses the commanded voltage and the actual voltage to determine whether to boost or buck (lower) the voltage. You can specify a time constant for the voltage response.

If	Then
$Volt_{cmd} > Src_{Volt}$	Boost
$Volt_{cmd} < Src_{Volt}$	Buck

The Bidirectional DC-DC block uses a time constant-based regulator to provide a fixed output voltage that is independent of load current. Using the output voltage and current, the block determines the losses of the DC-to-DC conversion. The block uses the conversion losses to calculate the input current. The block accounts for:

- Bidirectional current flow
  - Source to load — Battery discharge
  - Load to source — Battery charge
- Rated power limits

The block provides voltage control that is power limited based on these equations. The voltage is fixed. The block does not implement a voltage drop because the load current approximates DC-to-DC conversion with a bandwidth that is greater than the load current draw.

DC-to-DC converter load voltage	$LdVolt_{Cmd} = \min(Volt_{Cmd}, \frac{P_{limit}}{Ld_{Amp}}, 0)$ $LdVolt = LdVolt_{Cmd} \cdot \frac{1}{\tau s + 1}$
Power loss for single efficiency source to load	$Pwr_{Loss} = \frac{100 - Eff}{Eff} \cdot Ld_{Volt} \cdot Ld_{Amp}$

Power loss for single efficiency load to source	$Pwr_{Loss} = \frac{100 - Eff}{Eff} \cdot \lvert Ld_{Volt} \cdot Ld_{Amp} \rvert$
Power loss for tabulated efficiency	$Prw_{Loss} = f\left(Ld_{Volt}, Ld_{Amp}\right)$
Source current draw from DC-to-DC converter	$Src_{Amp} = \frac{Ld_{Pwr} + Prw_{Loss}}{Src_{Volt}}$
Source power from DC-to-DC converter	$Src_{Pwr} = Src_{Amp} \cdot Src_{Volt}$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			**Description**	**Variable**	**Equations**
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrBusSrc`	Source power to DC-to-DC converter	P_{src}	$P_{src} = SrcPwr$
		`PwrBusLd`	Load power from DC-to-DC converter	P_{bus}	$P_{bus} = -LdVolt$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrLoss`	Converter power loss	P_{loss}	$P_{loss} = PwrLoss$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease		*Not used*		

The equations use these variables.

$Volt_{Cmd}$	DC-to-DC converter commanded output voltage
Src_{Volt}	Source input voltage to DC-to-DC converter
Ld_{Amp}	Load current of DC-to-DC converter
Ld_{Volt}	Load voltage of DC-to-DC converter
Src_{Amp}	Source current draw from DC-to-DC converter
τ	Conversion time constant
V_{init}	Initial load voltage of the DC-to-DC converter
P_{limit}	Output power limit for DC-to-DC converter
Eff	Input to output efficiency
Src_{Pwr}	Source power to DC-to-DC converter
Ld_{Pwr}	Load power from DC-to-DC converter

Pwr_{Loss}	Power loss
$LdVolt_{Cmd}$	Commanded load voltage of DC-to-DC converter before application of time constant

Ports

Inputs

`VoltCmd` — Commanded voltage
`scalar`

DC-to-DC converter commanded output voltage, $Volt_{Cmd}$, in V.

`SrcVolt` — Input voltage
`scalar`

Source input voltage to DC-to-DC converter, Src_{Volt}, in V.

`LdCurr` — Load current
`scalar`

Load current of DC-to-DC converter, Ld_{Amp}, in A.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Variable	Units
`SrcPwr`			Source power to DC-to-DC converter	Src_{Pwr}	W
`LdPwr`			Load power from DC-to-DC converter	Ld_{Pwr}	W
`PwrLoss`			Power loss	Pwr_{Loss}	W
`LdVoltCmd`			Commanded load voltage of DC-to-DC converter before application of time constant	$LdVolt_{Cmd}$	V
`PwrInfo`	`PwrTrnsfrd`	`PwrBusSrc`	Source power to DC-to-DC converter	P_{src}	W
		`PwrBusLd`	Load power from DC-to-DC converter	P_{bus}	W
	`PwrNotTrnsfrd`	`PwrLoss`	Converter power loss	P_{loss}	W
	`PwrStored`	*Not used*			

`LdVolt` — Load voltage
`scalar`

Load voltage of DC-to-DC converter, Ld_{Volt}, in V.

`SrcCurr` — Source current
`scalar`

Source current draw from DC-to-DC converter, Src_{Amp}, in A.

Parameters

Electrical Control

`Converter response time constant` — Constant
`1/1000` (default) | `scalar`

Converter response time, τ, in s.

`Converter response initial voltage, Vinit` — Voltage
`0` (default) | `scalar`

Initial load voltage of the DC-to-DC converter, V_{init}, in V.

`Converter power limit, Plimit` — Power
`100000` (default) | `scalar`

Initial load voltage of the DC-to-DC converter, P_{limit}, in W.

Electrical Losses

`Parameterize losses by` — Loss calculation
`Single efficiency measurement` (default) | `Tabulated loss data` | `Tabulated efficiency data`

This table summarizes the loss options used to calculate electrical options.

Parameter Option	Description
`Single efficiency measurement`	Electrical loss calculated using a constant value for conversion efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of load current and voltage. DC-to-DC converter data sheets typically provide loss data in this format. When you use this option, provide data for all the operating quadrants in which the simulation will run. If you provide partial data, the block assumes the same loss pattern for other quadrants. The block does not extrapolate loss that is outside the range voltage and current that you provide. The block allows you to account for fixed losses that are still present for zero voltage or current.

Parameter Option	Description
`Tabulated efficiency data`	Electrical loss calculated using conversion efficiency that is a function of load current and voltage. When you use this option, provide data for all the operating quadrants in which the simulation will run. If you provide partial data, the block assumes the same efficiency pattern for other quadrants. The block: • Assumes zero loss when either the voltage or current is zero. • Uses linear interpolation to determine the loss. At lower power conditions, for calculation accuracy, provide efficiency at low voltage and low current.

`Overall DC to DC converter efficiency, eff` — Constant
`98` (default) | `scalar`

Overall conversion efficiency, *Eff*, in %.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Single efficiency measurement`.

`Vector of voltages (v) for tabulated loss, v_loss_bp` — Breakpoints
`[0 200 400 600 800 1000]` (default) | 1-by-`M` vector

Tabulated loss breakpoints for `M` load voltages, in V.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Vector of currents (i) for tabulated loss, i_loss_bp` — Breakpoints
`[0 25 50 75 100]` (default) | 1-by-`N` vector

Tabulated loss breakpoints for `N` load currents, in A.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Corresponding losses, losses_table` — 2-D lookup table
`N`-by-`M` matrix

Electrical loss map, as a function of `N` load currents and `M` load voltages, in W.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Vector of voltages (v) for tabulated efficiency, v_eff_bp` — Breakpoints
`[200 400 600 800 1000]` (default) | 1-by-`M` vector

Tabulated efficiency breakpoints for `M` load voltages, in V.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

`Vector of currents (i) for tabulated efficiency, i_eff_bp` — Breakpoints
`[25 50 75 100]` (default) | 1-by-`N` vector

Tabulated efficiency breakpoints for `N` load currents, in A.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

`Corresponding efficiency, efficiency_table` — 2-D lookup table
`N`-by-`M` matrix

Electrical efficiency map, as a function of `N` load currents and `M` load voltages, in %.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
Estimation Equivalent Circuit Battery | Equivalent Circuit Battery

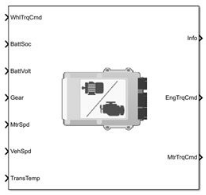
Topics
Battery Modeling

Introduced in R2017b

Equivalent Consumption Minimization Strategy

Energy management controller for P0–P4 hybrid electric vehicles

Library: Powertrain Blockset / Propulsion / Supervisory Controllers

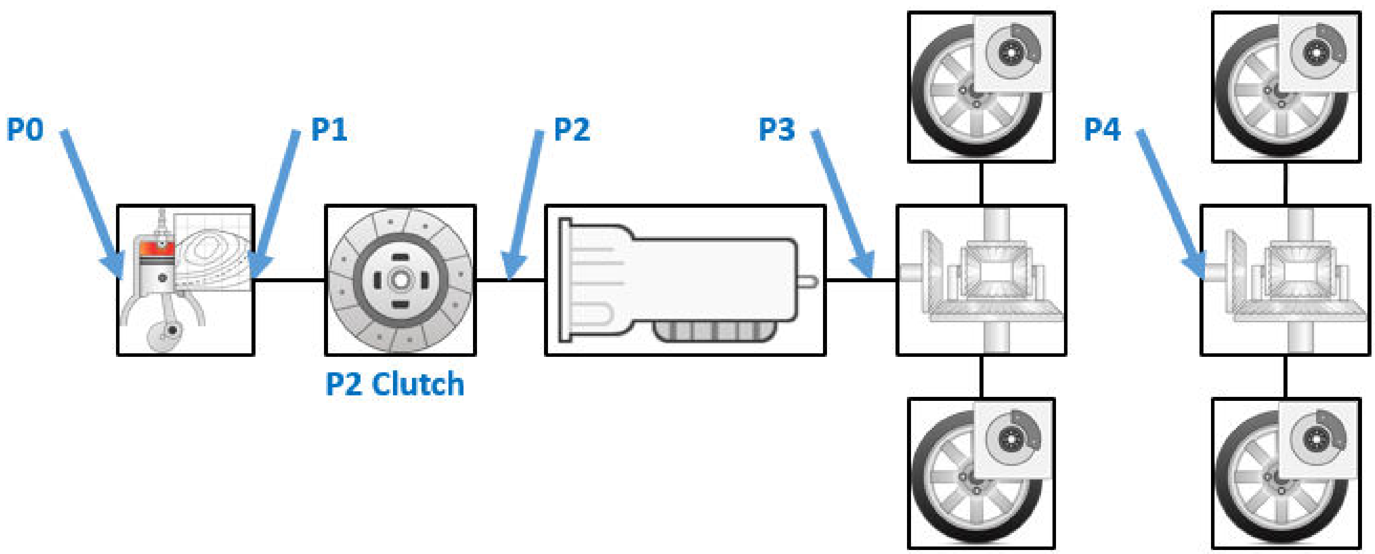


Description

Use the Equivalent Consumption Minimization Strategy (ECMS) block to control the energy management of hybrid electric vehicles (HEVs). The block optimizes the torque split between the engine and motor to minimize energy consumption while maintaining the battery state of charge (SOC).

The HEV P0, P1, P2, P3, and P4 reference applications use the Equivalent Consumption Minimization Strategy block for hybrid control.

Use the **Motor location** parameter to specify the HEV motor location.



Use the **ECMS method** parameter to implement either an adaptive or non-adaptive ECMS method. The HEV architectures are charge-sustaining, meaning the battery SOC must remain in a specified range because there is no plugin capability to recharge the battery. The battery is an energy buffer, and all energy comes from the fuel if the change in SOC is minimized over a drive cycle. To sustain the charge over a specified drive cycle, the block implements either of these ECMS methods.

<table>
<tr><th>ECMS Method</th><th>Description</th></tr>
<tr><td><code>Non-adaptive</code> (default)</td><td>The block uses a constant ECMS equivalence factor.
• Use this method to determine the best fuel economy over a drive cycle.
  ◦ If you change the drive cycle or HEV architecture, retune the ECMS weighting factor to maintain the ending SOC.
• By default, the block uses a single constant.</td></tr>
<tr><td><code>Adaptive</code></td><td>The block adjusts an ECMS equivalence factor by using the output of a PI controller.
• Use this method to maintain the SOC and minimize the delta SOC over many drive cycles. The block:
  ◦ Tunes the PI controller gains.
  ◦ Sustains the SOC.
• The PI controller minimizes the error between the target SOC and current SOC.</td></tr>
</table>

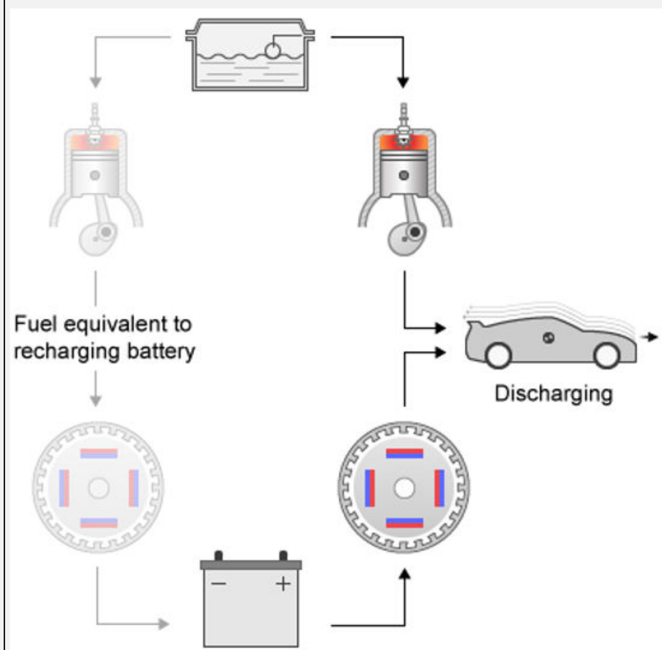
ECMS Control Algorithm

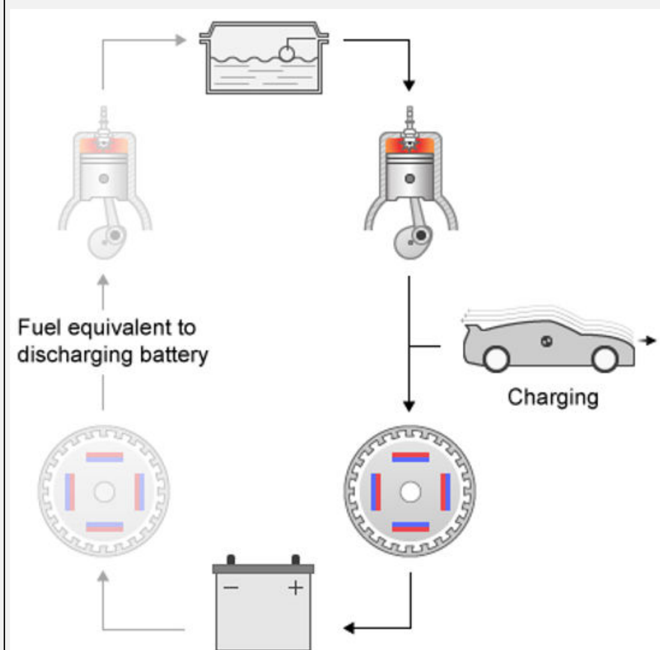
The block implements a dynamic supervisory controller that determines the engine torque, motor torque, starter, clutch, and brake pressure commands. Specifically, the block:

- Converts the driver accelerator pedal signal to a wheel torque request. To calculate the total powertrain torque at the wheels, the algorithm uses the maximum engine torque and motor torque curves and the transmission and differential gear ratios.
- Converts the driver brake pedal signal to a brake pressure request. The algorithm multiplies the brake pedal signal by a maximum brake pressure.
- Implements a regenerative braking algorithm for the traction motor to recover the maximum amount of kinetic energy from the vehicle.

  The block implements an ECMS algorithm[2] that optimizes the torque split between the engine and motor to minimize energy consumption while maintaining the battery SOC. Specifically, the ECMS:

  - Assigns a cost to electrical energy, so that using stored electrical energy is equal to consuming fuel energy.

Battery Mode	Equivalent Electrical Energy	Description
Discharging	Positive	Battery discharges stored electrical energy when the electric machine is in use. 

Battery Mode	Equivalent Electrical Energy	Description
Charging	Negative	Battery stores electrical energy from either the: • Engine and electric machine acting as a generator • Electric machine acting as a generator during regenerative braking 

- Is an instantaneous minimization method that the software solves at every controller time step. To implement the strategy, the ECMS selects the optimal motor and engine torque in the optimization strategy to minimize the equivalent energy consumption.
- Implements either an adaptive or non-adaptive ECMS method.

Ports

Input

`WhlTrqCmd` — Wheel torque command
`scalar`

Wheel torque command.

Data Types: `double`

`BattSoc` — Battery state of charge
`scalar`

Battery state of charge.

Data Types: `double`

BattVolt — Battery voltage
scalar

Battery voltage.

Data Types: double

Gear — Transmission gear
scalar

Transmission gear.

Data Types: double

MtrSpd — Motor speed
scalar

Motor speed.

Data Types: double

VehSpd — Vehicle speed
scalar

Vehicle speed, in m/s.

Data Types: double

TransTemp — Transmission temperature
scalar

Transmission temperature, in K.

Data Types: double

Output

Info — Block data
bus

Block data, returned as a bus signal that contains these block values.

Signal	Description	Units
EngTrqCmd	Engine torque command	N·m
MtrTrqCmd	Motor torque command	N·m
EquivFctr	Equivalence factor	NA
MinHamil	Minimum Hamiltonian	kW

EngTrqCmd — Engine torque command
scalar

Engine torque command, in N·m.

Data Types: double

MtrTrqCmd — Motor torque command
scalar

Motor torque command, in N·m.

Data Types: `double`

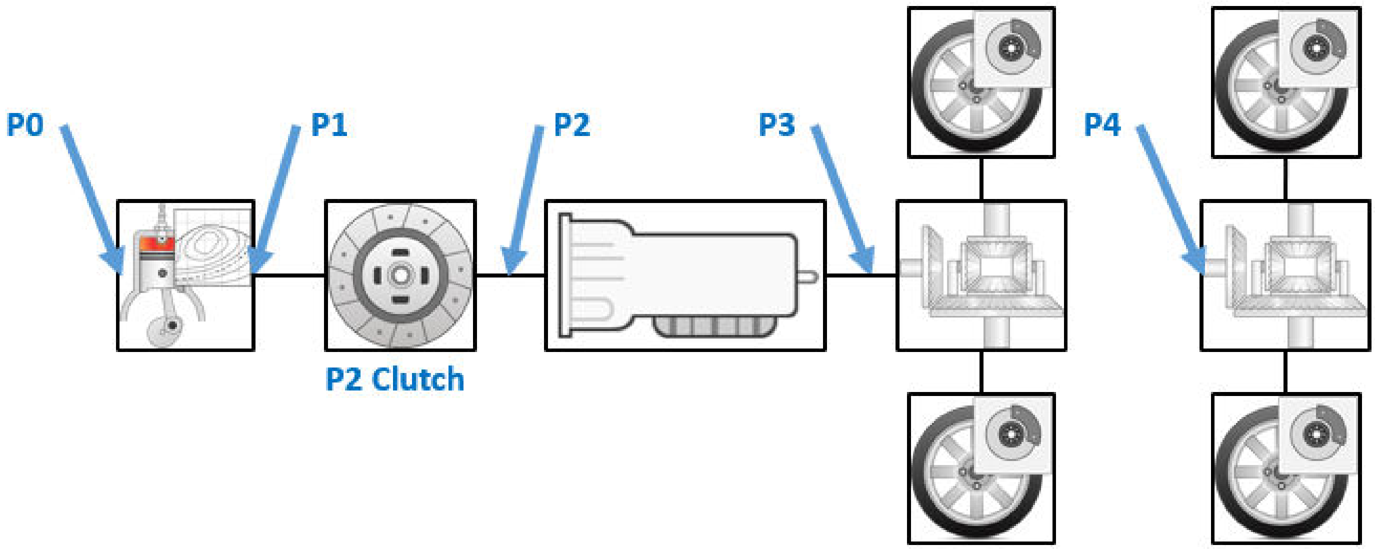
Parameters

Block Options

`Motor location` — Location of motor

`P0` (default) | `P1` | `P2` | `P3` | `P4`

Specify the HEV motor location.



`ECMS method` — ECMS method

`Non-adaptive` (default) | `Adaptive`

Use the **ECMS method** parameter to implement either an adaptive or non-adaptive ECMS method. The HEV architectures are charge-sustaining, meaning the battery SOC must remain in a specified range because there is no plugin capability to recharge the battery. The battery is an energy buffer, and all energy comes from the fuel if the change in SOC is minimized over a drive cycle. To sustain the charge over a specified drive cycle, the block implements either of these ECMS methods.

ECMS Method	Description
`Non-adaptive` (default)	The block uses a constant ECMS equivalence factor. • Use this method to determine the best fuel economy over a drive cycle. • If you change the drive cycle or HEV architecture, retune the **ECMS weighting factor** to maintain the ending SOC. • By default, the block uses a single constant.

ECMS Method	Description

Adaptive	The block adjusts an ECMS equivalence factor by using the output of a PI controller.
	• Use this method to maintain the SOC and minimize the delta SOC over many drive cycles. The block:
	  • Tunes the PI controller gains.
	  • Sustains the SOC.
	• The PI controller minimizes the error between the target SOC and current SOC.

Differential

Differential gear ratio, N_diff — Differential gear ratio
3.32 (default) | scalar

Differential gear ratio. No dimension.

Data Types: double

Differential efficiency factor, eta_diff — Differential efficiency factor
0.98 (default) | scalar

Differential efficiency factor. No dimension.

Data Types: double

Loaded wheel radius, Re — Loaded wheel radius
0.327 (default) | scalar

Loaded wheel radius, in m.

Data Types: double

Transmission

Transmission efficiency factors — Transmission efficiency factors
Gear, input torque, input speed, and temperature (default) | Gear only

Transmission efficiency factors.

Data Types: double

Transmission gear number vector, G_trans — Transmission gear number vector
[0 1 2 3 4 5 6] (default) | vector

Transmission gear number vector. No dimension.

Data Types: double

Transmission gear ratio vector, N_trans — Transmission gear ratio vector
[1 4.212 2.637 1.8 1.386 1 0.772] (default) | vector

Transmission gear ratio vector. No dimension.

Data Types: double

`Transmission efficiency vector, eta_trans` — Transmission efficiency vector
`[1 1 1 1 1 1 1]` (default) | `vector`

Transmission efficiency vector. No dimension.

Dependencies

To enable this parameter, set **Transmission efficiency factors** to `Gear only`.

Data Types: `double`

`Transmission efficiency torque breakpoints, Trq_trans_bpts` — Transmission efficiency torque breakpoints
`[25 50 75 100 150 200 250]` (default) | `vector`

Transmission efficiency torque breakpoints, in N·m.

Dependencies

To enable this parameter, set **Transmission efficiency factors** to `Gear, input torque, input speed, and temperature`.

Data Types: `double`

`Transmission efficiency speed breakpoints, omega_trans_bpts` — Transmission efficiency speed breakpoints
`[500.383141080919 749.619781962827 1002.676141478941 1250.957852702297 1499.239563925654 1747.521275149011 1995.802986372368 2501.915705404595 2998.479127851308 4001.155269330249 5003.83141080919]` (default) | `vector`

Transmission efficiency speed breakpoints, in rad/s.

Dependencies

To enable this parameter, set **Transmission efficiency factors** to `Gear, input torque, input speed, and temperature`.

Data Types: `double`

`Transmission efficiency temperature breakpoints, Temp_trans_bpts` — Transmission efficiency temperature breakpoints
`[313 358]` (default) | `vector`

Transmission efficiency temperature breakpoints, in K.

Dependencies

To enable this parameter, set **Transmission efficiency factors** to `Gear, input torque, input speed, and temperature`.

Data Types: `double`

`Transmission efficiency vector, eta_trans_tbl` — Transmission efficiency vector
`array`

Transmission efficiency vector. No dimension.

Dependencies

To enable this parameter, set **Transmission efficiency factors** to `Gear, input torque, input speed, and temperature`.

Data Types: `double`

Engine

`Speed breakpoints, f_tbrake_n_bpt` — Speed breakpoints
`[0 750 1053.57142857143 1357.14285714286 1660.71428571429 1964.28571428571 2267.85714285714 2571.42857142857 2875 3178.57142857143 3482.14285714286 3785.71428571429 4089.28571428571 4392.85714285714 4696.42857142857 5000]` (default) | `vector`

Speed breakpoints, in rpm.

Data Types: `double`

`Commanded torque breakpoints, f_tbrake_t_bpt` — Commanded torque breakpoints
`[0 15 26.4285714285714 37.8571428571429 49.2857142857143 60.7142857142857 72.1428571428571 83.5714285714286 95 106.428571428571 117.857142857143 129.285714285714 140.714285714286 152.142857142857 163.571428571429 175]` (default) | `vector`

Commanded torque breakpoints, in N·m.

Data Types: `double`

`Brake torque map, f_tbrake` — Brake torque map
`array`

Brake torque map, in N·m.

Data Types: `double`

`Minimum engine torque command table, f_tbrake_min` — Minimum engine torque command table
`vector`

Minimum engine torque command table, in N·m.

Data Types: `double`

`Fuel flow map, f_fuel` — Fuel flow map
`array`

Fuel flow map, in kg/s.

Data Types: `double`

`Minimum engine torque command, HEVEngTrq_min` — Minimum engine torque command
`16.18610438796213` (default) | `scalar`

Minimum engine torque command, in N·m.

Data Types: `double`

Fuel lower heating value, LHV — Fuel lower heating value
46000000 (default) | scalar

Fuel lower heating value, in J/kg.

Data Types: double

Engine idle speed, N_idle — Engine idle speed
750 (default) | scalar

Engine idle speed, in rpm.

Data Types: double

Battery

Battery state-of-charge breakpoints, SOC_bpt — Battery state-of-charge breakpoints
[0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1] (default) | vector

Battery state-of-charge breakpoints. No dimension.

Data Types: double

Battery charge limit table, ChrgLmt — Battery charge limit table
[1 1 1 1 1 1 1 0.9 0.7 0.5 0] (default) | vector

Battery charge limit table. No dimension.

Data Types: double

Battery discharge limit table, DischrgLmt — Battery discharge limit table
[0 0.5 0.7 0.9 1 1 1 1 1 1 1] (default) | vector

Battery discharge limit table. No dimension.

Data Types: double

Maximum battery current, BattCurrMax — Maximum battery current
150 (default) | scalar

Maximum battery current, in A.

Data Types: double

DC/DC converter efficiency, eta_dcdc — DC/DC converter efficiency
1 (default) | scalar

DC/DC converter efficiency. No dimension.

Data Types: double

Maximum battery charge power, BattChrgPwrMax — Maximum battery charge power
-30000 (default) | scalar

Maximum battery charge power, in W.

Data Types: double

Maximum battery discharge power, BattDischrgPwrMax — Maximum battery discharge power
46000 (default) | scalar

Maximum battery discharge power, in W.

Data Types: double

Motor

Motor maximum torque table, f_tmtr_max — Motor maximum torque table
vector

Motor maximum torque table, in N·m.

Data Types: double

Motor speed breakpoints, f_mtr_w_bpt — Motor speed breakpoints
vector

Motor speed breakpoints, in rpm.

Data Types: double

Motor torque breakpoints, f_mtr_t_bpt — Motor torque breakpoints
vector

Motor torque breakpoints, in N·m.

Data Types: double

Motor efficiency map, f_mtr_eta — Motor efficiency map
array

Motor efficiency map. No dimension.

Data Types: double

Number of motor torque calculation points, Ngrid — Number of motor torque calculation points
200 (default) | scalar

Number of motor torque calculation points. No dimension.

Data Types: double

P0 belt ratio, N_P0 — P0 belt ratio
3 (default) | scalar

P0 belt ratio. No dimension.

Dependencies

To enable this parameter, set **Motor location** to P0.

Data Types: double

Energy Management

ECMS weighting factor, ECMS_s — ECMS weighting factor
3.385 (default) | scalar

ECMS weighting factor. No dimension.

Data Types: double

Penalty factor power, PenaltyFctrPwr — Penalty factor power
3 (default) | scalar

Penalty factor power. No dimension.

Data Types: double

Adaptive ECMS proportional gain, ECMS_Kp — Adaptive ECMS proportional gain
0 (default) | scalar

Adaptive ECMS proportional gain. No dimension.

Dependencies

To enable this parameter, set **ECMS method** to Adaptive.

Data Types: double

Adaptive ECMS integral gain, ECMS_Ki — Adaptive ECMS integral gain
0 (default) | scalar

Adaptive ECMS integral gain. No dimension.

Dependencies

To enable this parameter, set **ECMS method** to Adaptive.

Data Types: double

Constraint penalty factor, PenaltyFctr — Constraint penalty factor
10000000 (default) | scalar

Constraint penalty factor. No dimension.

Data Types: double

Target battery state-of-charge, SOCTrgt — Target battery state-of-charge
60 (default) | scalar

Target battery state-of-charge. No dimension.

Data Types: double

Minimum battery state-of-charge, SOCmin — Minimum battery state-of-charge
40 (default) | scalar

Minimum battery state-of-charge. No dimension.

Data Types: double

Maximum battery state-of-charge, SOCmax — Maximum battery state-of-charge
80 (default) | scalar

Maximum battery state-of-charge. No dimension.

Data Types: double

Acknowledgments

MathWorks® would like to acknowledge the contribution of Dr. Simona Onori to the ECMS optimal control algorithm implemented in this block. Dr. Onori is a Professor of Energy Resources Engineering at Stanford University. Her research interests include electrochemical modeling, estimation and optimization of energy storage devices for automotive and grid-level applications, hybrid and electric vehicles modeling and control, PDE modeling, and model-order reduction and estimation of emission mitigation systems. She is a senior member of IEEE.

References

[1] Balazs, A., Morra, E., and Pischinger, S., *Optimization of Electrified Powertrains for City Cars*. SAE Technical Paper 2011-01-2451. Warrendale, PA: SAE International Journal of Alternative Powertrains, 2012.

[2] Onori, S., Serrao, L., and Rizzoni, G., *Hybrid Electric Vehicles Energy Management Systems*. New York: Springer, 2016.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

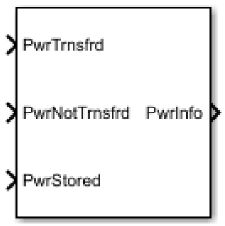
See Also

Topics
"Hybrid and Electric Vehicle Reference Application Projects"

Introduced in R2020b

Power Accounting Bus Creator

Create power information bus
Library: Powertrain Blockset / Utilities / Power Accounting



Description

Creates a power information bus for reporting system power and energy consumption. You can associate the block to a parent system, select types of power signals to track, and add signal descriptions. If you want to generate a power and energy report, you must use this block to log the power signals in your plant model blocks. The Powertrain Blockset plant blocks use the Power Accounting Bus Creator to log the power signals. The documentation for each block includes information about the logged power bus signals.

The system-level power and energy accounting satisfies the conservation of energy.

$$\sum P_{trans} + \sum P_{nottrans} = \sum P_{store}$$

To add the Power Accounting Bus Creator to your plant block, follow these steps:

1. Add the Power Accounting Bus Creator block to your block.
2. Select the types of power signals that you want to log. See “Power Signals” on page 3-53.
3. Associate the Power Accounting Bus Creator with a parent subsystem. See “Block Association” on page 3-54.
4. Connect the power signals to the Power Accounting Bus Creator.
   - Follow the sign convention.
   - To ensure that your plant block conserves energy, include all power associated with the block.
5. In the Power Accounting Bus Creator:
   - On the **Transferred** power tab, specify these parameters:
     - **Associated Port**
     - **Description**
   - On the **Not Transferred** power tab, specify the **Description** parameter:
6. In the plant block, connect the transferred power signals to the Power Accounting Bus Creator ports that are specified with the **Associated Port** parameter.

Power Signals

The Power Accounting Bus Creator sorts the signals into three power types.

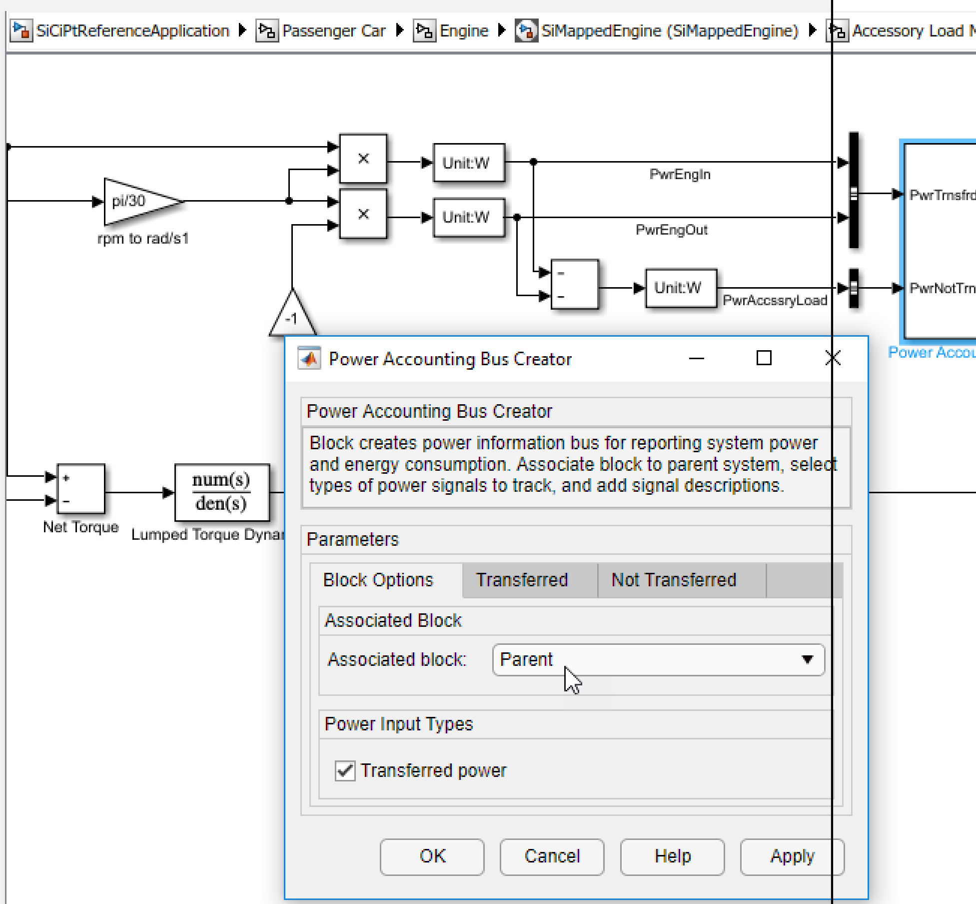
Power Type		Description	Examples
P_{trans}	Transferred	Power transferred between blocks: • Positive signals indicate flow into block • Negative signals indicate flow out of block	• Crankshaft power transferred from mapped engine to transmission. • Road load power transferred from wheel to vehicle. • Rate of heat flow transferred from throttle to manifold volume.

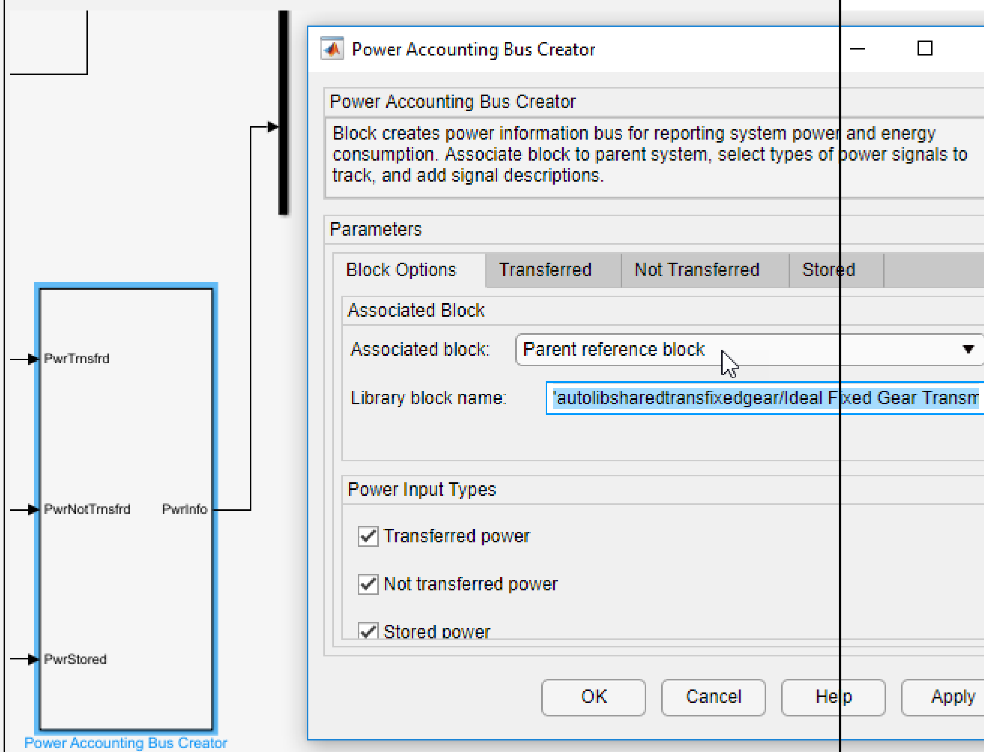
$P_{nottrans}$	Not transferred	Power crossing the block boundary, but not transferred:
		• Positive signals indicate an input
		• Negative signals indicate a loss
			• Rate of heat transfer with the environment.
			  • From environment is an input (positive signal)
			  • To environment is a loss (negative signal)
			• Flow boundary with the environment.
			  • From environment is an input (positive signal)
			  • To environment is a loss (negative signal)
			• Mapped engine fuel flow.

P_{store}	Stored	Stored energy rate of change: • Positive signals indicate an increase • Negative signals indicate a decrease	Energy rate of change: • Battery storage • Kinetic energy in drivetrain components • Vehicle potential energy • Vehicle velocity

Block Association

When you add the Power Accounting Bus Creator to your plant block, you associate the signals to a parent block. There are two association methods.

Method	Description	Example
`Parent`	Power Accounting Bus Creator associates the power bus signals with the parent block.	In the conventional vehicle reference application, navigate to the `Passenger Car > Engine > SiMappedEngine > Accessory Load Model` plant subsystem. Open the Power Accounting Bus Creator. The **Associated block** parameter is set to `Parent`, so the Power Accounting Bus Creator associates the power signals with the `Accessory Load Model` plant subsystem. 

Method	Description	Example
`Parent reference block`	Power Accounting Bus Creator associates the power bus signals with a reference block. Use the **Library block name** parameter to specify the block.	In the Ideal Fixed Gear Transmission block, navigate to the `Bus Creation` subsystem. Open the Power Accounting Bus Creator. The Power Accounting Bus Creator block uses these parameter settings to associate the power signals to the Ideal Fixed Gear Transmission block. • **Associated block** parameter is set to `Parent reference block`. • **Library block name** parameter is set to `'autolibsharedtransfixedgear/Ideal Fixed Gear Transmission'`. 

Ports

Input

`PwrTrnsfrd` — Power transferred between blocks
bus

`PwrTrnsfrd` — Power transferred between blocks

- Positive signals indicate flow into block
- Negative signals indicate flow out of block

Dependencies

To create this input port, select **Transferred power**.

`PwrNotTrnsfrd` — Power crossing block boundary, not transferred

`bus`

`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred

- Positive signals indicate an input
- Negative signals indicate a loss

Dependencies

To create this input port, select **Not transferred power**.

`PwrStored` — Stored energy rate of change

`bus`

`PwrStored` — Stored energy rate of change

- Positive signals indicate an increase
- Negative signals indicate a decrease

Dependencies

To create this input port, select **Stored power**.

Output

`PwrInfo` — Power information bus

`bus`

Power information bus

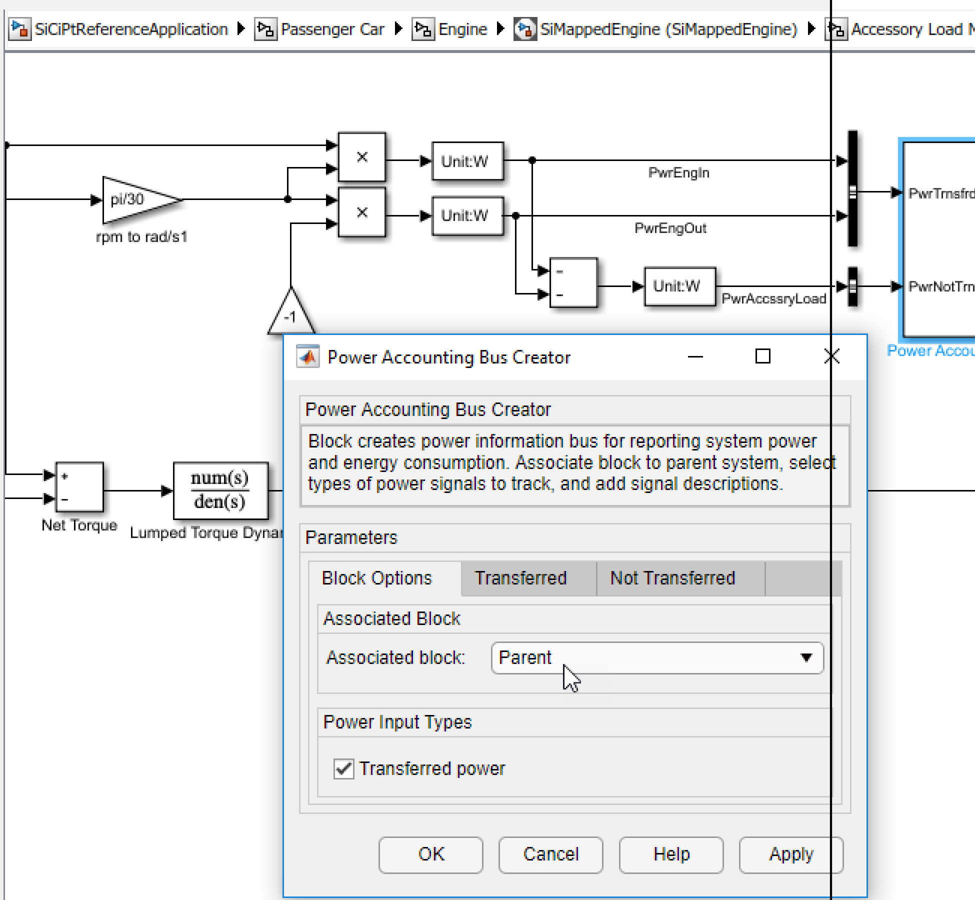
Parameters

Block Options

`Associated block` — Associated block

`Parent` (default) | `Parent reference block`

When you add the Power Accounting Bus Creator to your plant block, you associate the signals to a parent block. There are two association methods.

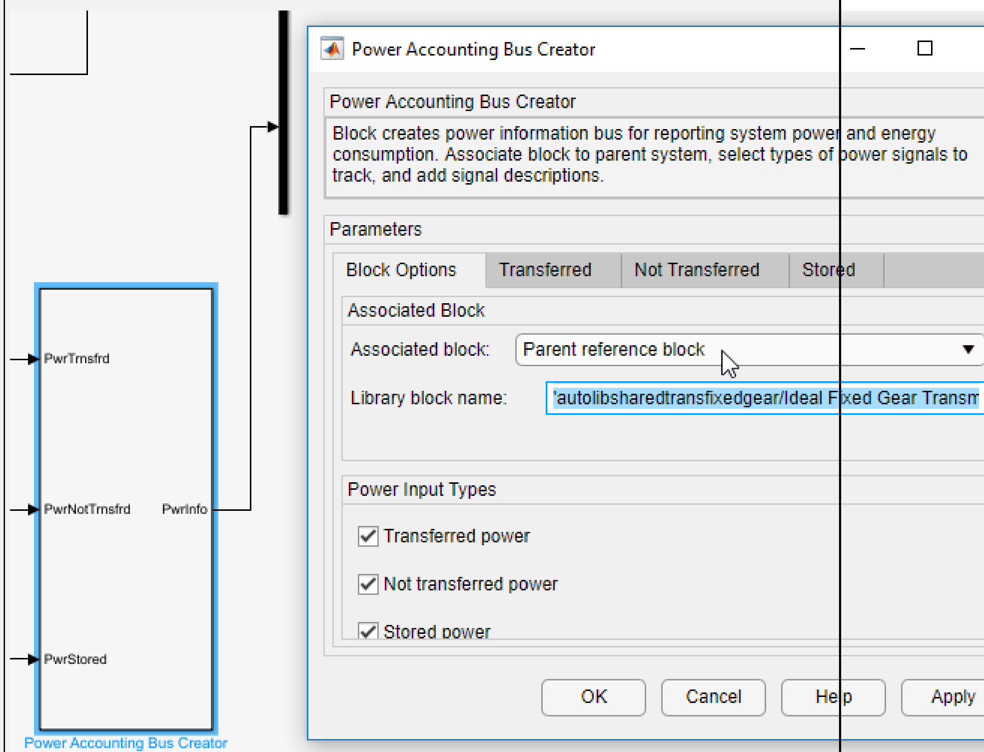
Method	Description	Example
`Parent`	Power Accounting Bus Creator associates the power bus signals with the parent block.	In the conventional vehicle reference application, navigate to the `Passenger Car > Engine > SiMappedEngine > Accessory Load Model` plant subsystem. Open the Power Accounting Bus Creator. The **Associated block** parameter is set to `Parent`, so the Power Accounting Bus Creator associates the power signals with the `Accessory Load Model` plant subsystem. 

<table>
<tr><th>Method</th><th>Description</th><th>Example</th></tr>
<tr>
<td><code>Parent reference block</code></td>
<td>Power Accounting Bus Creator associates the power bus signals with a reference block.

Use the Library block name parameter to specify the block.</td>
<td>In the Ideal Fixed Gear Transmission block, navigate to the <code>Bus Creation</code> subsystem. Open the Power Accounting Bus Creator.

The Power Accounting Bus Creator block uses these parameter settings to associate the power signals to the Ideal Fixed Gear Transmission block.

Associated block parameter is set to <code>Parent reference block</code>.
Library block name parameter is set to <code>'autolibsharedtransfixedgear/Ideal Fixed Gear Transmission'</code>.



</td>
</tr>
</table>

`Library block name` — Block name

`Block name`

Dependencies

To create this parameter, set **Associated block** to `Parent reference block`.

Power Input Types

`Transferred power` — Power transferred between blocks

on (default) | `off`

Power transferred between blocks.

Dependencies

Selecting this parameter creates the:

- `PwrTrnsfrd` input port
- **Transferred** parameters

`Not transferred power` — Power crossing block boundary
`on` (default) | `off`

Power crossing block boundary, but not transferred.

Dependencies

Selecting this parameter creates the:

- `PwrNotTrnsfrd` input port
- **Not Transferred** parameters

`Stored power` — Stored energy rate of change
`on` (default) | `off`

Stored energy rate of change.

Dependencies

Selecting this parameter creates the:

- `PwrStored` input port
- **Stored** parameters

Transferred

`Signal name` — Name of signal
`char`

Signal name.

For example, this table summarizes the Power Accounting Bus Creator parameter **Transferred** parameter values for the listed blocks.

Block	Power Accounting Bus Creator Parameter Values		
	Signal Name	Associated Port	Description
Ideal Fixed Gear Transmission	`PwrTrnsfrd.PwrDiffrntl`	`{'DiffTrq','DiffSpd'}`	`Differential`
	`PwrTrnsfrd.PwrEng`	`{'EngTrq','EngSpd'}`	`Engine`
Gearbox	`PwrTrnsfrd.PwrBase`	`{{'BTrq','BSpd'}'B'}`	`Base input`
	`PwrTrnsfrd.PwrFlwr`	`{{'FTrq','FSpd'}'F'}`	`Follower output`

Block	Power Accounting Bus Creator Parameter Values		
	Signal Name	Associated Port	Description
Boost Drive Shaft	PwrTrnsfrd.PwrCmpsr	'Cmpsr'	Compressor
	PwrTrnsfrd.PwrExt	'ExtTrq'	External
	PwrTrnsfrd.Turb	'Turb'	Turbine

`Associated Port` — Name of ports that transfer power
`{'PortA','PortB','PortC'}`

Name of ports that transfer power.

For example, this table summarizes the Power Accounting Bus Creator parameter **Transferred** parameter values for the listed blocks.

Block	Power Accounting Bus Creator Parameter Values		
	Signal Name	Associated Port	Description
Ideal Fixed Gear Transmission	PwrTrnsfrd.PwrDiffrntl	{'DiffTrq','DiffSpd'}	Differential
	PwrTrnsfrd.PwrEng	{'EngTrq','EngSpd'}	Engine
Gearbox	PwrTrnsfrd.PwrBase	{{'BTrq','BSpd'}'B'}	Base input
	PwrTrnsfrd.PwrFlwr	{{'FTrq','FSpd'}'F'}	Follower output
Boost Drive Shaft	PwrTrnsfrd.PwrCmpsr	'Cmpsr'	Compressor
	PwrTrnsfrd.PwrExt	'ExtTrq'	External
	PwrTrnsfrd.Turb	'Turb'	Turbine

`Description` — Signal description
`char`

Signal description.

For example, this table summarizes the Power Accounting Bus Creator parameter **Transferred** parameter values for the listed blocks.

Block	Power Accounting Bus Creator Parameter Values		
	Signal Name	Associated Port	Description
Ideal Fixed Gear Transmission	PwrTrnsfrd.PwrDiffrntl	{'DiffTrq','DiffSpd'}	Differential
	PwrTrnsfrd.PwrEng	{'EngTrq','EngSpd'}	Engine
Gearbox	PwrTrnsfrd.PwrBase	{{'BTrq','BSpd'}'B'}	Base input
	PwrTrnsfrd.PwrFlwr	{{'FTrq','FSpd'}'F'}	Follower output

Block	Power Accounting Bus Creator Parameter Values		
	Signal Name	Associated Port	Description
Boost Drive Shaft	PwrTrnsfrd.PwrCmpsr	'Cmpsr'	Compressor
	PwrTrnsfrd.PwrExt	'ExtTrq'	External
	PwrTrnsfrd.Turb	'Turb'	Turbine

Not Transferred

`Signal name` — Name of signal

`char`

Signal name.

For example, this table summarizes the Power Accounting Bus Creator parameter **Not Transferred** parameter values for the listed blocks.

Block	Power Accounting Bus Creator Parameter Values	
	Signal Name	Description
Ideal Fixed Gear Transmission	PwrNotTrnsfrd.PwrDampLoss	Damping loss
	PwrNotTrnsfrd.PwrEffLoss	Efficiency loss
Gearbox	PwrNotTrnsfrd.PwrDampLoss	Damping loss
	PwrNotTrnsfrd.PwrMechLoss	Mechanical loss
Boost Drive Shaft	PwrNotTrnsfrd.PwrMechLoss	Mechanical loss

`Description` — Signal description

`char`

Signal description.

For example, this table summarizes the Power Accounting Bus Creator parameter **Not Transferred** parameter values for the listed blocks.

Block	Power Accounting Bus Creator Parameter Values	
	Signal Name	Description
Ideal Fixed Gear Transmission	PwrNotTrnsfrd.PwrDampLoss	Damping loss
	PwrNotTrnsfrd.PwrEffLoss	Efficiency loss
Gearbox	PwrNotTrnsfrd.PwrDampLoss	Damping loss
	PwrNotTrnsfrd.PwrMechLoss	Mechanical loss
Boost Drive Shaft	PwrNotTrnsfrd.PwrMechLoss	Mechanical loss

Stored

`Signal name` — Name of signal
`char`

Signal name.

For example, this table summarizes the Power Accounting Bus Creator parameter **Stored** parameter values for the listed blocks.

Block	Power Accounting Bus Creator Parameter Values	
	Signal Name	Description
Ideal Fixed Gear Transmission	`PwrStored.PwrStoredTrans`	`Rotational`
Control Volume System	`PwrStored.PwrHeatStored`	`Stored heat`
Datasheet Battery	`PwrStored.PwrStoredBatt`	`Battery stored`

`Description` — Signal description
`char`

Signal description.

For example, this table summarizes the Power Accounting Bus Creator parameter **Stored** parameter values for the listed blocks.

Block	Power Accounting Bus Creator Parameter Values	
	Signal Name	Description
Ideal Fixed Gear Transmission	`PwrStored.PwrStoredTrans`	`Rotational`
Control Volume System	`PwrStored.PwrHeatStored`	`Stored heat`
Datasheet Battery	`PwrStored.PwrStoredBatt`	`Battery stored`

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

`autoblks.pwr.PlantInfo`

Topics

"Conventional Vehicle Powertrain Efficiency"
"Analyze Power and Energy"

Introduced in R2019a

4

Propulsion Blocks

Boost Drive Shaft

Boost drive shaft speed

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Boost

Description

The Boost Drive Shaft block uses the compressor, turbine, and external torques to calculate the drive shaft speed. Use the block to model turbochargers and superchargers in an engine model.

You can specify these configurations:

- Turbocharger — Connect the compressor to the turbine
  - Two-way ports for turbine and compressor connections
  - Option to add an externally applied input torque
- Compressor only — Connect the drive shaft to the compressor
  - Two-way port for compressor connection
  - Externally applied input torque
- Turbine only — Connect the drive shaft to the turbine
  - Two-way port for turbine connection
  - Externally applied load torque

For the `Turbine only` and `Turbocharger` configurations, the block modifies the turbine torque with a mechanical efficiency.

Equations

The Boost Drive Shaft block applies Newton’s Second Law for Rotation. Positive torques cause the drive shaft to accelerate. Negative torques impose a load and decelerate the drive shaft.

The block also calculates the power loss due to mechanical inefficiency.

Calculation	Equations
Shaft dynamics	$\frac{d\omega}{dt} = \frac{1}{J_{shaft}}(\eta_{mech}\tau_{turb} + \tau_{comp} + \tau_{ext})$ with initial speed ω_0
Speed constraint	$\omega_{min} \leq \omega \leq \omega_{max}$
Power loss	$\dot{W}_{loss} = \omega\tau_{turb}(1 - \eta_{mech})$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrCmpsr`	Shaft power from compressor	$\tau_{comp}\omega$
		`PwrTurb`	Shaft power from turbine	$\tau_{turb}\omega$
		`PwrExt`	Externally applied power	$\tau_{ext}\omega$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrMechLoss`	Mechanical power loss	$-\dot{W}_{turb}$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredDriveshft`	Rate change in rotational kinetic energy	$(\eta_{mech}\tau_{turb} + \tau_{comp} + \tau_{ext})\omega$

The equations use these variables.

ω	Shaft speed
ω_0	Initial drive shaft speed
ω_{min}	Minimum drive shaft speed
ω_{max}	Maximum drive shaft speed
J_{shaft}	Shaft inertia
η_{max}	Mechanical efficiency of turbine
τ_{comp}	Compressor torque
τ_{turb}	Turbine torque
τ_{ext}	Externally applied torque.
$\dot{W}_{loss}$	Power loss due to mechanical inefficiency

Ports

Input

`Cmprs` — Compressor torque

two-way connector port

Compressor torque, τ_{comp}, in N·m.

Dependencies

To create this port, for the **Configuration** parameter, select `Turbocharger` or `Compressor only`.

`Turb` — Turbine torque
two-way connector port

Turbine torque, τ_{turb}, in N·m.

Dependencies

To create this port, for the **Configuration** parameter, select `Turbocharger` or `Turbine only`.

`ExtTrq` — Externally applied torque
`scalar`

Externally applied torque, τ_{ext}, in N·m.

Dependencies

For turbocharger configurations, to create this port, set **Additional torque input** to `External torque input`.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
`DriveshftSpd`			Shaft speed	rad/s
`MechPwrLoss`			Mechanical power loss	W
`ExtTrq`			Applied external torque	N·m
`PwrInfo`	`PwrTrnsfrd`	`PwrCmpsr`	Shaft power from compressor	W
		`PwrTurb`	Shaft power from turbine	W
		`PwrExt`	Externally applied power	W
	`PwrNotTrnsfrd`	`PwrMechLoss`	Mechanical power loss	W
	`PwrStored`	`PwrStoredDriveshft`	Rate change in rotational kinetic energy	W

`Cmprs` — Compressor speed
two-way connector port

Compressor speed, ω, in rad/s.

Dependencies

To create this port, for the **Configuration** parameter, select `Turbocharger` or `Compressor only`.

`Turb` — Turbine speed
two-way connector port

Turbine speed, ω, in N·m.

Dependencies

To create this port, for the **Configuration** parameter, select `Turbocharger` or `Turbine only`.

Parameters

Block Options

`Configuration` — Specify configuration

`Turbocharger` (default) | `Turbine only` | `Compressor only`

Dependencies

- Selecting `Turbocharger` or `Compressor only` creates the `Cmprs` port.
- Selecting `Turbocharger` or `Turbine only` creates the `Turb` port.

`Additional torque input` — Specify external torque input

`External torque input` (default) | `No external torque`

Dependencies

- To enable this parameter, select a `Turbocharger` configuration.
- To create the `Trq` port, select `External torque input`.

`Shaft inertia, J_shaft` — Inertia

`1.55e-5` (default) | `scalar`

Shaft inertia, J_{shaft}, in kg·m^2.

`Initial shaft speed, w_0` — Speed

`1000` (default) | `scalar`

Initial drive shaft speed, ω_0, in rad/s.

`Min shaft speed, w_min` — Speed

`100` (default) | `scalar`

Minimum drive shaft speed, ω_{min}, in rad/s.

`Max shaft speed, w_max` — Speed

`20000` (default) | `scalar`

Maximum drive shaft speed, ω_{max}, in rad/s.

`Turbine mechanical efficiency, eta_mech` — Efficiency

`0.95` (default) | `scalar`

Mechanical efficiency of turbine η_{max}.

Dependencies

To enable this parameter, select the `Turbocharger` or `Turbine only` configuration.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

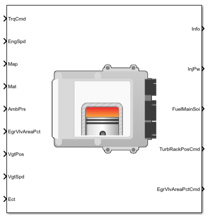
Compressor | Turbine

Introduced in R2017a

CI Controller

Compression-ignition controller that includes air mass flow, torque, and EGR estimation

Library: Powertrain Blockset / Propulsion / Combustion Engine Controllers



Description

The CI Controller block implements a compression-ignition (CI) controller with air mass flow, torque, exhaust gas recirculation (EGR) flow, exhaust back-pressure, and exhaust gas temperature estimation. You can use the CI Controller block in engine control design or performance, fuel economy, and emission tradeoff studies. The core engine block requires the commands that are output from the CI Controller block.

The block uses the commanded torque and measured engine speed to determine these open-loop actuator commands:

- Injector pulse-width
- Fuel injection timing
- Variable geometry turbocharger (VGT) rack position
- EGR valve area percent

The CI Controller block has two subsystems:

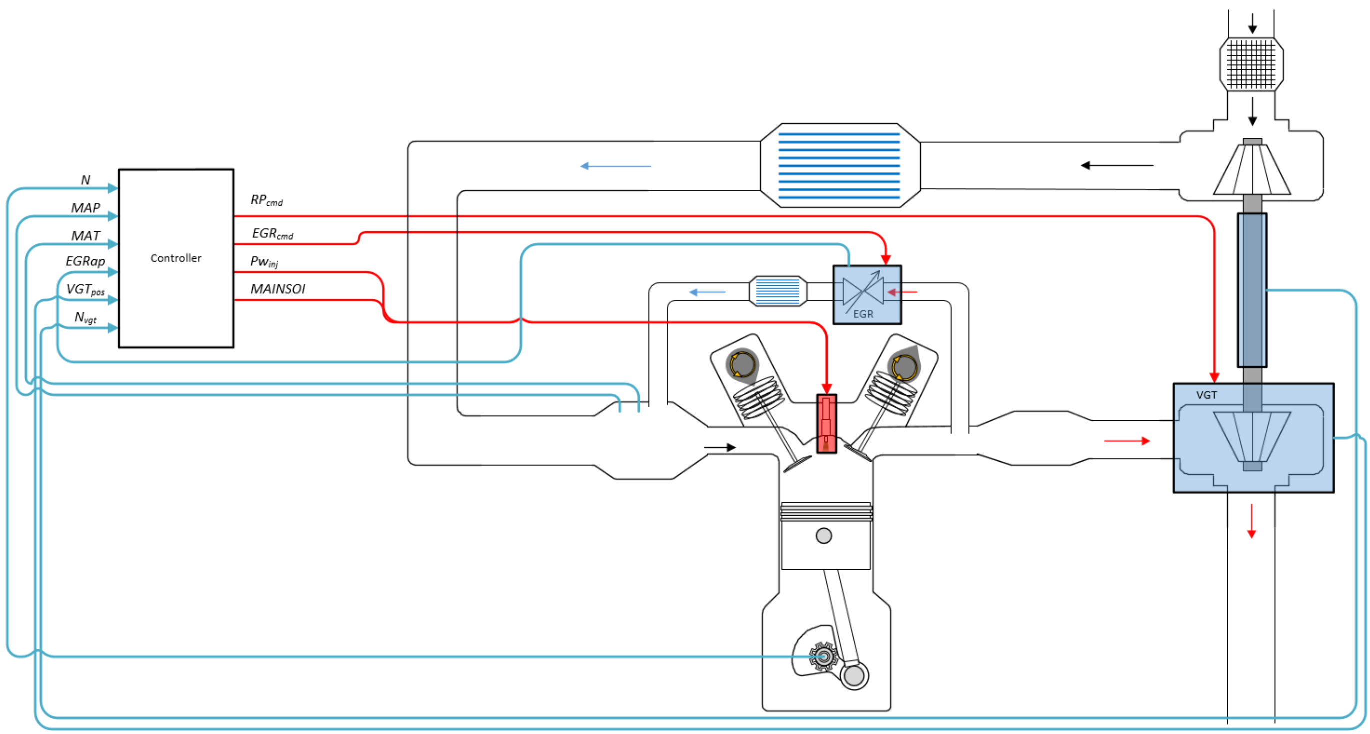
- The `Controller` subsystem — Determines the commands based on tables that are functions of commanded torque and measured engine speed.

Based On	Determines Commands for
Commanded torque Measured engine speed	Injector pulse-width Fuel injection timing VGT rack position EGR valve area percent

- The `Estimator` subsystem — Determines estimates based on these engine attributes.

Based On	Estimates
Measured engine speed Fuel injection timing Cycle average intake manifold pressure and temperature Fuel injector pulse-width Absolute ambient pressure EGR valve area percent VGT rack position VGT speed	Air mass flow Torque Exhaust gas temperature Exhaust gas back-pressure EGR valve gas mass flow

The figure illustrates the signal flow.



The figure uses these variables.

N	Engine speed
MAP	Cycle average intake manifold absolute pressure
MAT	Cycle average intake manifold gas absolute temperature
EGRap, EGR_{cmd}	EGR valve area percent and EGR valve area percent command, respectively
VGT_{pos}	VGT rack position

N_{vgt}	Corrected turbocharger speed
RP_{cmd}	VGT rack position command
Pw_{inj}	Fuel injector pulse-width
MAINSOI	Start of injection timing for main fuel injection pulse

The Model-Based Calibration Toolbox™ was used to develop the tables that are available with the Powertrain Blockset.

Controller

The controller governs the combustion process by commanding VGT rack position, EGR valve area percent, fuel injection timing, and injector pulse-width. Feedforward lookup tables, which are functions of measured engine speed and commanded torque, determine the control commands.

Air

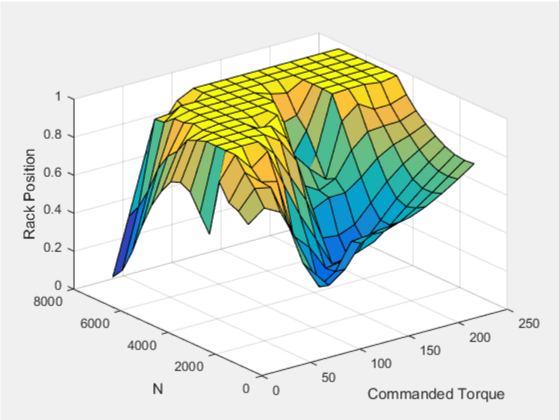
The controller commands the EGR valve area percent and VGT rack position. Changing the VGT rack position modifies the turbine flow characteristics. At low-requested torques, the rack position can reduce the exhaust back pressure, resulting in a low turbocharger speed and boost pressure. When the commanded fuel requires additional air mass flow, the rack position is set to close the turbocharger vanes, increasing the turbocharger speed and intake manifold boost pressure.

The variable geometry turbocharger (VGT) rack position lookup table is a function of commanded torque and engine speed

$$RP_{cmd} = f_{RPcmd}(Trq_{cmd}, N)$$

where:

- RP_{cmd} is VGT rack position command, in percent.
- Trq_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.

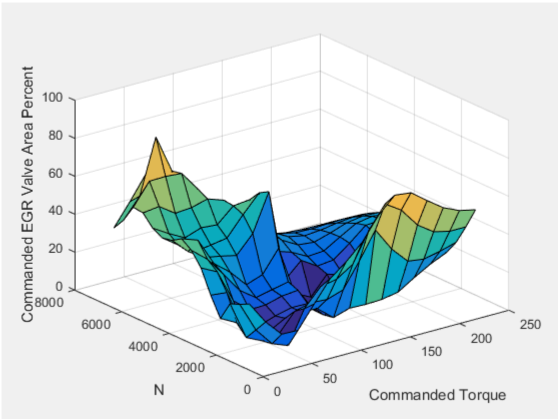


The commanded exhaust gas recirculation (EGR) valve area percent lookup table is a function of commanded torque and engine speed

$$EGR_{cmd} = f_{EGRcmd}(Trq_{cmd}, N)$$

where:

- EGR_{cmd} is commanded EGR valve area percent, in percent.
- Trq_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



Fuel

To initiate combustion, a CI engine injects fuel directly into the combustion chamber. After the injection, the fuel spontaneously ignites, increasing cylinder pressure. The total mass of the injected fuel and main injection timing determines the torque production.

Assuming constant fuel rail pressure, the CI controller commands the injector pulse-width based on the total requested fuel mass:

$$Pw_{inj} = \frac{F_{cmd,\ tot}}{S_{inj}}$$

The equation uses these variables.

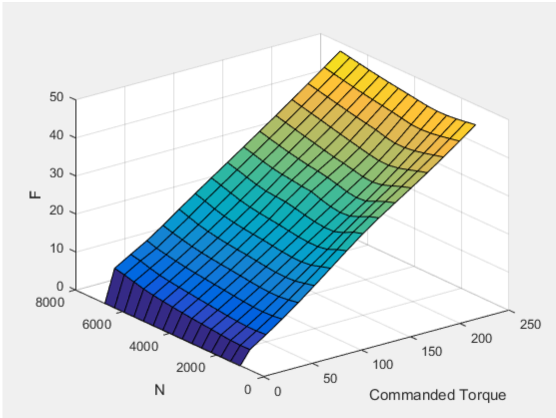
Pw_{inj}	Fuel injector pulse-width
S_{inj}	Fuel injector slope
$F_{cmd,tot}$	Commanded total fuel mass per injection
$MAINSOI$	Main start-of-injection timing
N	Engine speed

The commanded total fuel mass per injection table is a function of the torque command and engine speed

$$F_{cmd,\,tot} = f_{Fcmd,\,tot}(Trq_{cmd}, N)$$

where:

- $F_{cmd,tot} = F$ is commanded total fuel mass per injection, in mg per cylinder.
- Trq_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.

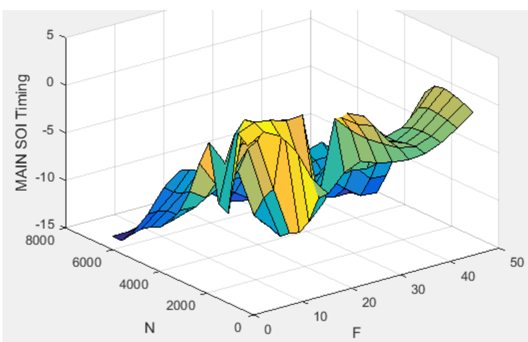


The main start-of-injection (SOI) timing lookup table is a function of commanded fuel mass and engine speed

$$MAINSOI = f(F_{cmd,\, tot}, N)$$

where:

- $MAINSOI$ is the main start-of-injection timing, in degrees crank angle after top dead center (degATDC).
- $F_{cmd,tot} = F$ is commanded fuel mass, in mg per injection.
- N is engine speed, in rpm.



Idle Speed

When the commanded torque is below a threshold value, the idle speed controller regulates the engine speed.

If	Idle Speed Controller
$Trq_{cmd,input} < Trq_{idlecmd,enable}$	Enabled
$Trq_{idlecmd,enable} \le Trq_{cmd,input}$	Not enabled

The idle speed controller uses a discrete PI controller to regulate the target idle speed by commanding a torque.

The PI controller uses this transfer function:

$$C_{idle}(z) = K_{p,\,idle} + K_{i,\,idle}\frac{t_s}{z-1}$$

The idle speed commanded torque must be less than the maximum commanded torque:

$0 \leq Trq_{idlecomd} \leq Trq_{idlecmd,max}$

Idle speed control is active under these conditions. If the commanded input torque drops below the threshold for enabling the idle speed controller ($Trq_{cmd,input} < Trq_{idlecmd,enable}$), the commanded engine torque is given by:

$Trq_{cmd} = \max(Trq_{cmd,input}, Trq_{idlecmd})$.

The equations use these variables.

Trq_{cmd}	Commanded engine torque
$Trq_{cmd,input}$	Input commanded engine torque
$Trq_{idlecmd,enable}$	Threshold for enabling idle speed controller
$Trq_{idlecmd}$	Idle speed controller commanded torque
$Trq_{idlecmd,max}$	Maximum commanded torque
N_{idle}	Base idle speed
$K_{p,idle}$	Idle speed controller proportional gain
$K_{i,idle}$	Idle speed controller integral gain

Speed Limiter

To prevent over revving the engine, the block implements an engine speed limit controller that limits the engine speed to the value specified by the **Rev-limiter speed threshold** parameter on the **Controls** > **Idle Speed** tab.

If the engine speed, N, exceeds the engine speed limit, N_{lim}, the block sets the commanded engine torque to 0.

To smoothly transition the torque command to 0 as the engine speed approaches the speed limit, the block implements a lookup table multiplier. The lookup table multiplies the torque command by a value that ranges from 0 (engine speed exceeds limit) to 1 (engine speed does not exceed the limit).

Estimator

Using the CI Core Engine block, the CI Controller block estimates the air mass flow rate, EGR valve mass flow, exhaust back-pressure, engine torque, AFR, and exhaust temperature from sensor feedback. The `Info` port provides the estimated values, but block does not use them to determine the open-loop engine actuator commands.

Air Mass Flow

To calculate the air mass flow, the compression-ignition (CI) engine uses the “CI Engine Speed-Density Air Mass Flow Model”. The speed-density model uses the speed-density equation to calculate the engine air mass flow, relating the engine intake port mass flow to the intake manifold pressure, intake manifold temperature, and engine speed.

EGR Valve Mass Flow

To calculate the estimated exhaust gas recirculation (EGR) valve mass flow, the block calculates the EGR flow that would occur at standard temperature and pressure conditions, and then corrects the flow to actual temperature and pressure conditions. The block EGR calculation uses estimated exhaust back-pressure, estimated exhaust temperature, standard temperature, and standard pressure.

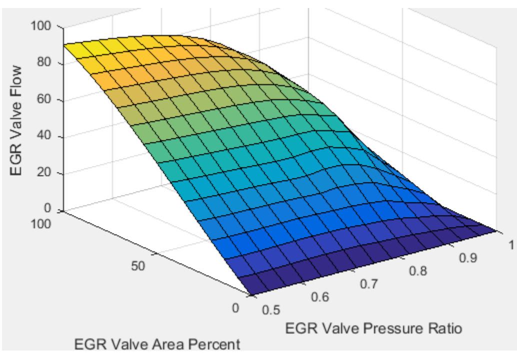
$$\dot{m}_{egr,\,est} = \dot{m}_{egr,\,std}\frac{P_{exh,\,est}}{P_{std}}\sqrt{\frac{T_{std}}{T_{exh,\,est}}}$$

- The standard exhaust gas recirculation (EGR) mass flow is a lookup table that is a function of the standard flow pressure ratio and EGR valve flow area

  $$\dot{m}_{egr,\,std} = f(\frac{MAP}{P_{exh,\,est}}, EGRap)$$

  where:

  - $\dot{m}_{egr,\,std}$ is the standard EGR valve mass flow, in g/s.
  - $P_{exh,est}$ is the estimated exhaust back-pressure, in Pa.
  - MAP is the cycle average intake manifold absolute pressure, in Pa.
  - $EGRap$ is the measured EGR valve area, in percent.



The equations use these variables.

$\dot{m}_{egr,\,est}$	Estimated EGR valve mass flow
$\dot{m}_{egr,\,std}$	Standard EGR valve mass flow
P_{std}	Standard pressure
T_{std}	Standard temperature
$T_{exh,est}$	Estimated exhaust manifold gas temperature
MAP	Measured cycle average intake manifold absolute pressure
$P_{exh,est}$	Estimated exhaust back-pressure
P_{Amb}	Absolute ambient pressure
$EGRap$	Measured EGR valve area percent

Exhaust Back-Pressure

To estimate the EGR valve mass flow, the block requires an estimate of the exhaust back-pressure. To estimate the exhaust back-pressure, the block uses the ambient pressure and the turbocharger pressure ratio.

$$P_{exh,\,est} = P_{Amb}Pr_{turbo}$$

For the turbocharger pressure ration calculation, the block uses two lookup tables. The first lookup table determines the approximate turbocharger pressure ratio as a function of turbocharger mass flow and corrected turbocharger speed. Using a second lookup table, the block corrects the approximate turbocharger pressure ratio for VGT rack position.

$$Pr_{turbo} = f(\dot{m}_{airstd}, N_{vgtcorr})f(VGT_{pos})$$

where:

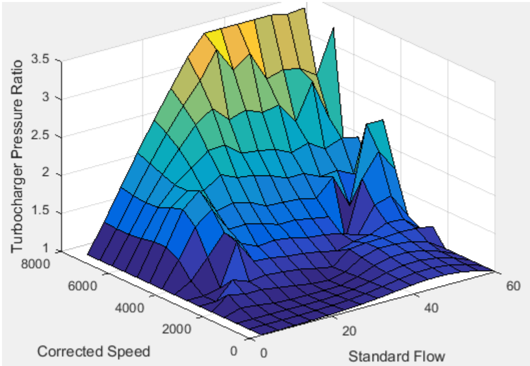
$$N_{vgtcorr} = \frac{N_{vgt}}{\sqrt{T_{exh,\,est}}}$$

The equations use these variables.

$\dot{m}_{egr,\,est}$	Estimated EGR valve mass flow
$\dot{m}_{egr,\,std}$	Standard EGR valve mass flow
$\dot{m}_{port,\,est}$	Estimated intake port mass flow rate
$\dot{m}_{airstd}$	Standard air mass flow
$EGRap$	Measured EGR valve area
MAP	Measured cycle average intake manifold absolute pressure
MAT	Measured cycle average intake manifold gas absolute temperature
P_{std}	Standard pressure
T_{std}	Standard temperature
$T_{exh,est}$	Estimated exhaust manifold gas temperature
$Pr_{vgtcorr}$	Turbocharger pressure ratio correction for VGT rack position
Pr_{turbo}	Turbocharger pressure ratio
$P_{exh,est}$	Estimated exhaust back-pressure
P_{Amb}	Absolute ambient pressure
$N_{vgtcorr}$	Corrected turbocharger speed
VGT_{pos}	Measured VGT rack position

The exhaust-back pressure calculation uses these lookup tables:

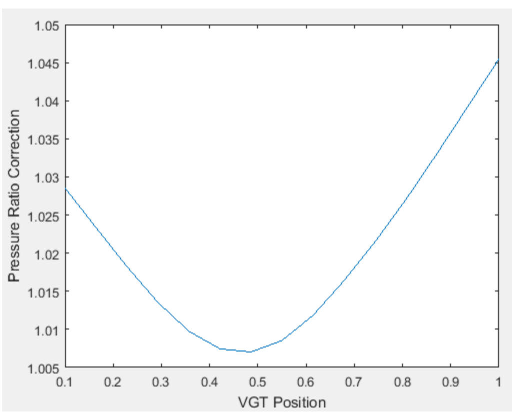
- The turbocharger pressure ratio, corrected for variable geometry turbocharger (VGT) speed, is a lookup table that is a function of the standard air mass flow and corrected turbocharger speed, $Pr_{turbo} = f(\dot{m}_{airstd}, N_{vgtcorr})$, where:
  - Pr_{turbo} is the turbocharger pressure ratio, corrected for VGT speed.
  - $\dot{m}_{airstd}$ is the standard air mass flow, in g/s.
  - $N_{vgtcorr}$ is the corrected turbocharger speed, in rpm/K^(1/2).



To calculate the standard air mass flow through the turbocharger, the block uses conservation of mass, the estimated intake port, and EGR mass flows (from the last estimated calculation). The calculation assumes negligible exhaust manifold filling dynamics.

$$\dot{m}_{airstd} = (\dot{m}_{port,\,est} - \dot{m}_{egr,\,est})\frac{P_{std}}{MAP}\sqrt{\frac{MAT}{T_{std}}}$$

- The variable geometry turbocharger pressure ratio correction is a function of the rack position, $Pr_{vgtcorr}= f(VGT_{pos})$, where:
  - $Pr_{vgtcorr}$ is the turbocharger pressure ratio correction.
  - VGT_{pos} is the variable geometry turbocharger (VGT) rack position.



Engine Torque

To calculate the engine torque, you can configure the block to use either of these torque models.

Brake Torque Model	Description
"CI Engine Torque Structure Model"	The CI core engine torque structure model determines the engine torque by reducing the maximum engine torque potential as these engine conditions vary from nominal: • Start of injection (SOI) timing • Exhaust back-pressure • Burned fuel mass • Intake manifold gas pressure, temperature, and oxygen percentage • Fuel rail pressure To account for the effect of post-inject fuel on torque, the model uses a calibrated torque offset table.
"CI Engine Simple Torque Model"	For the simple engine torque calculation, the CI engine uses a torque lookup table map that is a function of engine speed and injected fuel mass.

Exhaust Temperature

The exhaust temperature calculation depends on the torque model. For both torque models, the block implements lookup tables.

Torque Model	Description	Equations
`Simple Torque Lookup`	Exhaust temperature lookup table is a function of the injected fuel mass and engine speed.	$T_{exh} = f_{Texh}(F, N)$
`Torque Structure`	The nominal exhaust temperature, $Texh_{nom}$, is a product of these exhaust temperature efficiencies: • SOI timing • Intake manifold gas pressure • Intake manifold gas temperature • Intake manifold gas oxygen percentage • Fuel rail pressure • Optimal temperature The exhaust temperature, $Texh_{nom}$, is offset by a post temperature effect, ΔT_{post}, that accounts for post and late injections during the expansion and exhaust strokes.	$T_{exhnom} = SOI_{exhteff} MAP_{exhteff} MAT_{exhteff} O2p_{exhteff} FUI$ $T_{exh} = T_{exhnom} + \Delta T_{post}$ $SOI_{exhteff} = f_{SOI_{exhteff}}(\Delta SOI, N)$ $MAP_{exhteff} = f_{MAP_{exhteff}}(MAP_{ratio}, \lambda)$ $MAT_{exhteff} = f_{MAT_{exhteff}}(\Delta MAT, N)$ $O2p_{exhteff} = f_{O2p_{exhteff}}(\Delta O2p, N)$ $Texh_{opt} = f_{Texh}(F, N)$

The equations use these variables.

F	Compression stroke injected fuel mass
N	Engine speed
$Texh$	Exhaust manifold gas temperature
$Texh_{opt}$	Optimal exhaust manifold gas temperature
ΔT_{post}	Post injection temperature effect
$Texh_{nom}$	Nominal exhaust temperature
$SOI_{exhteff}$	Main SOI exhaust temperature efficiency multiplier
ΔSOI	Main SOI timing relative to optimal timing
MAP_{exheff}	Intake manifold gas pressure exhaust temperature efficiency multiplier
MAP_{ratio}	Intake manifold gas pressure ratio relative to optimal pressure ratio
λ	Intake manifold gas lambda
MAT_{exheff}	Intake manifold gas temperature exhaust temperature efficiency multiplier
ΔMAT	Intake manifold gas temperature relative to optimal temperature
$O2P_{exheff}$	Intake manifold gas oxygen exhaust temperature efficiency multiplier
$\Delta O2P$	Intake gas oxygen percent relative to optimal
$FUELP_{exheff}$	Fuel rail pressure exhaust temperature efficiency multiplier
$\Delta FUELP$	Fuel rail pressure relative to optimal

Air-Fuel Ratio

The measured engine speed and fuel injector pulse-width determine the commanded fuel mass flow rate:

$$\dot{m}_{fuel,cmd} = \frac{NS_{inj}Pw_{inj}N_{cyl}}{Cps\left(\frac{60s}{min}\right)\left(\frac{1000mg}{g}\right)}$$

The commanded total fuel mass flow and estimated port mass flow rates determine the estimated AFR:

$$AFR_{est} = \frac{\dot{m}_{port,est}}{\dot{m}_{fuel,cmd}}$$

The equations use these variables.

Pw_{inj}	Fuel injector pulse-width
AFR_{est}	Estimated air-fuel ratio
$\dot{m}_{fuel,cmd}$	Commanded fuel mass flow rate
S_{inj}	Fuel injector slope
N	Engine speed
N_{cyl}	Number of engine cylinders
Cps	Crankshaft revolutions per power stroke, rev/stroke
$\dot{m}_{port,est}$	Total estimated engine air mass flow at intake ports

Ports

Input

`TrqCmd` — Commanded engine torque
`scalar`

Commanded engine torque, $Trq_{cmd,input}$, in N·m.

`EngSpd` — Measured engine speed
`scalar`

Measured engine speed, N, in rpm.

`Map` — Measured intake manifold absolute pressure
`scalar`

Measured intake manifold absolute pressure, MAP, in Pa.

`Mat` — Measured intake manifold absolute temperature
`scalar`

Measured intake manifold absolute temperature, MAT, in K.

`AmbPrs` — Ambient pressure
`scalar`

Absolute ambient pressure, P_{Amb}, in Pa.

`EgrVlvAreaPct` — EGR valve area percent
`scalar`

Measured EGR valve area percent, $EGRap$, in %.

`VgtPos` — VGT speed
`scalar`

Measured VGT rack position, VGT_{pos}.

`VgtSpd` — VGT speed
`scalar`

Measured VGT speed, N_{vgt}, in rpm.

`Ect` — Engine cooling temperature
`scalar`

Engine cooling temperature, $T_{coolant}$, in K.

`IgSw` — Ignition switch
`Boolean`

State of the vehicle ignition switch, dimensionless.

Dependencies

To create this port, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

`ESSEnable` — Engine Stop-Start Enable
`Boolean`

Command to enable or disable the stop-start logic, dimensionless.

Dependencies

To create this port, on the **Stop-Start** tab, select **Enable Engine Stop-Start**. Select **External Enable Port**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Variable	Units
`InjPw`	Fuel injector pulse-width	Pw_{inj}	ms
`EgrVlvAreaPctCmd`	EGR valve area percent command	EGR_{cmd}	%
`TurbRackPosCmd`	VGT rack position command	RP_{cmd}	N/A
`TrqCmd`	Engine torque	Trq_{cmd}	N·m
`FuelMassTotCmd`	Commanded total fuel mass per injection	$F_{cmd,tot}$	mg
`FuelMainSoi`	Main start-of-injection timing	$MAINSOI$	degATDC
`FuelMassFlwCmd`	Commanded fuel mass flow rate	$\dot{m}_{fuel,\, cmd}$	kg/s
`EstIntkPortMassFlw`	Estimated port mass flow rate	$\dot{m}_{port,\, est}$	kg/s
`EstEngTrq`	Estimated engine torque	Trq_{est}	N·m
`EstExhManGasTemp`	Estimated exhaust manifold gas temperature	$T_{exh,est}$	K
`EstExhPrs`	Estimated exhaust back-pressure	Pex	Pa
`EstEGRFlow`	`EstEGRFlow`	`EstEGRFlow`	`EstEGRFlow`
`EstAfr`	Estimated air-fuel ratio	AFR_{est}	N/A
`EngRevLimAct`	Flag that indicates if rev-limiter control is active	N/A	N/A

`InjPw` — Fuel injector pulse-width
`scalar`

Fuel injector pulse-width, Pw_{inj}, in ms.

`FuelMainSoi` — Fuel main injecting timing
`scalar`

Main start-of-injection timing, $MAINSOI$, in degrees crank angle after top dead center (degATDC).

`TurbRackPosCmd` — Rack position
`scalar`

VGT rack position command, RP_{cmd}.

`EgrVlvAreaPctCmd` — Intake cam phaser angle command
`scalar`

EGR valve area percent command, EGR_{cmd}.

Parameters

Controls

Air - EGR

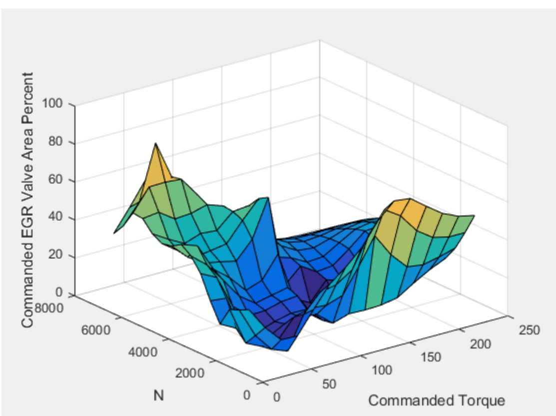
`EGR valve area percent, f_egrcmd` — Lookup table
`array`

The commanded exhaust gas recirculation (EGR) valve area percent lookup table is a function of commanded torque and engine speed

$$EGR_{cmd} = f_{EGRcmd}(Trq_{cmd}, N)$$

where:

- EGR_{cmd} is commanded EGR valve area percent, in percent.
- Trq_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



`Commanded torque breakpoints, f_egr_tq_bpt` — Breakpoints
`[10 26.43 42.86 59.29 75.71 92.14 108.6 125 141.4 157.9 174.3 190.7 207.1 223.6 240]` (default) | `vector`

Commanded torque breakpoints, in N·m.

`Speed breakpoints, f_egr_n_bpt` — Breakpoints
`[1000 1411 1821 2232 2643 3054 3464 3875 4286 4696 5107 5518 5929 6339 6750]` (default) | `vector`

Speed breakpoints, in rpm.

Air - VGR

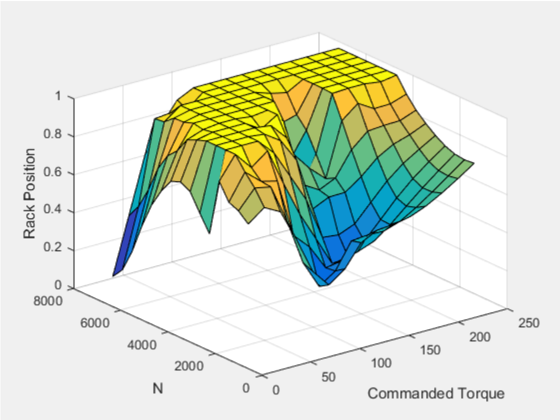
`VGT rack position table, f_rpcmd` — Lookup table
`array`

The variable geometry turbocharger (VGT) rack position lookup table is a function of commanded torque and engine speed

$$RP_{cmd} = f_{RPcmd}(Trq_{cmd}, N)$$

where:

- RP_{cmd} is VGT rack position command, in percent.
- Trq_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



`Commanded torque breakpoints, f_rp_tq_bpt` — Breakpoints
`[10 26.43 42.86 59.29 75.71 92.14 108.6 125 141.4 157.9 174.3 190.7 207.1 223.6 240]` (default) | `vector`

Breakpoints, in N·m.

`Speed breakpoints, f_rp_n_bpt` — Breakpoints
`[1000 1411 1821 2232 2643 3054 3464 3875 4286 4696 5107 5518 5929 6339 6750]` (default) | `vector`

Breakpoints, in rpm.

Fuel

`Injector slope, Sinj` — Slope
`6.452` (default) | `scalar`

Fuel injector slope, S_{inj}, in mg/ms.

`Stoichiometric air-fuel ratio, afr_stoich` — Ratio
`14.6` (default) | `scalar`

Stoichiometric air-fuel ratio, AFR_{stoich}.

Fuel lower heating value, `fuel_lhv` — Heat
42e6 (default) | `scalar`

Fuel lower heating value, in J/kg.

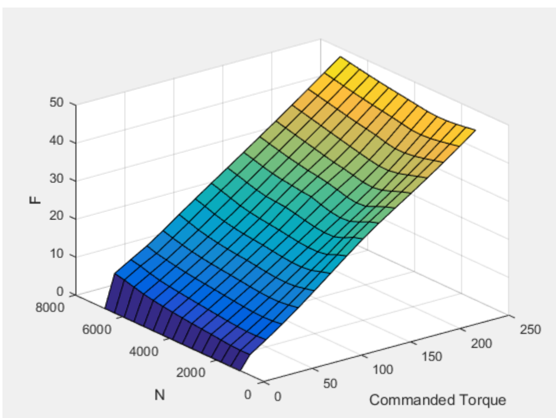
Fuel mass per injection table, `f_fcmd_tot` — Lookup table
`array`

The commanded total fuel mass per injection table is a function of the torque command and engine speed

$$F_{cmd,\,tot} = f_{Fcmd,\,tot}(Trq_{cmd}, N)$$

where:

- $F_{cmd,tot} = F$ is commanded total fuel mass per injection, in mg per cylinder.
- Trq_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



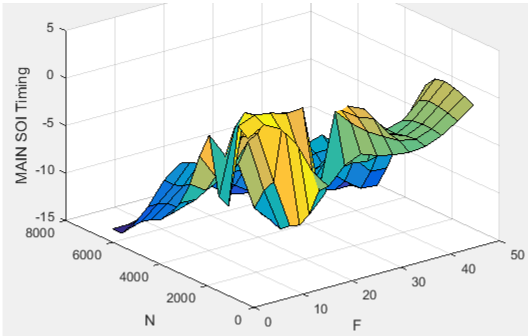
Fuel main injection timing table, `f_main_soi` — Lookup table
`array`

The main start-of-injection (SOI) timing lookup table is a function of commanded fuel mass and engine speed

$$MAINSOI = f(F_{cmd,\,tot}, N)$$

where:

- $MAINSOI$ is the main start-of-injection timing, in degrees crank angle after top dead center (degATDC).
- $F_{cmd,tot} = F$ is commanded fuel mass, in mg per injection.
- N is engine speed, in rpm.



`Fuel main injection timing fuel breakpoints, f_main_soi_f_bpt` — Breakpoints
`vector`

Fuel main injection timing fuel breakpoints, in mg per injection.

`Fuel main injection timing speed breakpoints, f_main_soi_n_bpt` — Breakpoints
`[1000,1410.71428571429,1821.42857142857,2232.14285714286,2642.85714285714,3053.57142857143,3464.28571428571,3875,4285.71428571429,4696.42857142857,5107.14285714286,5517.85714285714,5928.57142857143,6339.28571428572,6750]` (default) | `vector`

Fuel main injection timing speed breakpoints, in rpm.

`Commanded torque breakpoints, f_f_tot_tq_bpt` — Breakpoints
`[0 10 26.43 42.86 59.29 75.71 92.14 108.6 125 141.4 157.9 174.3 190.7 207.1 223.6 240]` (default) | `vector`

Commanded torque breakpoints, in N·m.

`Speed breakpoints, f_f_tot_n_bpt` — Breakpoints
`[1000 1411 1821 2232 2643 3054 3464 3875 4286 4696 5107 5518 5929 6339 6750]` (default) | `vector`

Speed breakpoints, in rpm.

Idle Speed

`Base idle speed, N_idle` — Speed
`750` (default) | `scalar`

Base idle speed, N_{idle}, in rpm.

`Enable torque command limit, Trq_idlecmd_enable` — Torque
`1` (default) | `scalar`

Torque to enable the idle speed controller, $Trq_{idlecmd,enable}$, in N·m.

`Maximum torque command, Trq_idlecmd_max` — Torque
`50` (default) | `scalar`

Maximum idle controller commanded torque, $Trq_{idlecmd,max}$, in N·m.

`Proportional gain, Kp_idle` — PI Controller
`0.05` (default) | `scalar`

Proportional gain for idle speed control, $K_{p,idle}$, in N·m/rpm.

`Integral gain, Ki_idle` — PI Controller
`0.2` (default) | `scalar`

Integral gain for idle speed control, $K_{i,idle}$, in N·m/(rpm·s).

`Rev-limiter speed threshold` — Engine speed limit
`scalar`

Engine speed limit, N_{lim}, in rpm.

If the engine speed, N, exceeds the engine speed limit, N_{lim}, the block sets the commanded engine torque to 0.

To smoothly transition the torque command to 0 as the engine speed approaches the speed limit, the block implements a lookup table multiplier. The lookup table multiplies the torque command by a value that ranges from 0 (engine speed exceeds limit) to 1 (engine speed does not exceed the limit).

Stop-Start

`Enable Engine Stop-Start` — Select to enable the engine stop-start logic
`off` (default) | `on`

Select to enable the engine stop-start logic. Selecting this option will activate additional parameters to modify the behavior of the Engine Stop-Start block.

`External Enable Port` — Create input port
`off` (default) | `on`

Select to add a port to the engine controller block which enables or disables the stop-start logic.

Dependencies

To enable this parameter, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

`Engine stop time, EngStopTime [s]` — Engine stop time
`5` (default) | `scalar`

Engine stop time for the stop-start logic, in s.

Dependencies

To enable this parameter, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

`Catalyst light off time, CatLightOffTime [s]` — Catalyst light off time
`0` (default) | `scalar`

Catalyst light off time for the stop-start logic, in s.

Dependencies

To enable this parameter, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

`Sample time, Ts [s]` — Sample time
`0.01` (default) | `scalar`

Sample time for the stop-start logic, in s.

Dependencies

To enable this parameter, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

Estimation

Air

`Number of cylinders, NCyl` — Engine cylinders
`4` (default) | `scalar`

Number of engine cylinders, N_{cyl}.

`Crank revolutions per power stroke, Cps` — Revolutions per stroke
`2` (default) | `scalar`

Crankshaft revolutions per power stroke, Cps, in rev/stroke.

`Total displaced volume, Vd` — Volume
`0.0015` (default) | `scalar`

Displaced volume, V_d, in m^3.

`Ideal gas constant air, Rair` — Constant
`287` (default) | `scalar`

Ideal gas constant, R_{air}, in J/(kg·K).

`Air standard pressure, Pstd` — Pressure
`101325` (default) | `scalar`

Standard air pressure, P_{std}, in Pa.

`Air standard temperature, Tstd` — Temperature
`293.15` (default) | `scalar`

Standard air temperature, T_{std}, in K.

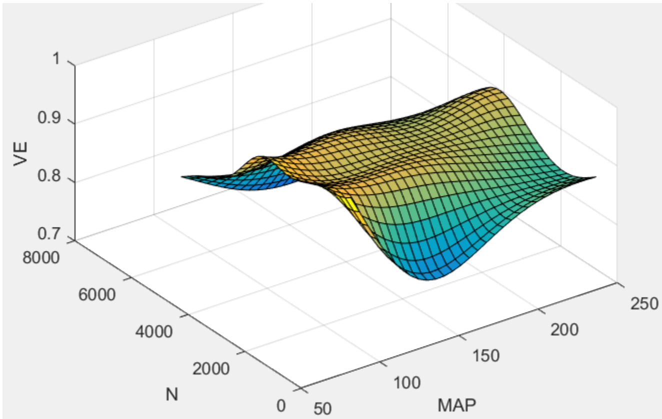
`Speed density volumetric efficiency, f_nv` — Lookup table
`array`

The volumetric efficiency lookup table is a function of the intake manifold absolute pressure at intake valve closing (IVC) and engine speed

$$\eta_v = f_{\eta_v}(MAP, N)$$

where:

- η_v is engine volumetric efficiency, dimensionless.
- MAP is intake manifold absolute pressure, in KPa.
- N is engine speed, in rpm.



`Speed density intake manifold pressure breakpoints, f_nv_prs_bpt` — Breakpoints
`[95 100.3 105.7 111 116.4 121.7 127.1 132.4 137.8 143.1 148.4 153.8 159.1 164.5 169.8 175.2 180.5 185.9 191.2 196.6 201.9 207.2 212.6 217.9 223.3 228.6 234 239.3 244.7 250]` (default) | `vector`

Intake manifold pressure breakpoints for speed-density volumetric efficiency lookup table, in KPa.

`Speed density engine speed breakpoints, f_nv_n_bpt` — Breakpoints
`[750 956.9 1164 1371 1578 1784 1991 2198 2405 2612 2819 3026 3233 3440 3647 3853 4060 4267 4474 4681 4888 5095 5302 5509 5716 5922 6129 6336 6543 6750]` (default) | `vector`

Engine speed breakpoints for speed-density volumetric efficiency lookup table, in rpm.

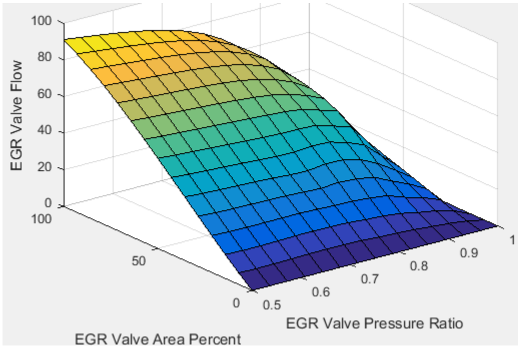
`EGR valve standard flow calibration, f_egr_stdflow` — Lookup table
`array`

The standard exhaust gas recirculation (EGR) mass flow is a lookup table that is a function of the standard flow pressure ratio and EGR valve flow area

$$\dot{m}_{egr,\,std} = f(\frac{MAP}{P_{exh,\,est}}, EGRap)$$

where:

- $\dot{m}_{egr,\,std}$ is the standard EGR valve mass flow, in g/s.
- $P_{exh,est}$ is the estimated exhaust back-pressure, in Pa.
- MAP is the cycle average intake manifold absolute pressure, in Pa.
- $EGRap$ is the measured EGR valve area, in percent.



EGR valve standard flow pressure ratio breakpoints, `f_egr_stdflow_pr_bpt` — Breakpoints
vector

EGR valve standard flow pressure ratio breakpoints, dimensionless.

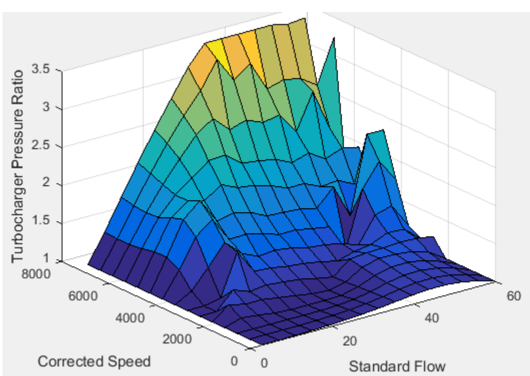
EGR valve standard flow area percent breakpoints, `f_egr_stdflow_egrap_bpt` — Breakpoints
vector

EGR valve standard flow area percent breakpoints, in percent.

Turbocharger pressure ratio, `f_turbo_pr` — Lookup table
array

The turbocharger pressure ratio, corrected for variable geometry turbocharger (VGT) speed, is a lookup table that is a function of the standard air mass flow and corrected turbocharger speed, $Pr_{turbo} = f(\dot{m}_{airstd}, N_{vgtcorr})$, where:

- Pr_{turbo} is the turbocharger pressure ratio, corrected for VGT speed.
- $\dot{m}_{airstd}$ is the standard air mass flow, in g/s.
- $N_{vgtcorr}$ is the corrected turbocharger speed, in rpm/K^(1/2).



Turbocharger pressure ratio standard flow breakpoints, `f_turbo_pr_stdflow_bpt` — Breakpoints
vector

Turbocharger pressure ratio standard flow breakpoints, in g/s.

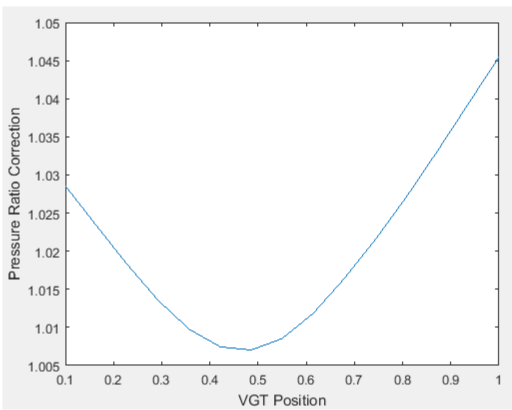
Turbocharger pressure ratio corrected speed breakpoints, f_turbo_pr_corrspd_bpt — Breakpoints
vector

Turbocharger pressure ratio corrected speed breakpoints, in rpm/K^(1/2).

Turbocharger pressure ratio VGT position correction, f_turbo_pr_vgtposcorr — Lookup table
array

The variable geometry turbocharger pressure ratio correction is a function of the rack position, $Pr_{vgtcorr} = f(VGT_{pos})$, where:

- $Pr_{vgtcorr}$ is the turbocharger pressure ratio correction.
- VGT_{pos} is the variable geometry turbocharger (VGT) rack position.



Turbocharger pressure ratio VGT position correction breakpoints, f_turbo_pr_vgtposcorr_bpt — Breakpoints
vector

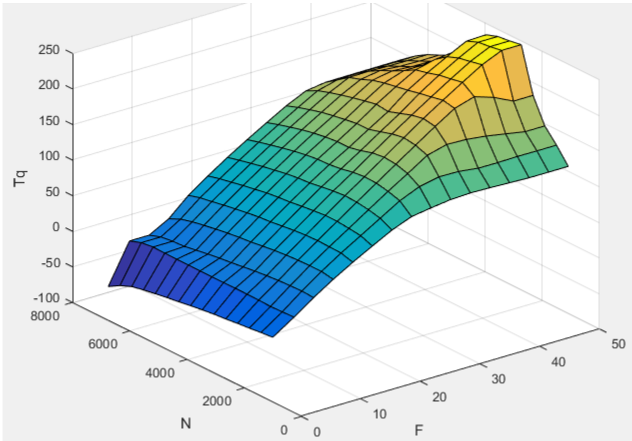
Turbocharger pressure ratio VGT position correction breakpoints, dimensionless.

Torque - Simple Torque Lookup

Torque table, f_tq_nf — Lookup table
array

For the simple torque lookup table model, the CI engine uses a lookup table is a function of engine speed and injected fuel mass, $T_{brake} = f_{Tnf}(F, N)$, where:

- $Tq = T_{brake}$ is engine brake torque after accounting for engine mechanical and pumping friction effects, in N·m.
- F is injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

Torque table fuel mass per injection breakpoints, f_tq_nf_f_bpt — Breakpoints
`[0 3.5714 7.1429 10.7143 14.2857 17.8571 21.4286 25 28.5714 32.1429 35.7143 39.2857 42.8571 46.4286 50]` (default) | `vector`

Torque table fuel mass per injection breakpoints, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

Torque table speed breakpoints, f_tq_nf_n_bpt — Breakpoints
`[1000 1410.7143 1821.4286 2232.1429 2642.8571 3053.5714 3464.2857 3875 4285.7143 4696.4286 5107.1429 5517.8571 5928.5714 6339.2857 6750]` (default) | `vector`

Engine speed breakpoints, in rpm.

Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

Torque - Torque Structure

Fuel mass per injection breakpoints, f_tqs_f_bpt — Breakpoints
`vector`

Fuel mass per injection breakpoints, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Engine speed breakpoints, f_tqs_n_bpt — Breakpoints
`[500 750 1000 1250 1500 1750 2000 2250 2500 2750 3000 3250 3500 3750 4000]` (default) | `vector`

Engine speed breakpoints, in rpm.

Dependencies

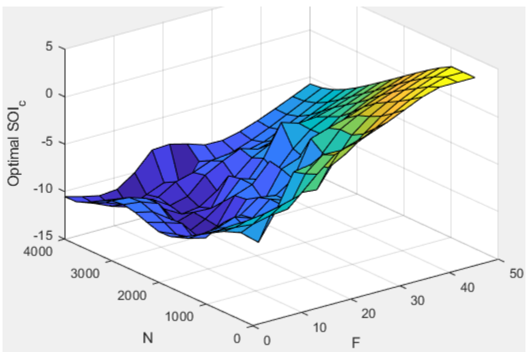
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal main start of injection timing, f_tqs_mainsoi` — Optimal MAINSOI

`array`

The optimal main start of injection (SOI) timing lookup table, f_{SOIc}, is a function of the engine speed and injected fuel mass, $SOI_c = f_{SOIc}(F,N)$, where:

- SOI_c is optimal SOI timing, in degATDC.
- F is compression stroke injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

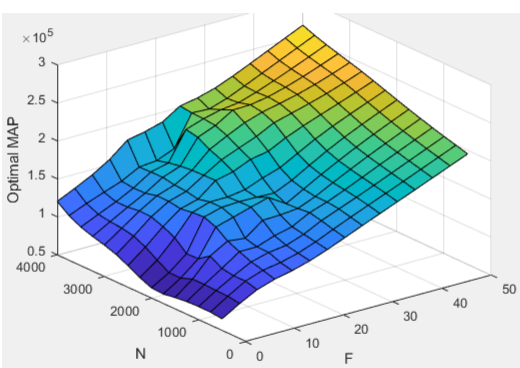
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal intake manifold gas pressure, f_tqs_map` — Optimal intake MAP

`array`

The optimal intake manifold gas pressure lookup table, f_{MAP}, is a function of the engine speed and injected fuel mass, $MAP = f_{MAP}(F,N)$, where:

- MAP is optimal intake manifold gas pressure, in Pa.
- F is compression stroke injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



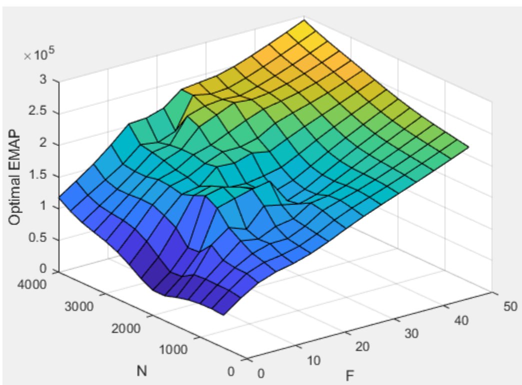
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal exhaust manifold gas pressure, f_tqs_emap` — Optimal exhaust MAP
`array`

The optimal exhaust manifold gas pressure lookup table, f_{EMAP}, is a function of the engine speed and injected fuel mass, $EMAP = f_{EMAP}(F,N)$, where:

- *EMAP* is optimal exhaust manifold gas pressure, in Pa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



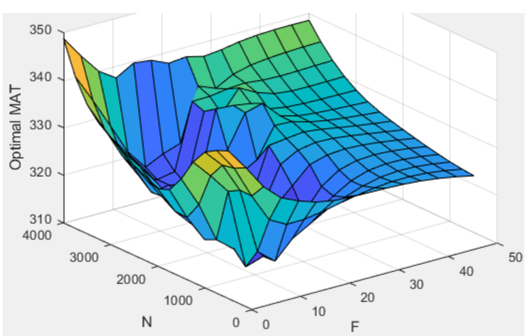
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal intake manifold gas temperature, f_tqs_mat` — Optimal intake MAT
`array`

The optimal intake manifold gas temperature lookup table, f_{MAT}, is a function of the engine speed and injected fuel mass, $MAT = f_{MAT}(F,N)$, where:

- *MAT* is optimal intake manifold gas temperature, in K.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



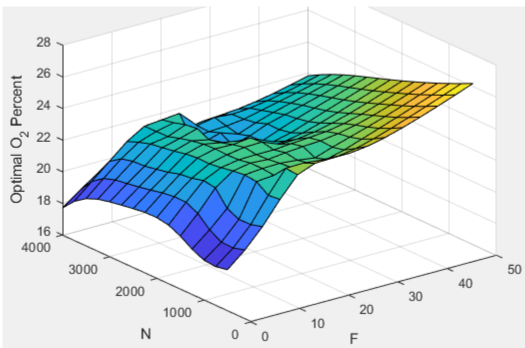
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal intake gas oxygen percent, f_tqs_o2pct` — Optimal intake gas oxygen
`array`

The optimal intake gas oxygen percent lookup table, f_{O2}, is a function of the engine speed and injected fuel mass, $O2PCT = f_{O2}(F,N)$, where:

- *O2PCT* is optimal intake gas oxygen, in percent.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



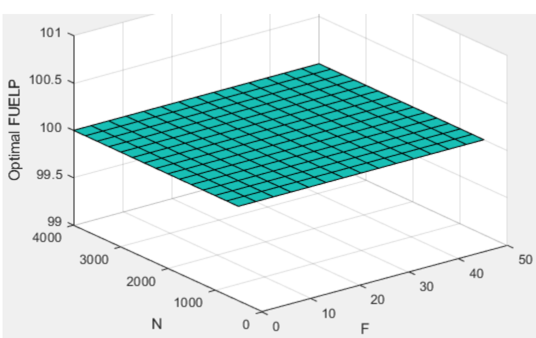
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal fuel rail pressure, f_tqs_fuelpress` — Optimal fuel rail pressure
`array`

The optimal fuel rail pressure lookup table, f_{fuelp}, is a function of the engine speed and injected fuel mass, $FUELP = f_{fuelp}(F,N)$, where:

- *FUELP* is optimal fuel rail pressure, in MPa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

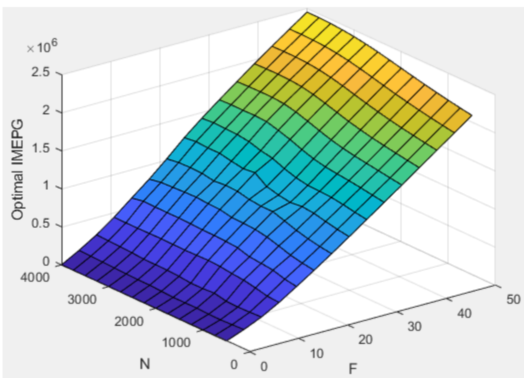
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal gross indicated mean effective pressure, f_tqs_imepg` — Optimal mean effective pressure

`array`

The optimal gross indicated mean effective pressure lookup table, f_{imepg}, is a function of the engine speed and injected fuel mass, $IMEPG = f_{imepg}(F,N)$, where:

- *IMEPG* is optimal gross indicated mean effective pressure, in Pa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

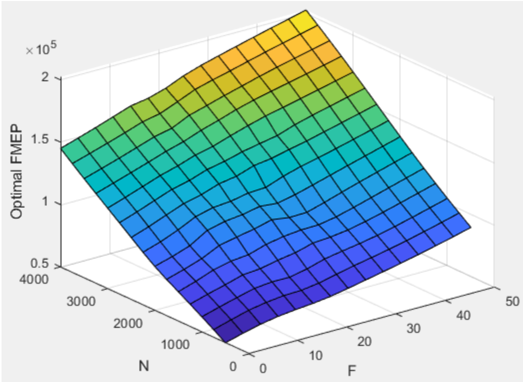
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal friction mean effective pressure, f_tqs_fmep` — Optimal friction mean effective pressure

`array`

The optimal friction mean effective pressure lookup table, f_{fmep}, is a function of the engine speed and injected fuel mass, $FMEP = f_{fmep}(F,N)$, where:

- *FMEP* is optimal friction mean effective pressure, in Pa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

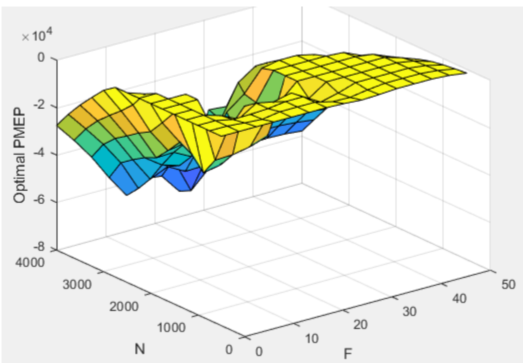
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal pumping mean effective pressure, f_tqs_pmep` — Optimal pumping mean effective pressure

`array`

The optimal pumping mean effective pressure lookup table, f_{pmep}, is a function of the engine speed and injected fuel mass, $PMEP = f_{pmep}(F,N)$, where:

- *PMEP* is optimal pumping mean effective pressure, in Pa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Friction multiplier as a function of temperature, f_tqs_fric_temp_mod` — Friction multiplier

`array`

Friction multiplier as a function of temperature, dimensionless.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Friction multiplier temperature breakpoints, f_tqs_fric_temp_bpt — Breakpoints
vector

Friction multiplier temperature breakpoints, in K.

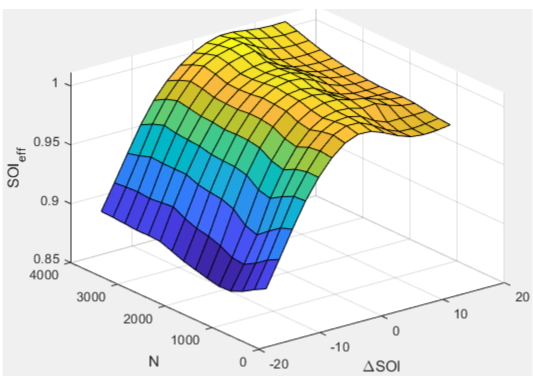
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Main start of injection timing efficiency multiplier, f_tqs_mainsoi_eff — MAINSOI efficiency multiplier
array

The main start of injection (SOI) timing efficiency multiplier lookup table, f_{SOIeff}, is a function of the engine speed and main SOI timing relative to optimal timing, $SOI_{eff} = f_{SOIeff}(\Delta SOI,N)$, where:

- SOI_{eff} is main SOI timing efficiency multiplier, dimensionless.
- ΔSOI is main SOI timing relative to optimal timing, in degBTDC.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Main start of injection timing relative to optimal timing breakpoints, f_tqs_mainsoi_delta_bpt — Breakpoints
vector

Main start of injection timing relative to optimal timing breakpoints, in degBTDC.

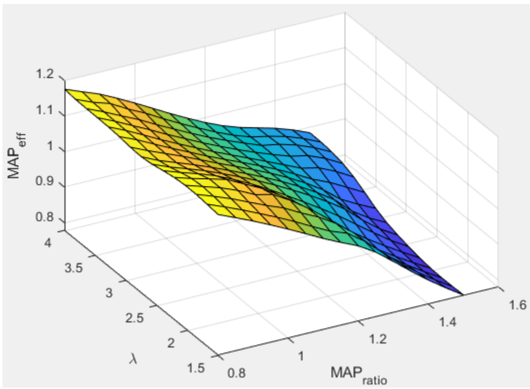
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas pressure efficiency multiplier, f_tqs_map_eff — Intake pressure efficiency multiplier
array

The intake manifold gas pressure efficiency multiplier lookup table, f_{MAPeff}, is a function of the intake manifold gas pressure ratio relative to optimal pressure ratio and lambda, $MAP_{eff} = f_{MAPeff}(MAP_{ratio},\lambda)$, where:

- MAP_{eff} is intake manifold gas pressure efficiency multiplier, dimensionless.
- MAP_{ratio} is intake manifold gas pressure ratio relative to optimal pressure ratio, dimensionless.
- λ is intake manifold gas lambda, dimensionless.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas pressure ratio relative to optimal pressure ratio breakpoints, f_tqs_map_ratio_bpt` — Breakpoints
`[0.8;0.85;0.9;0.95;1;1.05;1.1;1.15;1.2;1.25;1.3;1.35;1.4;1.45;1.5]` (default) | `vector`

Intake manifold gas pressure ratio relative to optimal pressure ratio breakpoints, dimensionless.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas lambda breakpoints, f_tqs_lambda_bpt` — Breakpoints
`[1.5 1.678571428571429 1.857142857142857 2.035714285714286 2.214285714285714 2.392857142857143 2.571428571428571 2.75 2.928571428571429 3.107142857142857 3.285714285714286 3.464285714285714 3.642857142857143 3.821428571428572 4]` (default) | `vector`

Intake manifold gas lambda breakpoints, dimensionless.

Dependencies

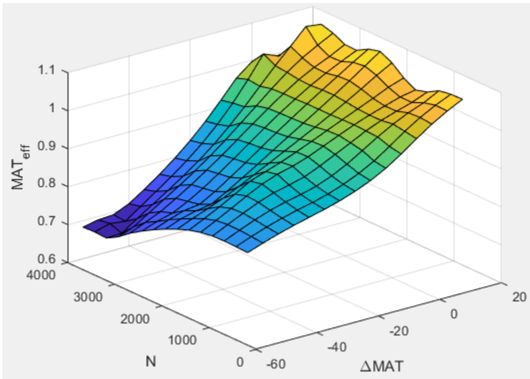
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas temperature efficiency multiplier, f_tqs_mat_eff` — Intake temperature efficiency multiplier
`array`

The intake manifold gas temperature efficiency multiplier lookup table, f_{MATeff}, is a function of the engine speed and intake manifold gas temperature relative to optimal temperature, $MAT_{eff} = f_{MATeff}(\Delta MAT,N)$, where:

- MAT_{eff} is intake manifold gas temperature efficiency multiplier, dimensionless.
- ΔMAT is intake manifold gas temperature relative to optimal temperature, in K.

- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas temperature relative to optimal gas temperature breakpoints, f_tqs_mat_delta_bpt` — Breakpoints
`[-55;-50;-45;-40;-35;-30;-25;-20;-15;-10;-5;0;5;10;15]` (default) | `vector`

Intake manifold gas temperature relative to optimal gas temperature breakpoints, in K.

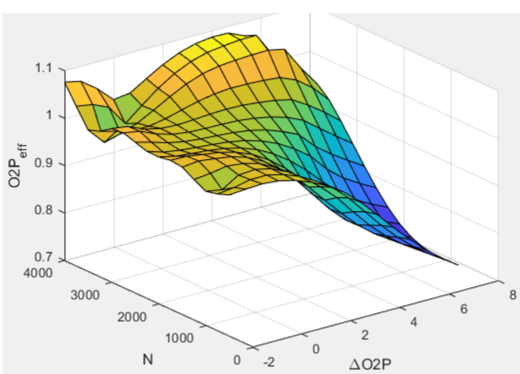
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas oxygen efficiency multiplier, f_tqs_o2pct_eff` — Intake oxygen efficiency multiplier
`array`

The intake manifold gas oxygen efficiency multiplier lookup table, f_{O2Peff}, is a function of the engine speed and intake manifold gas oxygen percent relative to optimal, $O2P_{eff} = f_{O2Peff}(\Delta O2P,N)$, where:

- $O2P_{eff}$ is intake manifold gas oxygen efficiency multiplier, dimensionless.
- $\Delta O2P$ is intake gas oxygen percent relative to optimal, in percent.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake gas oxygen percent relative to optimal breakpoints, f_tqs_o2pct_delta_bpt` — Breakpoints
`vector`

Intake gas oxygen percent relative to optimal breakpoints, in percent.

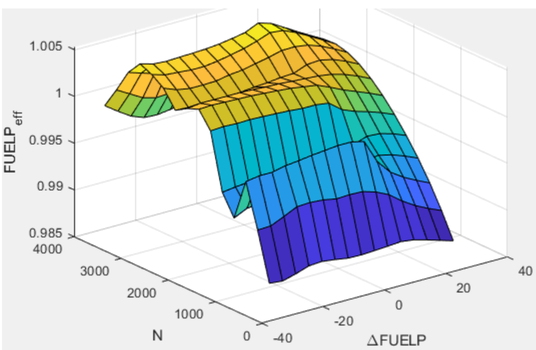
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Fuel rail pressure efficiency multiplier, f_tqs_fuelpress_eff` — Efficiency multiplier
`array`

The fuel rail pressure efficiency multiplier lookup table, $f_{FUELPeff}$, is a function of the engine speed and fuel rail pressure relative to optimal breakpoints, $FUELP_{eff} = f_{FUELPeff}(\Delta FUELP,N)$, where:

- $FUELP_{eff}$ is fuel rail pressure efficiency multiplier, dimensionless.
- $\Delta FUELP$ is fuel rail pressure relative to optimal, in MPa.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Fuel rail pressure relative to optimal breakpoints, f_tqs_fuelpress_delta_bpt` — Breakpoints
`vector`

Fuel rail pressure relative to optimal breakpoints, in MPa.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Fuel mass injection type identifier, f_tqs_f_inj_type` — Type identifier
`0` (default) | `scalar`

Fuel mass injection type identifier, dimensionless.

In the CI Core Engine and CI Controller blocks, you can represent multiple injections with the start of injection (SOI) and fuel mass inputs to the model. To specify the type of injection, use the **Fuel mass injection type identifier** parameter.

Type of Injection	Parameter Value
Pilot	`0`
Main	`1`
Post	`2`
Passed	`3`

The model considers `Passed` fuel injections and fuel injected later than a threshold to be unburned fuel. Use the **Maximum start of injection angle for burned fuel, f_tqs_f_burned_soi_limit** parameter to specify the threshold.

Dependencies

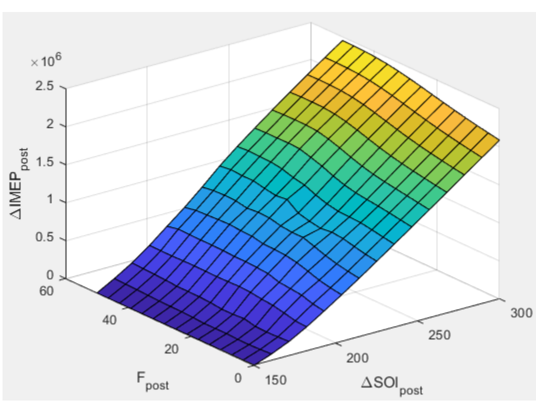
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Indicated mean effective pressure post inject correction, f_tqs_imep_post_corr` — Post inject correction

`array`

The indicated mean effective pressure post inject correction lookup table, $f_{IMEPpost}$, is a function of the engine speed and fuel rail pressure relative to optimal breakpoints, $\Delta IMEP_{post} = f_{IMEPpost}(\Delta SOI_{post}, F_{post})$, where:

- $\Delta IMEP_{post}$ is indicated mean effective pressure post inject correction, in Pa.
- ΔSOI_{post} is indicated mean effective pressure post inject start of inject timing centroid, in degATDC.
- F_{post} is indicated mean effective pressure post inject mass sum, in mg per injection.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Indicated mean effective pressure post inject mass sum breakpoints, f_tqs_f_post_sum_bpt` — Breakpoints

`[0 3.571428571428572 7.142857142857143 10.71428571428571 14.28571428571429 17.85714285714286 21.42857142857143 25 28.57142857142857 32.14285714285715`

35.71428571428572 39.28571428571428 42.85714285714285 46.42857142857143 50]
(default) | vector

Indicated mean effective pressure post inject mass sum breakpoints, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select Torque Structure.

Indicated mean effective pressure post inject start of inject timing centroid breakpoints, f_tqs_soi_post_cent_bpt — Breakpoints
[150 160.7142857142857 171.4285714285714 182.1428571428571 192.8571428571429 203.5714285714286 214.2857142857143 225 235.7142857142857 246.4285714285714 257.1428571428571 267.8571428571429 278.5714285714286 289.2857142857143 300] (default) | vector

Indicated mean effective pressure post inject start of inject timing centroid breakpoints, in degATDC.

Dependencies

To enable this parameter, for **Torque model**, select Torque Structure.

Maximum start of injection angle for burned fuel, f_tqs_f_burned_soi_limit — Maximum SOI angle for burned fuel
500 (default) | scalar

Maximum start of injection angle for burned fuel, in degATDC.

Dependencies

To enable this parameter, for **Torque model**, select Torque Structure.

Exhaust

Exhaust gas specific heat at constant pressure, cp_exh — Specific heat
1005 (default) | scalar

Exhaust gas-specific heat, Cp_{exh}, in J/(kg·K).

Exhaust Temperature - Simple Torque Lookup

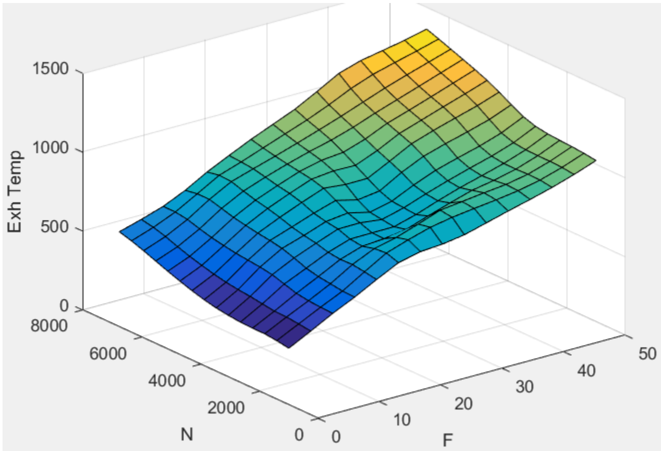
Exhaust temperature table, f_t_exh — Lookup table
array

The lookup table for the exhaust temperature is a function of injected fuel mass and engine speed

$$T_{exh} = f_{Texh}(F, N)$$

where:

- T_{exh} is exhaust temperature, in K.
- F is injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

`Fuel mass per injection breakpoints, f_t_exh_f_bpt` — Breakpoints

`[0 3.5714 7.1429 10.7143 14.2857 17.8571 21.4286 25 28.5714 32.1429 35.7143 39.2857 42.8571 46.4286 50]` (default) | `array`

Engine load breakpoints used for exhaust temperature lookup table, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

`Speed breakpoints, f_t_exh_n_bpt` — Breakpoints

`[1000 1410.7143 1821.4286 2232.1429 2642.8571 3053.5714 3464.2857 3875 4285.7143 4696.4286 5107.1429 5517.8571 5928.5714 6339.2857 6750]` (default) | `array`

Engine speed breakpoints used for exhaust temperature lookup table, in rpm.

Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

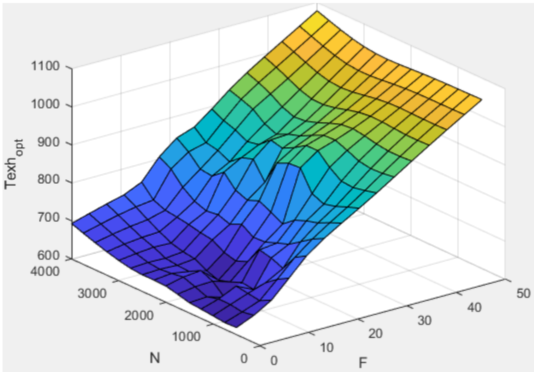
Exhaust Temperature - Torque Structure

`Optimal exhaust manifold gas temperature, f_tqs_exht` — Optimal exhaust manifold gas temperature

`array`

The optimal exhaust manifold gas temperature lookup table, f_{Texh}, is a function of the engine speed engine speed and injected fuel mass, $Texh_{opt} = f_{Texh}(F,N)$, where:

- $Texh_{opt}$ is optimal exhaust manifold gas temperature, in K.
- F is compression stroke injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

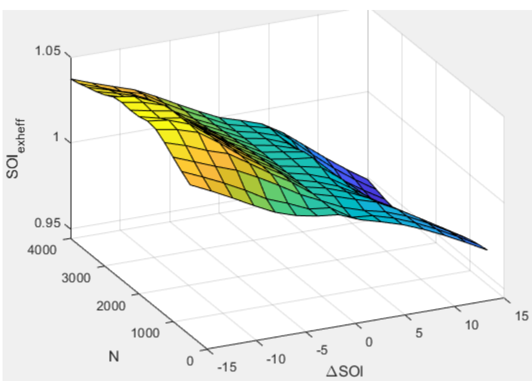
To enable this parameter, for **Torque model**, select `Torque Structure`.

Main start of injection timing exhaust temperature efficiency multiplier, f_tqs_exht_mainsoi_eff — Main SOI timing efficiency multiplier

`array`

The main start of injection (SOI) timing exhaust temperature efficiency multiplier lookup table, $f_{SOIexhteff}$, is a function of the engine speed engine speed and injected fuel mass, $SOI_{exhteff} = f_{SOIexhteff}(\Delta SOI,N)$, where:

- $SOI_{exhteff}$ is main SOI exhaust temperature efficiency multiplier, dimensionless.
- ΔSOI is main SOI timing relative to optimal timing, in degBTDC.
- N is engine speed, in rpm.



Dependencies

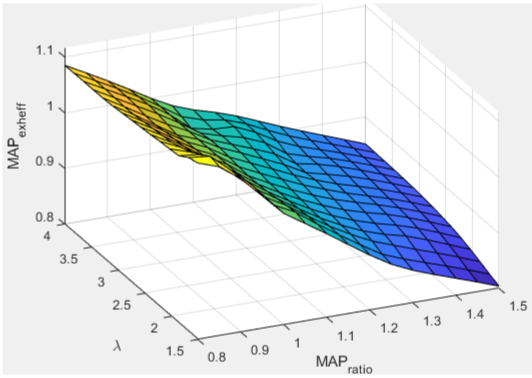
To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas pressure exhaust temperature efficiency multiplier, f_tqs_exht_map_eff — Intake manifold efficiency multiplier

`array`

The intake manifold gas pressure exhaust temperature efficiency multiplier lookup table, $f_{MAPexheff}$, is a function of the intake manifold gas pressure ratio relative to optimal pressure ratio and lambda, $MAP_{exheff} = f_{MAPexheff}(MAP_{ratio},\lambda)$, where:

- MAP_{exheff} is intake manifold gas pressure exhaust temperature efficiency multiplier, dimensionless.
- MAP_{ratio} is intake manifold gas pressure ratio relative to optimal pressure ratio, dimensionless.
- λ is intake manifold gas lambda, dimensionless.



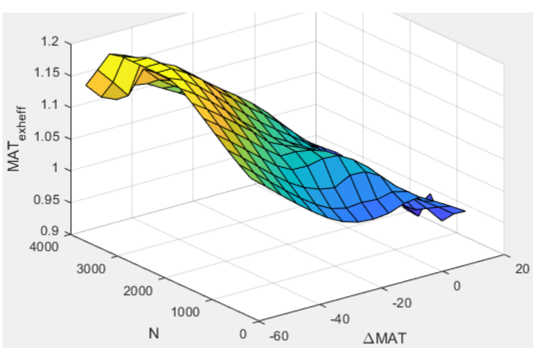
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas temperature exhaust temperature efficiency multiplier, f_tqs_exht_mat_eff` — Intake manifold efficiency multiplier
`array`

The intake manifold gas temperature exhaust temperature efficiency multiplier lookup table, $f_{MATexheff}$, is a function of the engine speed and intake manifold gas temperature relative to optimal temperature, $MAT_{exheff} = f_{MATexheff}(\Delta MAT,N)$, where:

- MAT_{exheff} is intake manifold gas temperature exhaust temperature efficiency multiplier, dimensionless.
- ΔMAT is intake manifold gas temperature relative to optimal temperature, in K.
- N is engine speed, in rpm.



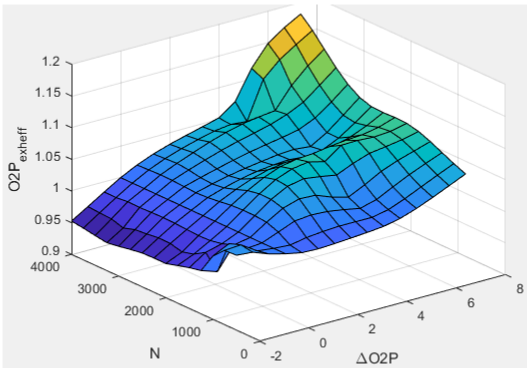
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas oxygen exhaust temperature efficiency multiplier, f_tqs_exht_o2pct_eff` — Intake manifold efficiency multiplier
`array`

The intake manifold gas oxygen exhaust temperature efficiency multiplier lookup table, $f_{O2Pexheff}$, is a function of the engine speed and intake manifold gas oxygen percent relative to optimal, $O2P_{exheff} = f_{O2Pexheff}(\Delta O2P,N)$, where:

- $O2P_{exheff}$ is intake manifold gas oxygen exhaust temperature efficiency multiplier, dimensionless.
- $\Delta O2P$ is intake gas oxygen percent relative to optimal, in percent.
- N is engine speed, in rpm.



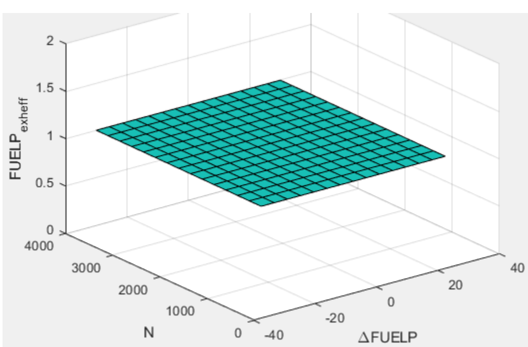
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Fuel rail pressure exhaust temperature efficiency multiplier, f_tqs_exht_fuelpress_eff` — Fuel rail pressure exhaust temperature efficiency multiplier
`array`

The fuel rail pressure efficiency exhaust temperature multiplier lookup table, $f_{FUELPexheff}$, is a function of the engine speed and fuel rail pressure relative to optimal breakpoints, $FUELP_{exheff} = f_{FUELPexheff}(\Delta FUELP,N)$, where:

- $FUELP_{exheff}$ is fuel rail pressure exhaust temperature efficiency multiplier, dimensionless.
- $\Delta FUELP$ is fuel rail pressure relative to optimal, in MPa.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Post-injection cylinder wall heat loss transfer coefficient, f_tqs_exht_post_inj_wall_htc` — Post-injection offset
`0` (default) | `scalar`

Post-injection cylinder wall heat loss transfer coefficient, in W/K.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
CI Core Engine | Mapped CI Engine

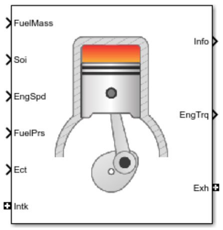
Topics
"Engine Calibration Maps"
"Generate Mapped CI Engine from a Spreadsheet"

Introduced in R2017a

CI Core Engine

Compression-ignition engine from intake to exhaust port

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Core Engine



Description

The CI Core Engine block implements a compression-ignition (CI) engine from intake to the exhaust port. You can use the block for hardware-in-the-loop (HIL) engine control design or vehicle-level fuel economy and performance simulations.

The CI Core Engine block calculates:

- Brake torque
- Exhaust temperature
- Air-fuel ratio (AFR)
- Fuel rail pressure
- Engine-out (EO) exhaust emissions:
  - Hydrocarbon (HC)
  - Carbon monoxide (CO)
  - Nitric oxide and nitrogen dioxide (NOx)
  - Carbon dioxide (CO_2)
  - Particulate matter (PM)

Air Mass Flow

To calculate the air mass flow, the compression-ignition (CI) engine uses the “CI Engine Speed-Density Air Mass Flow Model”. The speed-density model uses the speed-density equation to calculate the engine air mass flow, relating the engine intake port mass flow to the intake manifold pressure, intake manifold temperature, and engine speed.

Brake Torque

To calculate the engine torque, you can configure the block to use either of these torque models.

Brake Torque Model	Description
"CI Engine Torque Structure Model"	The CI core engine torque structure model determines the engine torque by reducing the maximum engine torque potential as these engine conditions vary from nominal: • Start of injection (SOI) timing • Exhaust back-pressure • Burned fuel mass • Intake manifold gas pressure, temperature, and oxygen percentage • Fuel rail pressure To account for the effect of post-inject fuel on torque, the model uses a calibrated torque offset table.
"CI Engine Simple Torque Model"	For the simple engine torque calculation, the CI engine uses a torque lookup table map that is a function of engine speed and injected fuel mass.

Fuel Flow

In the CI Core Engine and CI Controller blocks, you can represent multiple injections with the start of injection (SOI) and fuel mass inputs to the model. To specify the type of injection, use the **Fuel mass injection type identifier** parameter.

Type of Injection	Parameter Value
Pilot	`0`
Main	`1`
Post	`2`
Passed	`3`

The model considers `Passed` fuel injections and fuel injected later than a threshold to be unburned fuel. Use the **Maximum start of injection angle for burned fuel, f_tqs_f_burned_soi_limit** parameter to specify the threshold.

To calculate the engine fuel mass flow, the CI Core Engine block uses fuel mass flow delivered by the injectors and the engine airflow.

$$\dot{m}_{fuel} = \frac{N \cdot N_{cyl}}{Cps\left(\frac{60s}{\min}\right)\left(\frac{1000mg}{g}\right)} \sum m_{fuel,inj}$$

To calculate the fuel economy for high-fidelity models, the block uses the volumetric fuel flow.

$$Q_{fuel} = \frac{\dot{m}_{fuel}}{\left(\frac{1000kg}{m^3}\right) Sg_{fuel}}$$

The equation uses these variables.

$\dot{m}_{fuel}$	Fuel mass flow, g/s

$m_{fuel,inj}$	Fuel mass per injection
Cps	Crankshaft revolutions per power stroke, rev/stroke
N_{cyl}	Number of engine cylinders
N	Engine speed, rpm
Q_{fuel}	Volumetric fuel flow
Sg_{fuel}	Specific gravity of fuel

The block uses the internal signal `FlwDir` to track the direction of the flow.

Air-Fuel Ratio

To calculate the air-fuel (AFR) ratio, the CI Core Engine and SI Core Engine blocks implement this equation.

$$AFR = \frac{\dot{m}_{air}}{\dot{m}_{fuel}}$$

The CI Core Engine uses this equation to calculate the relative AFR.

$$\lambda = \frac{AFR}{AFR_S}$$

To calculate the exhaust gas recirculation (EGR), the blocks implement this equation. The calculation expresses the EGR as a percent of the total intake port flow.

$$EGR_{pct} = 100\frac{\dot{m}_{intk,\,b}}{\dot{m}_{intk}} = 100y_{intk,\,b}$$

The equations use these variables.

AFR	Air-fuel ratio
AFR_s	Stoichiometric air-fuel ratio
$\dot{m}_{intk}$	Engine air mass flow
$\dot{m}_{fuel}$	Fuel mass flow
λ	Relative AFR
$y_{intk,b}$	Intake burned mass fraction
EGR_{pct}	EGR percent
$\dot{m}_{intk,\,b}$	Recirculated burned gas mass flow rate

Exhaust Temperature

The exhaust temperature calculation depends on the torque model. For both torque models, the block implements lookup tables.

Torque Model	Description	Equations
`Simple Torque Lookup`	Exhaust temperature lookup table is a function of the injected fuel mass and engine speed.	$T_{exh} = f_{Texh}(F, N)$
`Torque Structure`	The nominal exhaust temperature, $Texh_{nom}$, is a product of these exhaust temperature efficiencies: • SOI timing • Intake manifold gas pressure • Intake manifold gas temperature • Intake manifold gas oxygen percentage • Fuel rail pressure • Optimal temperature The exhaust temperature, $Texh_{nom}$, is offset by a post temperature effect, ΔT_{post}, that accounts for post and late injections during the expansion and exhaust strokes.	$T_{exhnom} = SOI_{exhteff} MAP_{exhteff} MAT_{exhteff} O2p_{exhteff} FU$ $T_{exh} = T_{exhnom} + \Delta T_{post}$ $SOI_{exhteff} = f_{SOI_{exhteff}}(\Delta SOI, N)$ $MAP_{exhteff} = f_{MAP_{exhteff}}(MAP_{ratio}, \lambda)$ $MAT_{exhteff} = f_{MAT_{exhteff}}(\Delta MAT, N)$ $O2p_{exhteff} = f_{O2p_{exhteff}}(\Delta O2p, N)$ $Texh_{opt} = f_{Texh}(F, N)$

The equations use these variables.

F	Compression stroke injected fuel mass
N	Engine speed
$Texh$	Exhaust manifold gas temperature
$Texh_{opt}$	Optimal exhaust manifold gas temperature
ΔT_{post}	Post injection temperature effect
$Texh_{nom}$	Nominal exhaust temperature
$SOI_{exhteff}$	Main SOI exhaust temperature efficiency multiplier
ΔSOI	Main SOI timing relative to optimal timing
MAP_{exheff}	Intake manifold gas pressure exhaust temperature efficiency multiplier
MAP_{ratio}	Intake manifold gas pressure ratio relative to optimal pressure ratio
λ	Intake manifold gas lambda
MAT_{exheff}	Intake manifold gas temperature exhaust temperature efficiency multiplier
ΔMAT	Intake manifold gas temperature relative to optimal temperature
$O2P_{exheff}$	Intake manifold gas oxygen exhaust temperature efficiency multiplier
$\Delta O2P$	Intake gas oxygen percent relative to optimal
$FUELP_{exheff}$	Fuel rail pressure exhaust temperature efficiency multiplier
$\Delta FUELP$	Fuel rail pressure relative to optimal

EO Exhaust Emissions

The block calculates these engine-out (EO) exhaust emissions:

- Hydrocarbon (HC)
- Carbon monoxide (CO)
- Nitric oxide and nitrogen dioxide (NOx)
- Carbon dioxide (CO_2)
- Particulate matter (PM)

The exhaust temperature determines the specific enthalpy.

$$h_{exh} = Cp_{exh}T_{exh}$$

The exhaust mass flow rate is the sum of the intake port air mass flow and the fuel mass flow.

$$\dot{m}_{exh} = \dot{m}_{intake} + \dot{m}_{fuel}$$

To calculate the exhaust emissions, the block multiplies the emission mass fraction by the exhaust mass flow rate. To determine the emission mass fractions, the block uses lookup tables that are functions of the engine torque and speed.

$$y_{exh,\,i} = f_{i\_frac}(T_{brake}, N)$$
$$\dot{m}_{exh,\,i} = \dot{m}_{exh}y_{exh,\,i}$$

The fraction of air and fuel entering the intake port, injected fuel, and stoichiometric AFR determine the air mass fraction that exits the exhaust.

$$y_{exh,\,air} = \max\left[y_{in,\,air} - \frac{\dot{m}_{fuel} + y_{in,\,fuel}\dot{m}_{intake}}{\dot{m}_{fuel} + \dot{m}_{intake}}AFR_s\right]$$

If the engine is operating at the stoichiometric or fuel rich AFR, no air exits the exhaust. Unburned hydrocarbons and burned gas comprise the remainder of the exhaust gas. This equation determines the exhaust burned gas mass fraction.

$$y_{exh,\,b} = \max\left[(1 - y_{exh,\,air} - y_{exh,\,HC}), 0\right]$$

The equations use these variables.

T_{exh}	Engine exhaust temperature
h_{exh}	Exhaust manifold inlet-specific enthalpy
Cp_{exh}	Exhaust gas specific heat
$\dot{m}_{intk}$	Intake port air mass flow rate
$\dot{m}_{fuel}$	Fuel mass flow rate
$\dot{m}_{exh}$	Exhaust mass flow rate
$y_{in,\,fuel}$	Intake fuel mass fraction
$y_{exh,i}$	Exhaust mass fraction for i = CO_2, CO, HC, NOx, air, burned gas, and PM
$\dot{m}_{exh,\,i}$	Exhaust mass flow rate for i = CO_2, CO, HC, NOx, air, burned gas, and PM

T_{brake}	Engine brake torque
N	Engine speed
$y_{exh,air}$	Exhaust air mass fraction
$y_{exh,b}$	Exhaust air burned mass fraction

Power Accounting

For the power accounting, the block implements equations that depend on **Torque model**.

When you set **Torque model** to `Simple Torque Lookup`, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrIntkHeatFlw`	Intake heat flow	$\dot{m}_{intk}h_{intk}$
		`PwrExhHeatFlw`	Exhaust heat flow	$-\dot{m}_{exh}h_{exh}$
		`PwrCrkshft`	Crankshaft power	$-T_{brake}\omega$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFuel`	Fuel input power	$\dot{m}_{fuel}LHV$
		`PwrLoss`	All losses	$T_{brake}\omega - \dot{m}_{fuel}LHV - \dot{m}_{intk}h_{intk} + \dot{m}_{exh}h_{exh}$

Bus Signal			Description	Equations
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	*Not used*		

When you set **Torque model** to `Torque Structure`, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrIntkHeatFlw`	Intake heat flow	$\dot{m}_{intk} h_{intk}$
		`PwrExhHeatFlw`	Exhaust heat flow	$-\dot{m}_{exh} h_{exh}$
		`PwrCrkshft`	Crankshaft power	$-T_{brake}\omega$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFuel`	Fuel input power	$\dot{m}_{fuel} LHV$
		`PwrFricLoss`	Friction loss	$-T_{fric}\omega$
		`PwrPumpLoss`	Pumping loss	$-T_{pump}\omega$
		`PwrHeatTrnsfrLoss`	Heat transfer loss	$T_{brake}\omega - \dot{m}_{fuel} LHV - \dot{m}_{intk} h_{intk} + \dot{m}_{exh} h_{exh} + T_{fric}\omega + T_{pump}\omega$

Bus Signal		Description	Equations
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	*Not used*	

h_{exh}	Exhaust manifold inlet-specific enthalpy
h_{intk}	Intake port specific enthalpy
$\dot{m}_{intk}$	Intake port air mass flow rate
$\dot{m}_{fuel}$	Fuel mass flow rate
$\dot{m}_{exh}$	Exhaust mass flow rate
ω	Engine speed
T_{brake}	Brake torque
T_{pump}	Engine pumping work offset to inner torque
T_{fric}	Engine friction torque
LHV	Fuel lower heating value

Ports

Input

`FuelMass` — Fuel injector pulse-width

`vector`

Fuel mass per injection, $m_{fuel,inj}$, in mg per injection.

`Soi` — Start of fuel injection timing

`vector`

Fuel injection timing, *SOI*, in degrees crank angle after top dead center (degATDC). First vector value, `Soi(1)`, is main injection timing.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

EngSpd — Engine speed

`scalar`

Engine speed, *N*, in rpm.

`FuelPrs` — Fuel rail pressure
`scalar`

Fuel rail pressure, *FUELP*, in MPa.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Ect` — Engine cooling temperature
`scalar`

Engine cooling temperature, $T_{coolant}$, in K.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intk` — Intake port pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the upstream:

- `Prs` — Pressure, in Pa
- `Temp` — Temperature, in K
- `Enth` — Specific enthalpy, in J/kg
- `MassFrac` — Intake port mass fractions, dimensionless. Exhaust gas recirculation (EGR) mass flow at the intake port is burned gas.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Exh — Exhaust port pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the exhaust:

- `Prs` — Pressure, in Pa

- `Temp` — Temperature, in K
- `Enth` — Specific enthalpy, in J/kg
- `MassFrac` — Exhaust port mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Variable	Units
`IntkGasMassFlw`	Engine intake air mass flow.	$\dot{m}_{air}$	kg/s
`IntkAirMassFlw`	Engine intake port mass flow.	$\dot{m}_{intk}$	kg/s
`NrmlzdAirChrg`	Engine load (that is, normalized cylinder air mass) corrected for final steady-state cam phase angles	L	N/A
`Afr`	Air-fuel ratio at engine exhaust port	AFR	N/A
`FuelMassFlw`	Fuel flow into engine	$\dot{m}_{fuel}$	kg/s
`FuelVolFlw`	Volumetric fuel flow	Q_{fuel}	m^3/s
`ExhManGasTemp`	Exhaust gas temperature at exhaust manifold inlet	T_{exh}	K
`EngTrq`	Engine brake torque	T_{brake}	N·m
`EngSpd`	Engine speed	N	rpm

Signal			Description	Variable	Units
`IntkCamPhase`			Intake cam phaser angle	φ_{ICP} i	degrees crank advance
`ExhCamPhase`			Exhaust cam phaser angle	φ_{ECP}	degrees crank retard
`CrkAng`			Engine crankshaft absolute angle	$\int_0^{(360)Cps} EngSpd \frac{180}{30} d\theta$ where Cps is crankshaft revolutions per power stroke	degrees crank angle
`EgrPct`			EGR percent	EGR_{pct}	N/A
`EoAir`			EO air mass flow rate	$\dot{m}_{exh}$	kg/s
`EoBrndGas`			EO burned gas mass flow rate	$y_{exh,b}$	kg/s
`EoHC`			EO hydrocarbon emission mass flow rate	$y_{exh,HC}$	kg/s
`EoCO`			EO carbon monoxide emission mass flow rate	$y_{exh,CO}$	kg/s
`EoNOx`			EO nitric oxide and nitrogen dioxide emissions mass flow rate	$y_{exh,NOx}$	kg/s
`EoCO2`			EO carbon dioxide emission mass flow rate	$y_{exh,CO2}$	kg/s
`EoPm`			EO particulate matter emission mass flow rate	$y_{exh,PM}$	kg/s
`PwrInfo`	`PwrTrnsfrd`	`PwrIntkHeatFlw`	Intake heat flow	$\dot{m}_{intk} h_{intk}$	W
		`PwrExhHeatFlw`	Exhaust heat flow	$-\dot{m}_{exh} h_{exh}$	W
		`PwrCrkshft`	Crankshaft power	$-T_{brake}\omega$	W
	`PwrNotTrnsfrd`	`PwrFuel`	Fuel input power	$\dot{m}_{fuel} LHV$	W
		`PwrLoss`	For **Torque model** set to `Simple Torque Lookup`: All losses	$T_{brake}\omega - \dot{m}_{fuel} LHV - \dot{m}_{intk} h_{intk} + \dot{m}_{exh} h_{exh}$	W
		`PwrFricLoss`	For **Torque model** set to `Torque Structure`: Friction loss	$-T_{fric}\omega$	W

Signal			Description	Variable	Units
		PwrPumpLoss	For **Torque model** set to `Torque Structure`: Pumping loss	$-T_{pump}\omega$	W
		PwrHeatTrnsfrLoss	For **Torque model** set to `Torque Structure`: Heat transfer loss	$T_{brake}\omega - \dot{m}_{fuel}LHV - \dot{m}_{intk}h_{intk} + \dot{m}_{exh}h_{exh} + T_{fric}\omega + T_{pump}\omega$	W
	PwrStored	*Not used*			

`EngTrq` — Engine brake torque
`scalar`

Engine brake torque, T_{brake}, in N·m.

`Intk` — Intake port mass flow rate, heat flow rate, temperature, mass fraction
two-way connector port

Bus containing:

- `MassFlwRate` — Intake port mass flow rate, in kg/s
- `HeatFlwRate` — Intake port heat flow rate, in J/s
- `ExhManGasTemp` — Intake port temperature, in K
- `MassFrac` — Intake port mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

`Exh` — Exhaust port mass flow rate, heat flow rate, temperature, mass fraction
two-way connector port

Bus containing:

- `MassFlwRate` — Exhaust port mass flow rate, in kg/s

- `HeatFlwRate` — Exhaust heat flow rate, in J/s
- `ExhManGasTemp` — Exhaust port temperature, in K
- `MassFrac` — Exhaust port mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Parameters

Block Options

`Torque model` — Select torque model
`Torque Structure` (default) | `Simple Torque Lookup`

To calculate the engine torque, you can configure the block to use either of these torque models.

Brake Torque Model	Description
"CI Engine Torque Structure Model"	The CI core engine torque structure model determines the engine torque by reducing the maximum engine torque potential as these engine conditions vary from nominal: • Start of injection (SOI) timing • Exhaust back-pressure • Burned fuel mass • Intake manifold gas pressure, temperature, and oxygen percentage • Fuel rail pressure To account for the effect of post-inject fuel on torque, the model uses a calibrated torque offset table.
"CI Engine Simple Torque Model"	For the simple engine torque calculation, the CI engine uses a torque lookup table map that is a function of engine speed and injected fuel mass.

Air

`Number of cylinders, NCyl` — Engine cylinders
4 (default) | `scalar`

Number of engine cylinders, N_{cyl}.

`Air standard temperature, Pstd` — Temperature
`293.15` (default) | `scalar`

Standard air temperature, T_{std}, in K.

`Crank revolutions per power stroke, Cps` — Revolutions per stroke
2 (default) | `scalar`

Crankshaft revolutions per power stroke, Cps, in rev/stroke.

`Total displaced volume, Vd` — Volume
`0.0015` (default) | `scalar`

Displaced volume, V_d, in m^3.

`Ideal gas constant air, Rair` — Constant
`287.05` (default) | `scalar`

Ideal gas constant, R_{air}, in J/(kg·K).

`Air standard pressure, Pstd` — Pressure
`101325` (default) | `scalar`

Standard air pressure, P_{std}, in Pa.

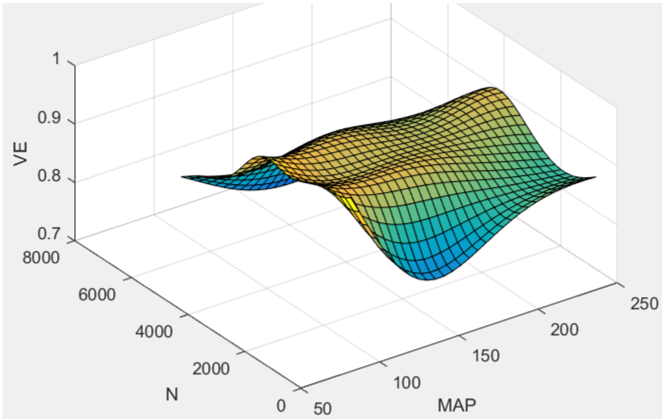
`Speed-density volumetric efficiency, f_nv` — Lookup table
`array`

The volumetric efficiency lookup table is a function of the intake manifold absolute pressure at intake valve closing (IVC) and engine speed

$$\eta_v = f_{\eta_v}(MAP, N)$$

where:

- η_v is engine volumetric efficiency, dimensionless.
- MAP is intake manifold absolute pressure, in KPa.
- N is engine speed, in rpm.



`Speed-density intake manifold pressure breakpoints, f_nv_prs_bpt` — Breakpoints
`vector`

Intake manifold pressure breakpoints for speed-density volumetric efficiency lookup table, in KPa.

`Speed-density engine speed breakpoints, f_nv_n_bpt` — Breakpoints
`vector`

Engine speed breakpoints for speed-density volumetric efficiency lookup table, in rpm.

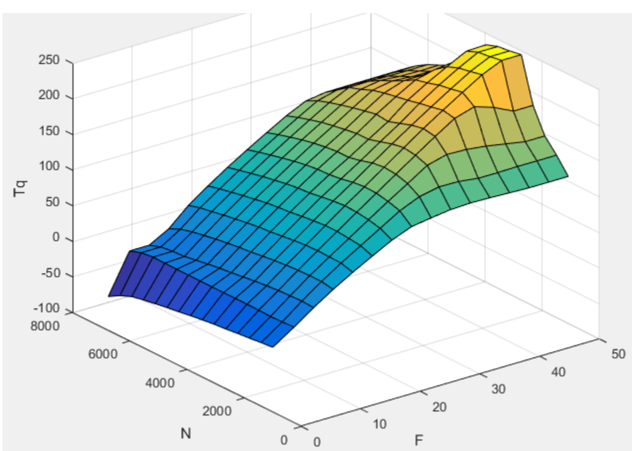
Torque

Torque - Simple Torque Lookup

`Torque table, f_tq_nf` — Lookup table
`array`

For the simple torque lookup table model, the CI engine uses a lookup table is a function of engine speed and injected fuel mass, $T_{brake} = f_{Tnf}(F, N)$, where:

- $Tq = T_{brake}$ is engine brake torque after accounting for engine mechanical and pumping friction effects, in N·m.
- F is injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

`Torque table fuel mass per injection breakpoints, f_tq_nf_f_bpt` — Breakpoints

`[0 3.5714 7.1429 10.7143 14.2857 17.8571 21.4286 25 28.5714 32.1429 35.7143 39.2857 42.8571 46.4286 50]` (default) | `vector`

Torque table fuel mass per injection breakpoints, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

`Torque table speed breakpoints, f_tq_nf_n_bpt` — Breakpoints

`[1000 1410.7143 1821.4286 2232.1429 2642.8571 3053.5714 3464.2857 3875 4285.7143 4696.4286 5107.1429 5517.8571 5928.5714 6339.2857 6750]` (default) | `vector`

Engine speed breakpoints, in rpm.

Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

Torque - Torque Structure

`Fuel mass per injection breakpoints, f_tqs_f_bpt` — Breakpoints

`vector`

Fuel mass per injection breakpoints, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Engine speed breakpoints, f_tqs_n_bpt` — Breakpoints

`[500 750 1000 1250 1500 1750 2000 2250 2500 2750 3000 3250 3500 3750 4000]` (default) | `vector`

Engine speed breakpoints, in rpm.

Dependencies

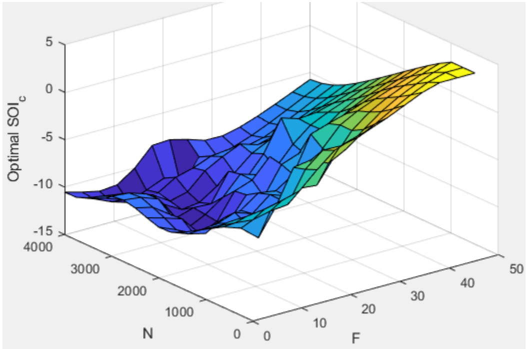
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal main start of injection timing, f_tqs_mainsoi` — Optimal MAINSOI

`array`

The optimal main start of injection (SOI) timing lookup table, f_{SOIc}, is a function of the engine speed and injected fuel mass, $SOI_c = f_{SOIc}(F,N)$, where:

- SOI_c is optimal SOI timing, in degATDC.
- F is compression stroke injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

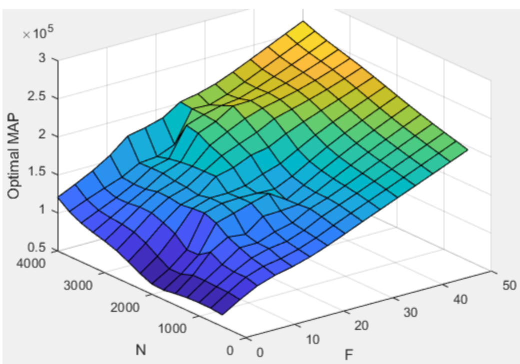
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal intake manifold gas pressure, f_tqs_map` — Optimal intake MAP

array

The optimal intake manifold gas pressure lookup table, f_{MAP}, is a function of the engine speed and injected fuel mass, $MAP = f_{MAP}(F,N)$, where:

- *MAP* is optimal intake manifold gas pressure, in Pa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

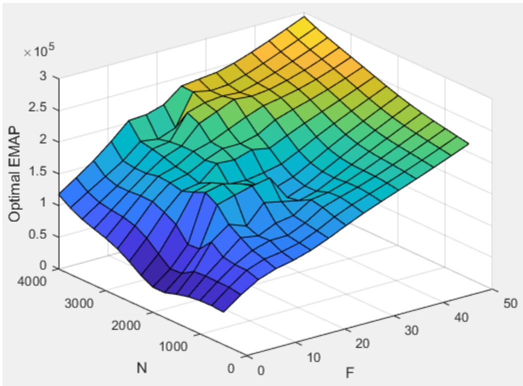
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal exhaust manifold gas pressure, f_tqs_emap` — Optimal exhaust MAP

array

The optimal exhaust manifold gas pressure lookup table, f_{EMAP}, is a function of the engine speed and injected fuel mass, $EMAP = f_{EMAP}(F,N)$, where:

- *EMAP* is optimal exhaust manifold gas pressure, in Pa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

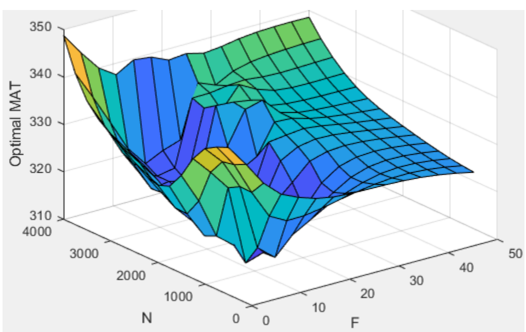
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal intake manifold gas temperature, f_tqs_mat` — Optimal intake MAT

`array`

The optimal intake manifold gas temperature lookup table, f_{MAT}, is a function of the engine speed and injected fuel mass, $MAT = f_{MAT}(F,N)$, where:

- *MAT* is optimal intake manifold gas temperature, in K.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

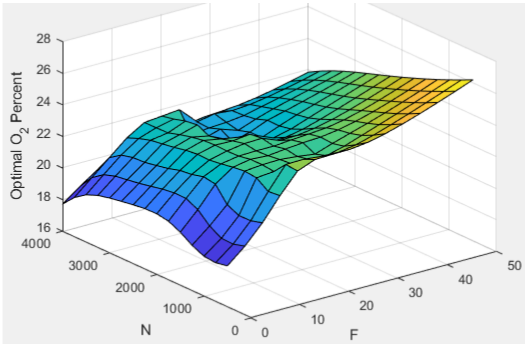
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal intake gas oxygen percent, f_tqs_o2pct` — Optimal intake gas oxygen

`array`

The optimal intake gas oxygen percent lookup table, f_{O2}, is a function of the engine speed and injected fuel mass, $O2PCT = f_{O2}(F,N)$, where:

- *O2PCT* is optimal intake gas oxygen, in percent.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



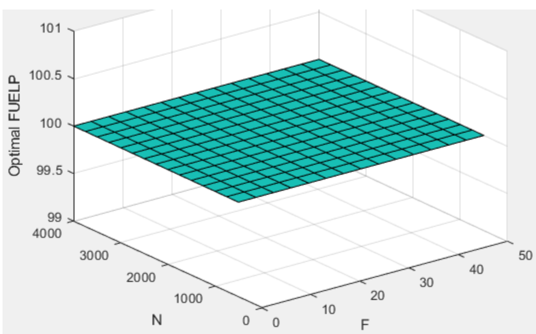
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal fuel rail pressure, f_tqs_fuelpress` — Optimal fuel rail pressure
array

The optimal fuel rail pressure lookup table, f_{fuelp}, is a function of the engine speed and injected fuel mass, $FUELP = f_{fuelp}(F,N)$, where:

- *FUELP* is optimal fuel rail pressure, in MPa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



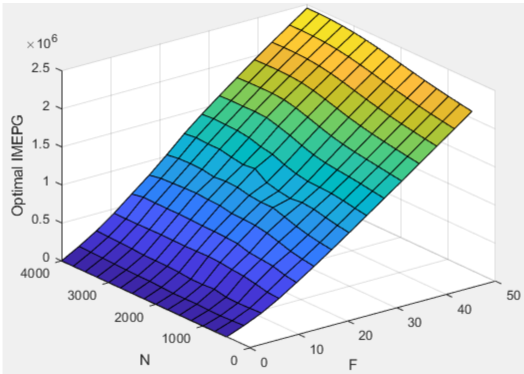
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal gross indicated mean effective pressure, f_tqs_imepg` — Optimal mean effective pressure
array

The optimal gross indicated mean effective pressure lookup table, f_{imepg}, is a function of the engine speed and injected fuel mass, $IMEPG = f_{imepg}(F,N)$, where:

- *IMEPG* is optimal gross indicated mean effective pressure, in Pa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

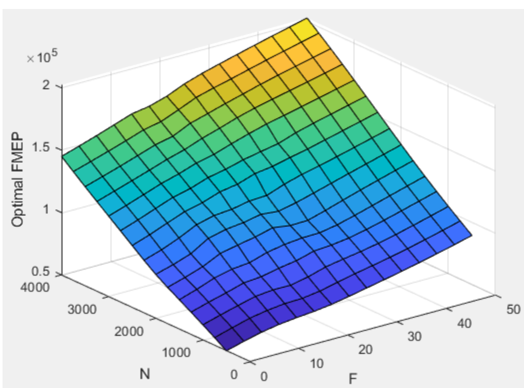
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Optimal friction mean effective pressure, f_tqs_fmep` — Optimal friction mean effective pressure

`array`

The optimal friction mean effective pressure lookup table, f_{fmep}, is a function of the engine speed and injected fuel mass, $FMEP = f_{fmep}(F,N)$, where:

- *FMEP* is optimal friction mean effective pressure, in Pa.
- *F* is compression stroke injected fuel mass, in mg per injection.
- *N* is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

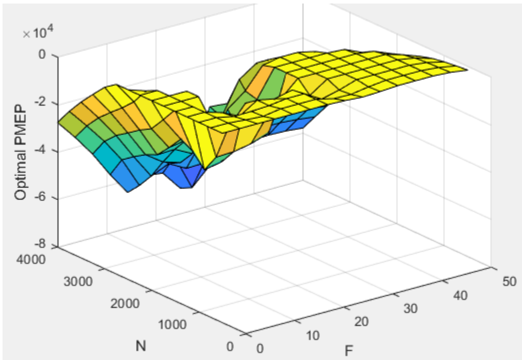
`Optimal pumping mean effective pressure, f_tqs_pmep` — Optimal pumping mean effective pressure

`array`

The optimal pumping mean effective pressure lookup table, f_{pmep}, is a function of the engine speed and injected fuel mass, $PMEP = f_{pmep}(F,N)$, where:

- *PMEP* is optimal pumping mean effective pressure, in Pa.

- F is compression stroke injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Friction multiplier as a function of temperature, f_tqs_fric_temp_mod` — Friction multiplier
`array`

Friction multiplier as a function of temperature, dimensionless.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Friction multiplier temperature breakpoints, f_tqs_fric_temp_bpt` — Breakpoints
`vector`

Friction multiplier temperature breakpoints, in K.

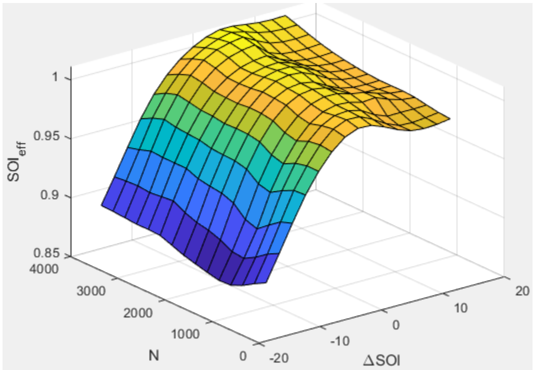
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Main start of injection timing efficiency multiplier, f_tqs_mainsoi_eff` — MAINSOI efficiency multiplier
`array`

The main start of injection (SOI) timing efficiency multiplier lookup table, f_{SOIeff}, is a function of the engine speed and main SOI timing relative to optimal timing, $SOI_{eff} = f_{SOIeff}(\Delta SOI,N)$, where:

- SOI_{eff} is main SOI timing efficiency multiplier, dimensionless.
- ΔSOI is main SOI timing relative to optimal timing, in degBTDC.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Main start of injection timing relative to optimal timing breakpoints, f_tqs_mainsoi_delta_bpt` — Breakpoints
`vector`

Main start of injection timing relative to optimal timing breakpoints, in degBTDC.

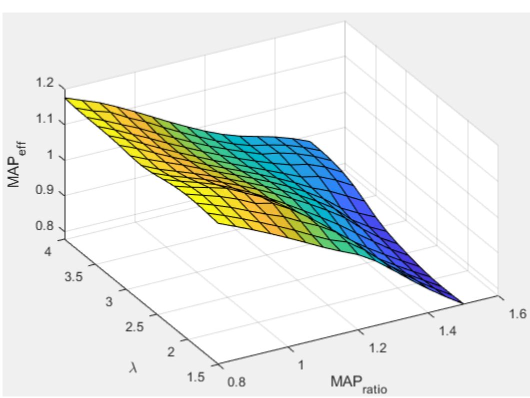
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas pressure efficiency multiplier, f_tqs_map_eff` — Intake pressure efficiency multiplier
`array`

The intake manifold gas pressure efficiency multiplier lookup table, f_{MAPeff}, is a function of the intake manifold gas pressure ratio relative to optimal pressure ratio and lambda, $MAP_{eff} = f_{MAPeff}(MAP_{ratio},\lambda)$, where:

- MAP_{eff} is intake manifold gas pressure efficiency multiplier, dimensionless.
- MAP_{ratio} is intake manifold gas pressure ratio relative to optimal pressure ratio, dimensionless.
- λ is intake manifold gas lambda, dimensionless.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas pressure ratio relative to optimal pressure ratio breakpoints, f_tqs_map_ratio_bpt — Breakpoints
[0.8;0.85;0.9;0.95;1;1.05;1.1;1.15;1.2;1.25;1.3;1.35;1.4;1.45;1.5] (default) | vector

Intake manifold gas pressure ratio relative to optimal pressure ratio breakpoints, dimensionless.

Dependencies

To enable this parameter, for **Torque model**, select Torque Structure.

Intake manifold gas lambda breakpoints, f_tqs_lambda_bpt — Breakpoints
[1.5 1.678571428571429 1.857142857142857 2.035714285714286 2.214285714285714 2.392857142857143 2.571428571428571 2.75 2.928571428571429 3.107142857142857 3.285714285714286 3.464285714285714 3.642857142857143 3.821428571428572 4] (default) | vector

Intake manifold gas lambda breakpoints, dimensionless.

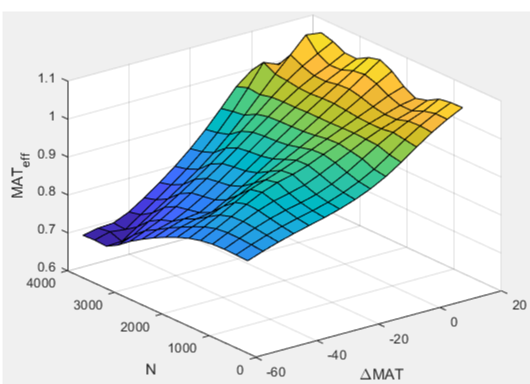
Dependencies

To enable this parameter, for **Torque model**, select Torque Structure.

Intake manifold gas temperature efficiency multiplier, f_tqs_mat_eff — Intake temperature efficiency multiplier
array

The intake manifold gas temperature efficiency multiplier lookup table, f_{MATeff}, is a function of the engine speed and intake manifold gas temperature relative to optimal temperature, $MAT_{eff} = f_{MATeff}(\Delta MAT,N)$, where:

- MAT_{eff} is intake manifold gas temperature efficiency multiplier, dimensionless.
- ΔMAT is intake manifold gas temperature relative to optimal temperature, in K.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select Torque Structure.

Intake manifold gas temperature relative to optimal gas temperature breakpoints, f_tqs_mat_delta_bpt — Breakpoints
[-55;-50;-45;-40;-35;-30;-25;-20;-15;-10;-5;0;5;10;15] (default) | vector

Intake manifold gas temperature relative to optimal gas temperature breakpoints, in K.

Dependencies

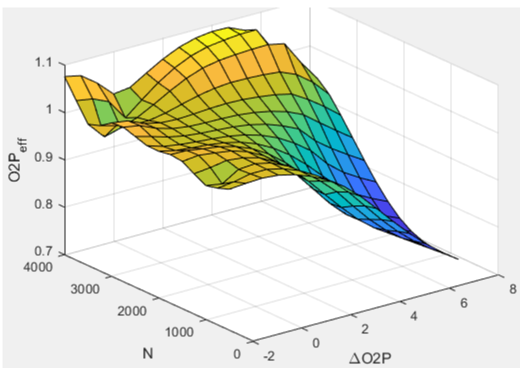
To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas oxygen efficiency multiplier, f_tqs_o2pct_eff — Intake oxygen efficiency multiplier

array

The intake manifold gas oxygen efficiency multiplier lookup table, f_{O2Peff}, is a function of the engine speed and intake manifold gas oxygen percent relative to optimal, $O2P_{eff} = f_{O2Peff}(\Delta O2P,N)$, where:

- $O2P_{eff}$ is intake manifold gas oxygen efficiency multiplier, dimensionless.
- $\Delta O2P$ is intake gas oxygen percent relative to optimal, in percent.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake gas oxygen percent relative to optimal breakpoints, f_tqs_o2pct_delta_bpt — Breakpoints

vector

Intake gas oxygen percent relative to optimal breakpoints, in percent.

Dependencies

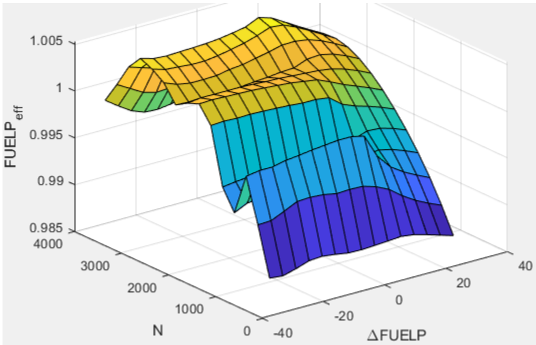
To enable this parameter, for **Torque model**, select `Torque Structure`.

Fuel rail pressure efficiency multiplier, f_tqs_fuelpress_eff — Efficiency multiplier

array

The fuel rail pressure efficiency multiplier lookup table, $f_{FUELPeff}$, is a function of the engine speed and fuel rail pressure relative to optimal breakpoints, $FUELP_{eff} = f_{FUELPeff}(\Delta FUELP,N)$, where:

- $FUELP_{eff}$ is fuel rail pressure efficiency multiplier, dimensionless.
- $\Delta FUELP$ is fuel rail pressure relative to optimal, in MPa.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Fuel rail pressure relative to optimal breakpoints, f_tqs_fuelpress_delta_bpt` — Breakpoints
`vector`

Fuel rail pressure relative to optimal breakpoints, in MPa.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Fuel mass injection type identifier, f_tqs_f_inj_type` — Type identifier
`0` (default) | `scalar`

Fuel mass injection type identifier, dimensionless.

In the CI Core Engine and CI Controller blocks, you can represent multiple injections with the start of injection (SOI) and fuel mass inputs to the model. To specify the type of injection, use the **Fuel mass injection type identifier** parameter.

Type of Injection	Parameter Value
Pilot	`0`
Main	`1`
Post	`2`
Passed	`3`

The model considers `Passed` fuel injections and fuel injected later than a threshold to be unburned fuel. Use the **Maximum start of injection angle for burned fuel, f_tqs_f_burned_soi_limit** parameter to specify the threshold.

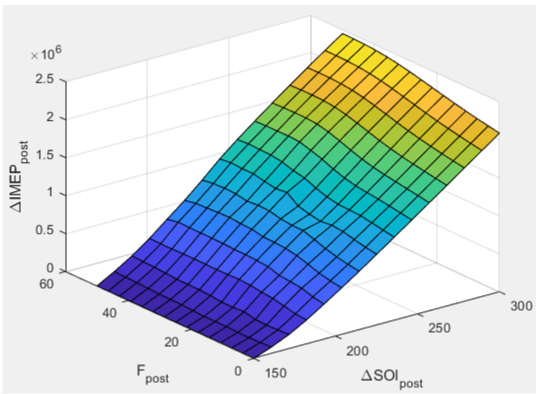
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Indicated mean effective pressure post inject correction, f_tqs_imep_post_corr` — Post inject correction
`array`

The indicated mean effective pressure post inject correction lookup table, $f_{IMEPpost}$, is a function of the engine speed and fuel rail pressure relative to optimal breakpoints, $\Delta IMEP_{post} = f_{IMEPpost}(\Delta SOI_{post},F_{post})$, where:

- $\Delta IMEP_{post}$ is indicated mean effective pressure post inject correction, in Pa.
- ΔSOI_{post} is indicated mean effective pressure post inject start of inject timing centroid, in degATDC.
- F_{post} is indicated mean effective pressure post inject mass sum, in mg per injection.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Indicated mean effective pressure post inject mass sum breakpoints, f_tqs_f_post_sum_bpt — Breakpoints

`[0 3.571428571428572 7.142857142857143 10.71428571428571 14.28571428571429 17.85714285714286 21.42857142857143 25 28.57142857142857 32.14285714285715 35.71428571428572 39.28571428571428 42.85714285714285 46.42857142857143 50]` (default) | `vector`

Indicated mean effective pressure post inject mass sum breakpoints, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Indicated mean effective pressure post inject start of inject timing centroid breakpoints, f_tqs_soi_post_cent_bpt — Breakpoints

`[150 160.7142857142857 171.4285714285714 182.1428571428571 192.8571428571429 203.5714285714286 214.2857142857143 225 235.7142857142857 246.4285714285714 257.1428571428571 267.8571428571429 278.5714285714286 289.2857142857143 300]` (default) | `vector`

Indicated mean effective pressure post inject start of inject timing centroid breakpoints, in degATDC.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Maximum start of injection angle for burned fuel, f_tqs_f_burned_soi_limit — Maximum SOI angle for burned fuel

`500` (default) | `scalar`

Maximum start of injection angle for burned fuel, in degATDC.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Exhaust

Exhaust Temperature - Simple Torque Lookup

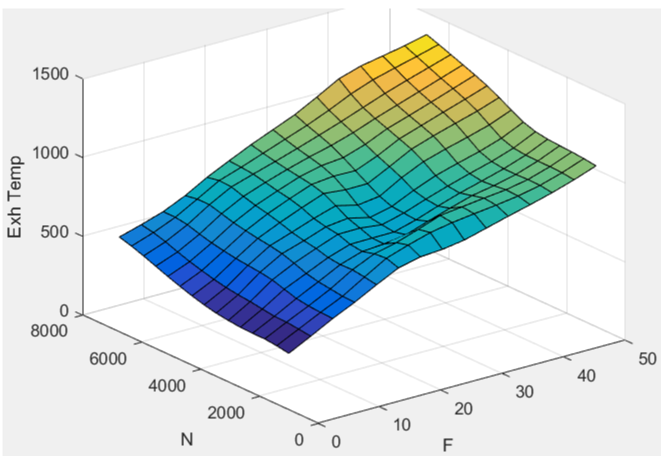
`Exhaust temperature table, f_t_exh` — Lookup table
`array`

The lookup table for the exhaust temperature is a function of injected fuel mass and engine speed

$$T_{exh} = f_{Texh}(F, N)$$

where:

- T_{exh} is exhaust temperature, in K.
- F is injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

`Fuel mass per injection breakpoints, f_t_exh_f_bpt` — Breakpoints
`[0 3.5714 7.1429 10.7143 14.2857 17.8571 21.4286 25 28.5714 32.1429 35.7143 39.2857 42.8571 46.4286 50]` (default) | `array`

Engine load breakpoints used for exhaust temperature lookup table, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

`Speed breakpoints, f_t_exh_n_bpt` — Breakpoints
`[1000 1410.7143 1821.4286 2232.1429 2642.8571 3053.5714 3464.2857 3875 4285.7143 4696.4286 5107.1429 5517.8571 5928.5714 6339.2857 6750]` (default) | `array`

Engine speed breakpoints used for exhaust temperature lookup table, in rpm.

Dependencies

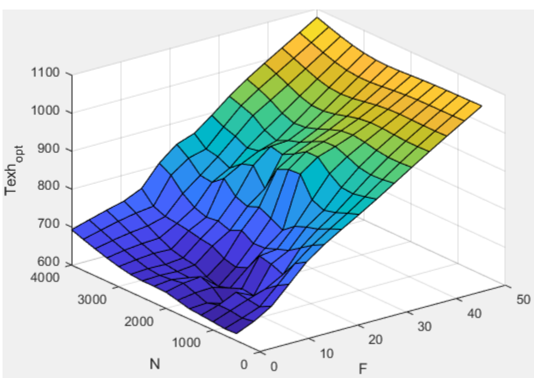
To enable this parameter, for **Torque model**, select `Simple Torque Lookup`.

Exhaust Temperature - Torque Structure

`Optimal exhaust manifold gas temperature, f_tqs_exht` — Optimal exhaust manifold gas temperature
`array`

The optimal exhaust manifold gas temperature lookup table, f_{Texh}, is a function of the engine speed engine speed and injected fuel mass, $Texh_{opt} = f_{Texh}(F,N)$, where:

- $Texh_{opt}$ is optimal exhaust manifold gas temperature, in K.
- F is compression stroke injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



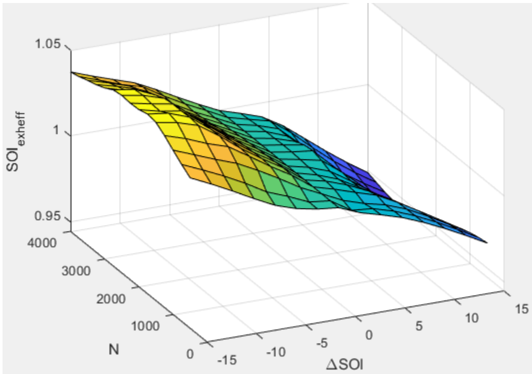
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Main start of injection timing exhaust temperature efficiency multiplier, f_tqs_exht_mainsoi_eff` — Main SOI timing efficiency multiplier
`array`

The main start of injection (SOI) timing exhaust temperature efficiency multiplier lookup table, $f_{SOIexhteff}$, is a function of the engine speed engine speed and injected fuel mass, $SOI_{exhteff} = f_{SOIexhteff}(\Delta SOI,N)$, where:

- $SOI_{exhteff}$ is main SOI exhaust temperature efficiency multiplier, dimensionless.
- ΔSOI is main SOI timing relative to optimal timing, in degBTDC.
- N is engine speed, in rpm.



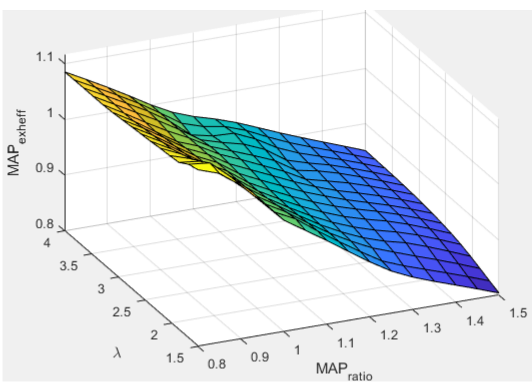
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas pressure exhaust temperature efficiency multiplier, f_tqs_exht_map_eff` — Intake manifold efficiency multiplier
`array`

The intake manifold gas pressure exhaust temperature efficiency multiplier lookup table, $f_{MAPexheff}$, is a function of the intake manifold gas pressure ratio relative to optimal pressure ratio and lambda, $MAP_{exheff} = f_{MAPexheff}(MAP_{ratio},\lambda)$, where:

- MAP_{exheff} is intake manifold gas pressure exhaust temperature efficiency multiplier, dimensionless.
- MAP_{ratio} is intake manifold gas pressure ratio relative to optimal pressure ratio, dimensionless.
- λ is intake manifold gas lambda, dimensionless.



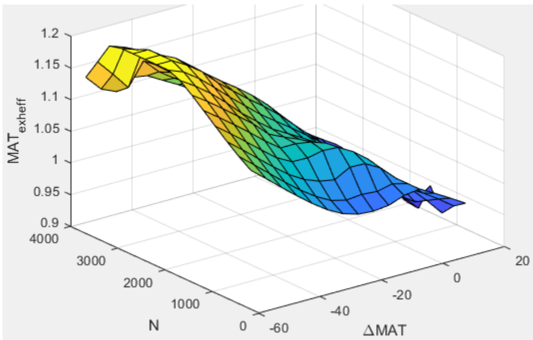
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas temperature exhaust temperature efficiency multiplier, f_tqs_exht_mat_eff` — Intake manifold efficiency multiplier
`array`

The intake manifold gas temperature exhaust temperature efficiency multiplier lookup table, $f_{MATexheff}$, is a function of the engine speed and intake manifold gas temperature relative to optimal temperature, $MAT_{exheff} = f_{MATexheff}(\Delta MAT,N)$, where:

- MAT_{exheff} is intake manifold gas temperature exhaust temperature efficiency multiplier, dimensionless.
- ΔMAT is intake manifold gas temperature relative to optimal temperature, in K.
- N is engine speed, in rpm.



Dependencies

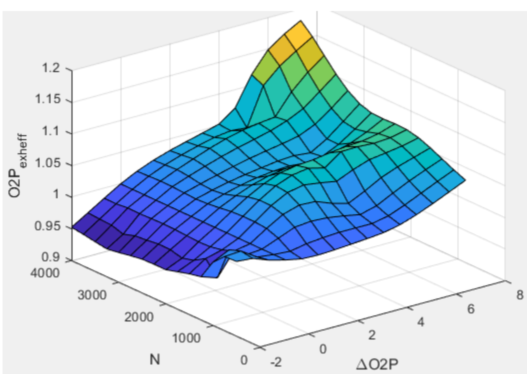
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas oxygen exhaust temperature efficiency multiplier, f_tqs_exht_o2pct_eff` — Intake manifold efficiency multiplier

`array`

The intake manifold gas oxygen exhaust temperature efficiency multiplier lookup table, $f_{O2Pexheff}$, is a function of the engine speed and intake manifold gas oxygen percent relative to optimal, $O2P_{exheff} = f_{O2Pexheff}(\Delta O2P, N)$, where:

- $O2P_{exheff}$ is intake manifold gas oxygen exhaust temperature efficiency multiplier, dimensionless.
- $\Delta O2P$ is intake gas oxygen percent relative to optimal, in percent.
- N is engine speed, in rpm.



Dependencies

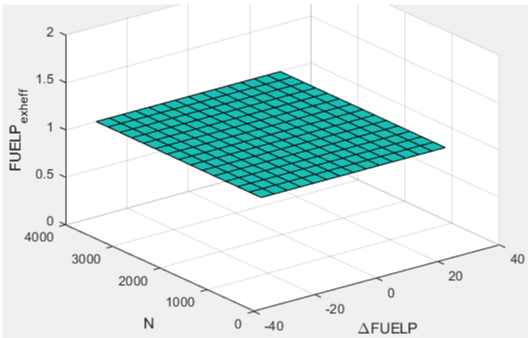
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Fuel rail pressure exhaust temperature efficiency multiplier, f_tqs_exht_fuelpress_eff` — Fuel rail pressure exhaust temperature efficiency multiplier

`array`

The fuel rail pressure efficiency exhaust temperature multiplier lookup table, $f_{FUELPexheff}$, is a function of the engine speed and fuel rail pressure relative to optimal breakpoints, $FUELP_{exheff} = f_{FUELPexheff}(\Delta FUELP, N)$, where:

- $FUELP_{exheff}$ is fuel rail pressure exhaust temperature efficiency multiplier, dimensionless.
- $\Delta FUELP$ is fuel rail pressure relative to optimal, in MPa.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Post-injection cylinder wall heat loss transfer coefficient, f_tqs_exht_post_inj_wall_htc` — Post-injection offset
`0` (default) | `scalar`

Post-injection cylinder wall heat loss transfer coefficient, in W/K.

Dependencies

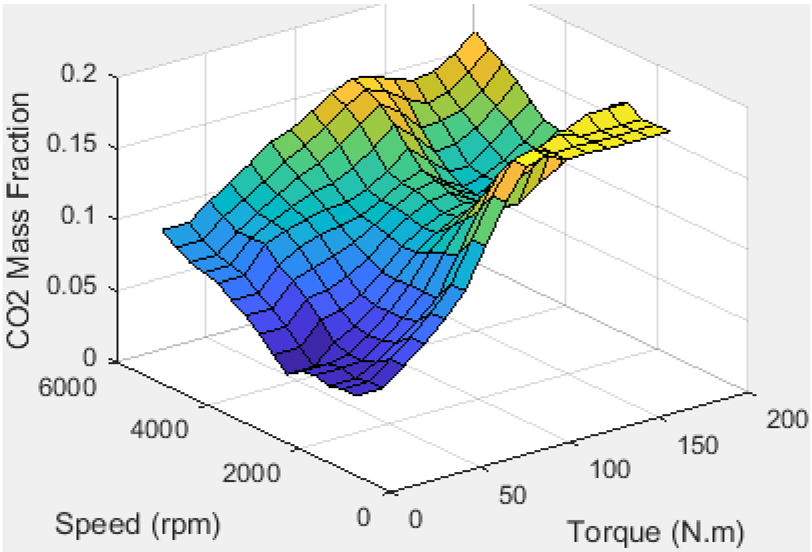
To enable this parameter, for **Torque model**, select `Torque Structure`.

Emissions

`CO2 mass fraction table, f_CO2_frac` — Carbon dioxide (CO_2) emission lookup table
`array`

The CI Core Engine CO_2 emission mass fraction lookup table is a function of engine torque and engine speed, *CO2 Mass Fraction* = ƒ(*Speed*, *Torque*), where:

- *CO2 Mass Fraction* is the CO_2 emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.



Dependencies

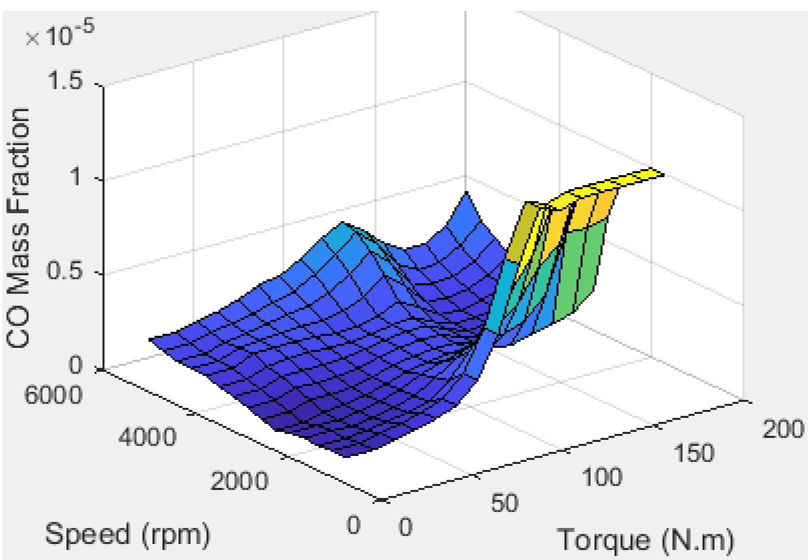
To enable this parameter, on the **Exhaust** tab, select **CO2**.

`CO mass fraction table, f_CO_frac` — Carbon monoxide (CO) emission lookup table

`array`

The CI Core Engine CO emission mass fraction lookup table is a function of engine torque and engine speed, *CO Mass Fraction* = f(*Speed*, *Torque*), where:

- *CO Mass Fraction* is the CO emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.



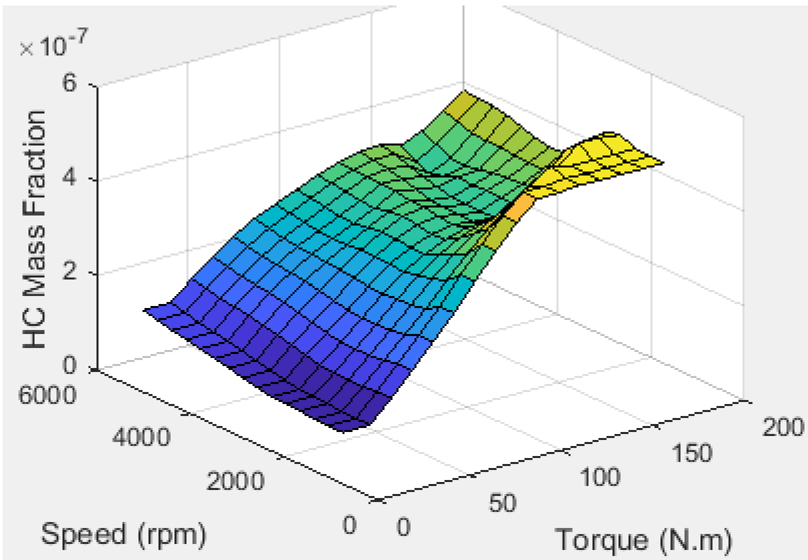
Dependencies

To enable this parameter, on the **Exhaust** tab, select **CO**.

`HC mass fraction table, f_HC_frac` — Hydrocarbon (HC) emission lookup table
`array`

The CI Core Engine HC emission mass fraction lookup table is a function of engine torque and engine speed, *HC Mass Fraction* = *f*(*Speed*, *Torque*), where:

- *HC Mass Fraction* is the HC emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.



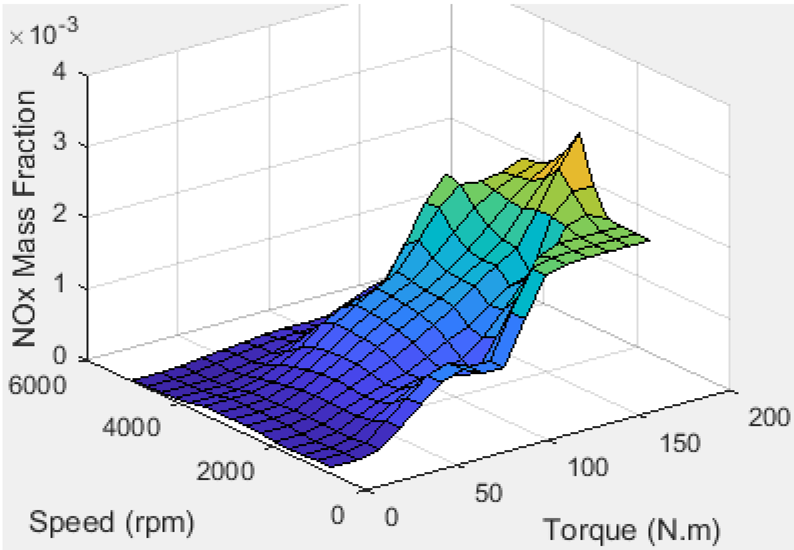
Dependencies

To enable this parameter, on the **Exhaust** tab, select **HC**.

`NOx mass fraction table, f_NOx_frac` — Nitric oxide and nitrogen dioxide (NOx) emission lookup table
`array`

The CI Core Engine NOx emission mass fraction lookup table is a function of engine torque and engine speed, *NOx Mass Fraction* = *f*(*Speed*, *Torque*), where:

- *NOx Mass Fraction* is the NOx emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.



Dependencies

To enable this parameter, on the **Exhaust** tab, select **NOx**.

PM mass fraction table, f_PM_frac — Particulate matter (PM) emission lookup table

array

The CI Core Engine PM emission mass fraction lookup table is a function of engine torque and engine speed where:

- *PM* is the PM emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.

Dependencies

To enable this parameter, on the **Exhaust** tab, select **PM**.

Engine speed breakpoints, f_exhfrac_n_bpt — Breakpoints

[750 1053.57142857143 1357.14285714286 1660.71428571429 1964.28571428571 2267.85714285714 2571.42857142857 2875 3178.57142857143 3482.14285714286 3785.71428571429 4089.28571428571 4392.85714285714 4696.42857142857 5000] (default) | vector

Engine speed breakpoints used for the emission mass fractions lookup tables, in rpm.

Dependencies

To enable this parameter, on the **Exhaust** tab, select **CO2**, **CO**, **NOx**, **HC**, or **PM**.

Engine torque breakpoints, f_exhfrac_trq_bpt — Breakpoints

[0 15 26.4285714285714 37.8571428571429 49.2857142857143 60.7142857142857 72.1428571428571 83.5714285714286 95 106.428571428571 117.857142857143 129.285714285714 140.714285714286 152.142857142857 163.571428571429 175] (default) | vector

Engine torque breakpoints used for the emission mass fractions lookup tables, in N·m.

Dependencies

To enable this parameter, on the **Exhaust** tab, select **CO2**, **CO**, **NOx**, **HC**, or **PM**.

`Exhaust gas specific heat at constant pressure, cp_exh` — Specific heat
`1005` (default) | `scalar`

Exhaust gas-specific heat, Cp_{exh}, in J/(kg·K).

Fuel

`Stoichiometric air-fuel ratio, afr_stoich` — Air-fuel ratio
`14.6` (default) | `scalar`

Air-fuel ratio, *AFR*.

`Fuel lower heating value, fuel_lhv` — Heating value
`42e6` (default) | `scalar`

Fuel lower heating value, *LHV*, in J/kg.

`Fuel specific gravity, fuel_sg` — Specific gravity
`0.832` (default) | `scalar`

Specific gravity of fuel, Sg_{fuel}, dimensionless.

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
CI Controller | Mapped CI Engine

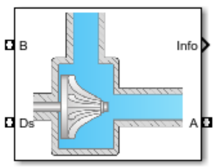
Topics
"CI Core Engine Air Mass Flow and Torque Production"
"Engine Calibration Maps"

Introduced in R2017a

Compressor

Compressor for boosted engines

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Boost

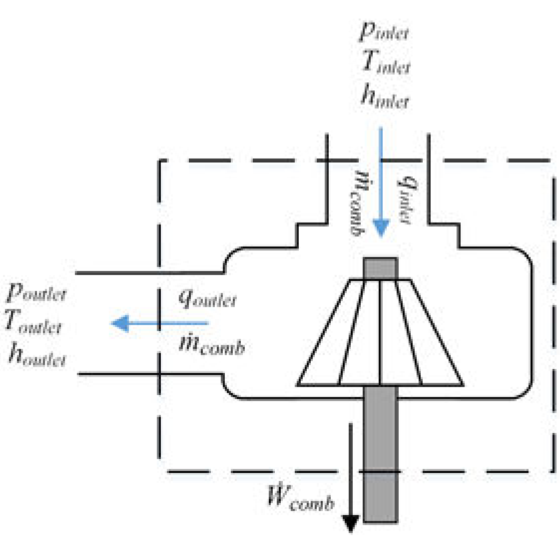


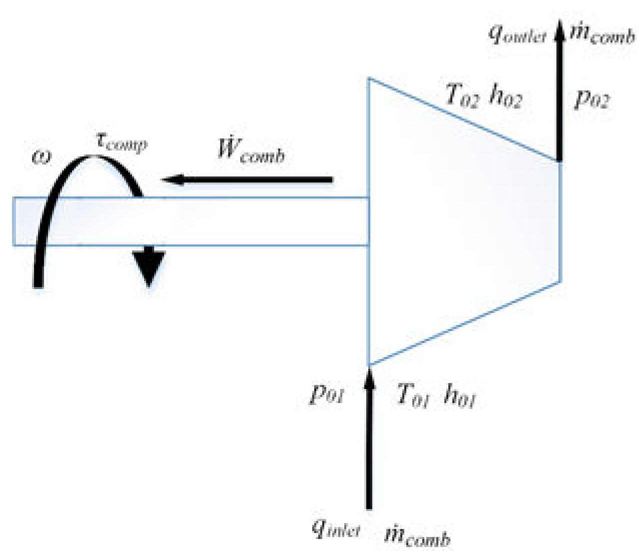
Description

The Compressor block simulates engine boost by using the drive shaft energy to increase the intake manifold pressure. The block is a component of supercharger and turbocharger models. The block uses two-way ports to connect to the inlet and outlet control volumes and the drive shaft. The control volumes provide the pressure, temperature, and specific enthalpy for the compressor to calculate the mass and energy flow rates. To calculate the torque and flow rates, the drive shaft provides the speed to the compressor. Typically, compressor manufacturers provide the mass flow rate and efficiency tables as a function of corrected speed and pressure ratio. You can specify the lookup tables to calculate the mass flow rate and efficiency. The block does not support reverse mass flow.

If you have Model-Based Calibration Toolbox, click **Calibrate Performance Maps** to virtually calibrate the mass flow rate and turbine efficiency lookup tables using measured data.

The mass flows from the inlet control volume to the outlet control volume.





Virtual Calibration

If you have Model-Based Calibration Toolbox, click **Calibrate Performance Maps** to virtually calibrate the mass flow rate and turbine efficiency lookup tables using measured data. The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import compressor data</td><td>Import this compressor data from a file. For more information, see “Using Data” (Model-Based Calibration Toolbox).
Speed, Spd, in rad/s
Mass flow rate, MassFlwRate, in kg/s
Pressure ratio, PrsRatio, dimensionless
Efficiency, Eff, dimensionless
The speed, mass flow rate, pressure ratio, and efficiency are in the 2nd-5th columns of the data file, respectively. The first and second rows of the data file provide the variable names and units. For example, use this format.
<table>
<tr><td>Name:</td><td>Spd</td><td>MassFlwRate</td><td>PrsRatio</td><td>Eff</td></tr>
<tr><td>Unit:</td><td>rad/s</td><td>kg/s</td><td></td><td></td></tr>
<tr><td>Data:</td><td>8373.3</td><td>0.02</td><td>1.21</td><td>0.44</td></tr>
<tr><td></td><td>...</td><td>...</td><td>...</td><td>...</td></tr>
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Model-Based Calibration Toolbox limits the speed and pressure ratio breakpoint values to the maximum values in the file.

To filter or edit the data, select Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
<tr><td>Generate response models</td><td>Model-Based Calibration Toolbox fits the imported data to the response models.
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<tr><th>Data</th><th>Response Model</th></tr>
<tr><td>Mass flow rate</td><td>Extended ellipse response model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
<tr><td>Efficiency</td><td>Polynomial</td></tr>
</table>
To assess or adjust the response model fit, select Edit in Application. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</td></tr>
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To assess or adjust the calibration, select Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</td></tr>
</table>

Task	Description
Update block parameters	Update these mass flow rate and efficiency parameters with the calibration. • **Corrected mass flow rate table, mdot_corr_tbl** • **Efficiency table, eta_comp_tbl** • **Corrected speed breakpoints, w_corr_bpts1** • **Pressure ratio breakpoints, Pr_bpts2**

Thermodynamics

The block uses these equations to model the thermodynamics.

Calculation	Equations
Forward mass flow	$\dot{m}_{comp} > 0$ $p_{01} = p_{inlet}$ $p_{02} = p_{outlet}$ $T_{01} = T_{inlet}$ $h_{01} = h_{inlet}$
First law of thermodynamics	$\dot{W}_{comp} = \dot{m}_{comp} c_p (T_{01} - T_{02})$
Isentropic efficiency	$\eta_{comp} = \frac{h_{02s} - h_{01}}{h_{02} - h_{01}} = \frac{T_{02s} - T_{01}}{T_{02} - T_{01}}$
Isentropic outlet temperature, assuming ideal gas and constant specific heats	$T_{02s} = T_{01} \left(\frac{p_{02}}{p_{01}} \right)^{\frac{\gamma - 1}{\gamma}}$
Specific heat ratio	$\gamma = \frac{c_p}{c_p - R}$
Outlet temperature	$T_{02} = T_{01} + \frac{T_{01}}{\eta_{comb}} \left\{ \left(\frac{p_{02}}{p_{01}} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right\}$
Heat flows	$q_{inlet} = \dot{m}_{comp} h_{01}$ $q_{outlet} = \dot{m}_{comp} h_{02} = \dot{m}_{comp} c_p T_{02}$
Corrected mass flow rate	$\dot{m}_{corr} = \dot{m}_{comp} \frac{\sqrt{T_{01}/T_{ref}}}{p_{01}/p_{ref}}$
Corrected speed	$\omega_{corr} = \frac{\omega}{\sqrt{T_{01}/T_{ref}}}$
Pressure ratio	$p_r = \frac{p_{01}}{p_{02}}$

The block uses the internal signal `FlwDir` to track the direction of the flow.

The equations use these variables.

p_{inlet}, p_{01}	Inlet control volume total pressure
T_{inlet}, T_{01}	Inlet control volume total temperature
h_{inlet}, h_{01}	Inlet control volume total specific enthalpy
p_{outlet}, p_{02}	Outlet control volume total pressure
T_{outlet}	Outlet control volume total temperature
h_{outlet}	Outlet control volume total specific enthalpy
$\dot{W}_{comp}$	Drive shaft power
T_{02}	Outlet total temperature
h_{02}	Outlet total specific enthalpy
$\dot{m}_{comp}$	Mass flow rate through compressor
q_{inlet}	Inlet heat flow rate
q_{outlet}	Outlet heat flow rate
η_{comp}	Compressor isentropic efficiency
T_{02s}	Isentropic outlet total temperature
h_{02s}	Isentropic outlet total specific enthalpy
R	Ideal gas constant
c_p	Specific heat at constant pressure
γ	Specific heat ratio
$\dot{m}_{corr}$	Corrected mass flow rate
ω	Drive shaft speed
ω_{corr}	Corrected drive shaft speed
T_{ref}	Lookup table reference temperature
P_{ref}	Lookup table reference pressure
τ_{comp}	Compressor drive shaft torque
p_r	Pressure ratio
$\eta_{comb,\,tbl}$	Compressor efficiency 3-D lookup table
$\dot{m}_{corr,\,tbl}$	Corrected mass flow rate 3-D lookup table
$\omega_{corr,\,bpts1}$	Corrected speed breakpoints
$p_{r,\,bpts2}$	Pressure ratio breakpoints

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrDriveshft	Power transmitted from the shaft	$-\dot{W}_{turb}$
		PwrHeatFlwIn	Heat flow rate at port A	q_{outlet}
		PwrHeatFlwOut	Heat flow rate at port B	q_{outlet}
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrLoss	Power loss	$-q_{inlet} - q_{outlet} + \dot{W}_{turb}$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	*Not used*		

The equations use these variables.

$\dot{W}_{turb}$	Drive shaft power
q_{outlet}	Total outlet heat flow rate
q_{inlet}	Total inlet heat flow rate

Ports

Input

Ds — Drive shaft speed
two-way connector port

ShftSpd — Signal containing the drive shaft angular speed, ω, in rad/s.

A — Inlet pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the inlet control volume:

- InPrs — Pressure, p_{inlet}, in Pa
- InTemp — Temperature, T_{inlet}, in K
- InEnth — Specific enthalpy, h_{inlet}, in J/kg

B — Outlet pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the outlet control volume:

- `OutPrs` — Pressure, p_{outlet}, in Pa
- `OutTemp` — Temperature, T_{outlet}, in K
- `OutEnth` — Specific enthalpy, h_{outlet}, in J/kg

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

<table>
<tr><th colspan="3">Signal</th><th>Description</th><th>Units</th></tr>
<tr><td colspan="3">CmprsOutletTemp</td><td>Temperature exiting the compressor</td><td>K</td></tr>
<tr><td colspan="3">DriveshftPwr</td><td>Drive shaft power</td><td>W</td></tr>
<tr><td colspan="3">DriveshftTrq</td><td>Drive shaft torque</td><td>N·m</td></tr>
<tr><td colspan="3">CmprsMassFlw</td><td>Mass flow rate through compressor</td><td>kg/s</td></tr>
<tr><td colspan="3">PrsRatio</td><td>Pressure ratio</td><td>N/A</td></tr>
<tr><td colspan="3">DriveshftCorrSpd</td><td>Corrected drive shaft speed</td><td>rad/s</td></tr>
<tr><td colspan="3">CmprsEff</td><td>Compressor isentropic efficiency</td><td>N/A</td></tr>
<tr><td colspan="3">CorrMassFlw</td><td>Corrected mass flow rate</td><td>kg/s</td></tr>
<tr><td rowspan="5">PwrInfo</td><td rowspan="3">PwrTrnsfrd</td><td>PwrDriveshft</td><td>Power transmitted from the shaft</td><td>W</td></tr>
<tr><td>PwrHeatFlwIn</td><td>Heat flow rate at port A</td><td>W</td></tr>
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<tr><td colspan="2">PwrStored</td><td>Not used</td><td>W</td></tr>
</table>

`Ds` — Drive shaft torque
two-way connector port

`Trq` — Signal containing the drive shaft torque, τ_{comp}, in N·m.

`A` — Inlet mass flow rate, heat flow rate, temperature, mass fractions
two-way connector port

Bus containing:

- `MassFlwRate` — Mass flow rate through inlet,$\dot{m}_{comp}$, in kg/s
- `HeatFlwRate` — Inlet heat flow rate, q_{inlet}, in J/s
- `Temp` — Inlet temperature, in K
- `MassFrac` — Inlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

- `O2MassFrac` — Oxygen
- `N2MassFrac` — Nitrogen
- `UnbrndFuelMassFrac` — Unburned fuel
- `CO2MassFrac` — Carbon dioxide
- `H2OMassFrac` — Water
- `COMassFrac` — Carbon monoxide
- `NOMassFrac` — Nitric oxide
- `NO2MassFrac` — Nitrogen dioxide
- `NOxMassFrac` — Nitric oxide and nitrogen dioxide
- `PmMassFrac` — Particulate matter
- `AirMassFrac` — Air
- `BrndGasMassFrac` — Burned gas

B — Outlet mass flow rate, heat flow rate, temperature, mass fractions
two-way connector port

Bus containing:

- `MassFlwRate` — Outlet mass flow rate, $\dot{m}_{comp}$, in kg/s
- `HeatFlwRate` — Outlet heat flow rate, q_{outlet}, in J/s
- `Temp` — Outlet temperature, in K
- `MassFrac` — Outlet mass fractions, dimensionless.

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Parameters

Performance Tables

`Calibrate Performance Maps` — Calibrate tables with measured data
`selection`

If you have Model-Based Calibration Toolbox, click **Calibrate Performance Maps** to virtually calibrate the mass flow rate and turbine efficiency lookup tables using measured data. The dialog box steps through these tasks.

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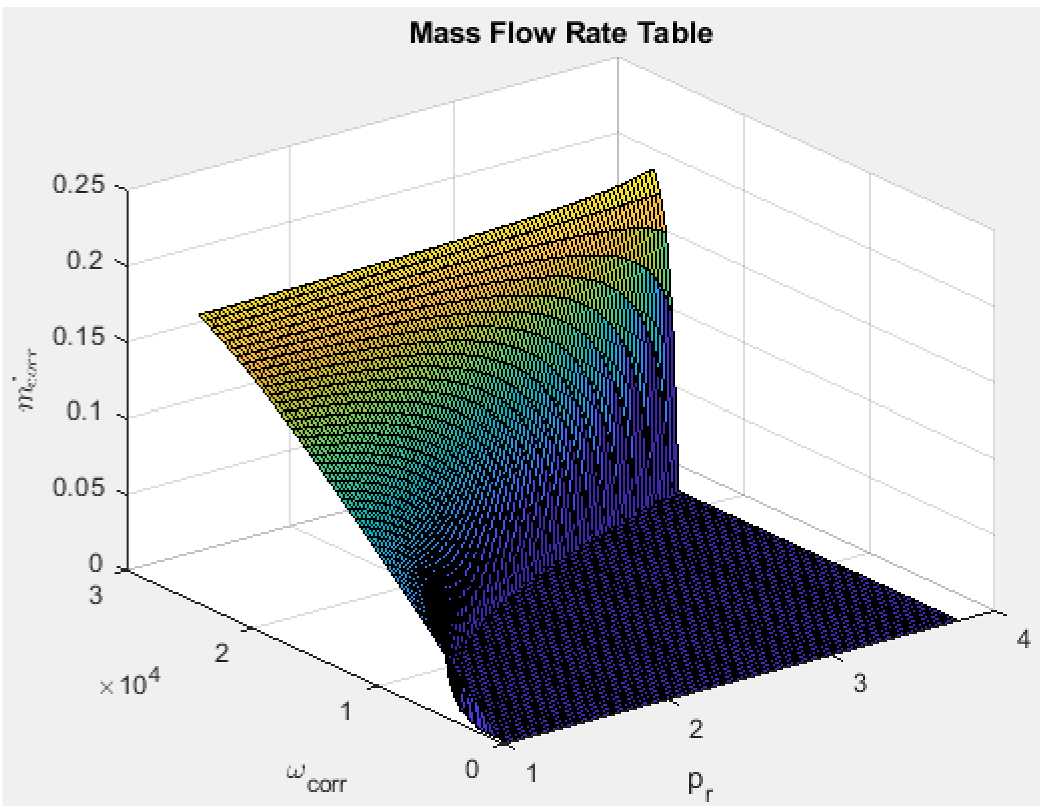
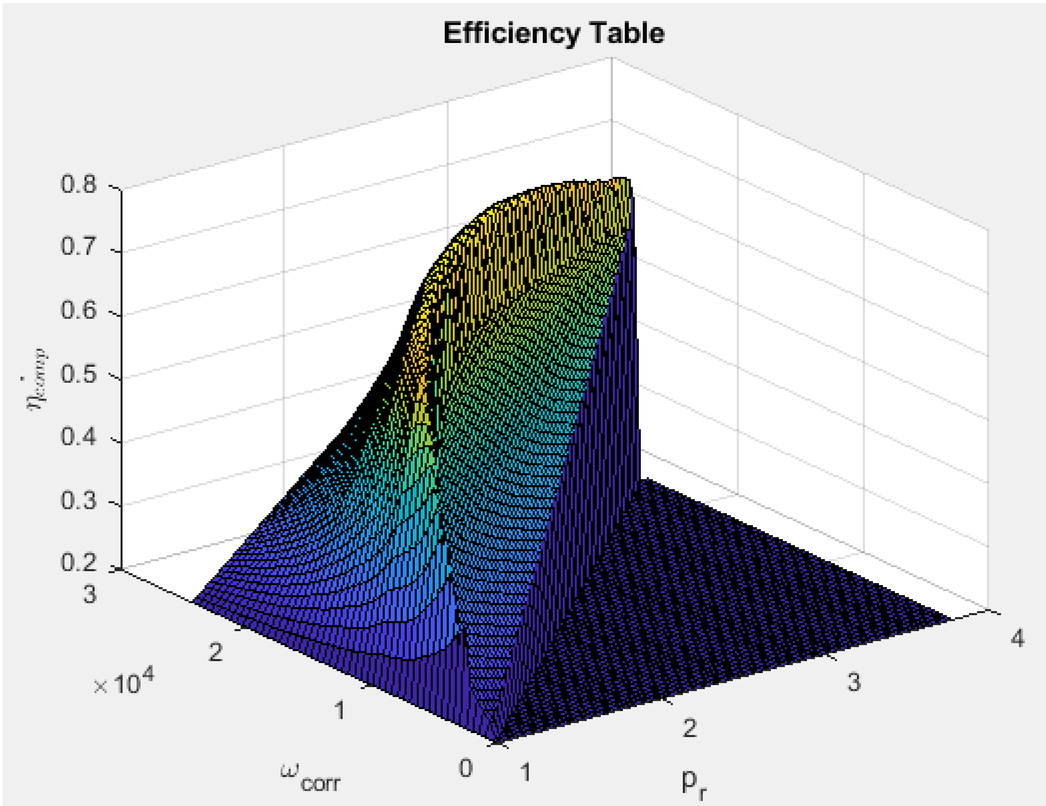
`Corrected mass flow rate table, mdot_corr_tbl` — Lookup table
`array`

Corrected mass flow rate lookup table, $\dot{m}_{corr,tbl}$, as a function of corrected driveshaft speed, ω_{corr}, and pressure ratio, p_r, in kg/s.



`Efficiency table, eta_comp_tbl` — Lookup table
`array`

Efficiency lookup table, $\eta_{comb,tbl}$, as a function of corrected driveshaft speed, ω_{corr}, and pressure ratio, p_r, dimensionless.



Corrected speed breakpoints, w_corr_bpts1 — Breakpoints
vector

Corrected drive shaft speed breakpoints, $\omega_{corr,\,bpts1}$, in rad/s.

Pressure ratio breakpoints, Pr_bpts2 — Breakpoints
vector

Pressure ratio breakpoints, $p_{r,\,bpts2}$.

Reference temperature, T_ref — Reference
293.15 (default) | scalar

Lookup table reference temperature, T_{ref}, in K.

Reference pressure, P_ref — Reference
101325 (default) | scalar

Lookup table reference pressure, P_{ref}, in Pa.

Gas Properties

Ideal gas constant, R — Constant
287 (default) | scalar

Ideal gas constant, R, in J/(kg*K).

`Specific heat at constant pressure, cp` — Specific heat
`1005` (default) | `scalar`

Specific heat at constant pressure, c_p, in J/(kg*K).

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

[2] Eriksson, Lars and Lars Nielsen. *Modeling and Control of Engines and Drivelines*. Chichester, West Sussex, United Kingdom: John Wiley & Sons Ltd, 2014.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Boost Drive Shaft | Turbine

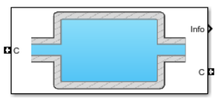
Topics
"Model-Based Calibration Toolbox"

Introduced in R2017a

Control Volume System

Constant volume open thermodynamic system with heat transfer

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Fundamental Flow



Description

The Control Volume System block models a constant volume open thermodynamic system with heat transfer. The block uses the conservation of mass and energy, assuming an ideal gas, to determine the pressure and temperature. The block implements an automotive-specific Constant Volume Pneumatic Chamber block that includes thermal effects related to the under hood of passenger vehicles. You can specify heat transfer models:

- Constant
- External input
- External wall convection

You can use the Control Volume System block to represent engine components that contain volume, including pipes and manifolds.

Thermodynamics

The Control Volume System block implements a constant volume chamber containing an ideal gas. To determine the rate changes in temperature and pressure, the block uses the continuity equation and the first law of thermodynamics.

$$\frac{dT_{vol}}{dt} = \frac{RT_{vol}}{c_v V_{ch} P_{vol}} \left(\sum (q_i - T_{vol} c_v \dot{m}_i) - Q_{wall} \right)$$

$$\frac{dP_{vol}}{dt} = \frac{P_{vol}}{T_{vol}} \frac{dT_{vol}}{dt} + \frac{RT_{vol}}{V_{ch}} \sum \dot{m}_i$$

The block uses this equation for the volume-specific enthalpy.

$$h_{vol} = c_p T_{vol}$$

The equations use these variables.

$\dot{m}_i$	Mass flow rate at port
q_i	Heat flow rate at port
V_{ch}	Chamber volume
P_{vol}	Absolute pressure in the chamber
R	Ideal gas constant
c_v	Specific heat at constant volume

T_{vol}	Absolute gas temperature
Q_{wall}	Wall heat transfer rate
h_{vol}	Volume-specific enthalpy
c_p	Specific heat capacity

Mass Fractions

The Control Volume Source block is part of a flow network. Blocks in the network determine the mass fractions that the block will track during simulation. The block can track these mass fractions:

- `O2` — Oxygen
- `N2` — Nitrogen
- `UnburnedFuel` — Unburned fuel
- `CO2` — Carbon dioxide
- `H2O` — Water
- `CO` — Carbon monoxide
- `NO` — Nitric oxide
- `NO2` — Nitrogen dioxide
- `PM` — Particulate matter
- `Air` — Air
- `BurnedGas` — Burned gas

Using the conservation of mass for each gas constituent, this equation determines the rate change:

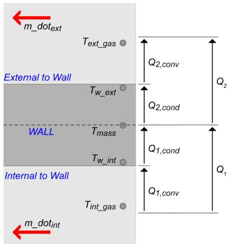
$$\frac{dy_{vol,j}}{dt} = \frac{RT_{vol}}{P_{vol}V_{ch}}\left(\sum \dot{m}_i y_{i,j} + y_{vol,j}\sum \dot{m}_i\right)$$

The equations use these variables.

V_{ch}	Chamber volume
P_{vol}	Absolute pressure in the chamber
R	Ideal gas constant
T_{vol}	Absolute gas temperature
$y_{i,j}$	I-th port mass fraction for j = O_2, N_2, unburned fuel, CO_2, H_2O, CO, NO, NO_2, PM, air, and burned gas
$y_{vol,j}$	Control volume mass fraction for j = O_2, N_2, unburned fuel, CO_2, H_2O, CO, NO, NO_2, PM, air, and burned gas
$\dot{m}_i$	Mass flow rate for i = O_2, N_2, unburned fuel, CO_2, H_2O, CO, NO, NO_2, PM, air, and burned gas

External Wall Convection Heat Transfer Model

To calculate the heat transfer, you can configure the Control Volume Source block to calculate the heat transfer across the wall of the control volume.



The block implements these equations to calculate the heat transfer, Q_1, from the internal control volume gas to the internal wall depth, D_{int_cond}.

$$Q_1 = Q_{1,conv} = Q_{1,cond}$$

$$Q_{1,conv} = h_{int}(x_{int}) \bullet A_{int\_conv} \bullet \left(T_{int\_gas} - T_{w\_int}\right)$$

$$Q_{1,cond} = k_{int} \bullet \frac{A_{int\_cond}}{D_{int\_cond}} \bullet \left(T_{w\_int} - T_{mass}\right)$$

The block implements these equations to calculate the heat transfer, Q_2, from the external wall depth, D_{ext_cond} to the external gas.

$$Q_2 = Q_{2,conv} = h_{ext}(x_{ext}) \bullet A_{ext\_conv} \bullet \left(T_{w\_ext} - T_{ext\_gas}\right)$$

$$Q_{2,cond} = k_{ext} \bullet \frac{A_{ext\_cond}}{D_{ext\_cond}} \bullet \left(T_{mass} - T_{w\_ext}\right)$$

This equation expresses the heat stored in the thermal mass.

$$\frac{dT_{mass}}{dt} = \frac{Q_1 - Q_2}{c_{p_{wall}} m_{wall}}$$

The block determines the interior convection heat transfer coefficient using a lookup table that is a function of the average mass flow rate.

$$\dot{m}_{int\_gas} = \frac{1}{2}\sum|\dot{m}_i|$$

The equations use these variables.

Q_1	Heat flow from the internal gas to a specified wall depth
$Q_{1,conv}$	Heat flow convection from the internal gas to the internal wall
$Q_{1,cond}$	Conduction heat transfer rate
Q_2	Heat transfer rate
$Q_{2,conv}$	Convection heat transfer
$Q_{2,cond}$	Heat flow conduction from the external middle portion of the wall to the external wall
Q_{mass}	Heat stored in thermal mass
h_{int}	Internal convection heat transfer coefficient
x_{int}	Internal mass flow rate breakpoints

A_{int_conv}	Internal flow convection area
T_{int_gas}	Temperature of the gas inside the chamber
T_{w_int}	Temperature of the inside wall of the chamber
k_{int}	Internal wall thermal conductivity
A_{int_cond}	Internal conduction area
D_{int_cond}	Internal wall thickness
h_{ext}	External convection heat transfer coefficient
x_{ext}	External velocity breakpoints
A_{ext_conv}	External convection area
T_{ext_gas}	External gas temperature
T_{w_ext}	Temperature of the external wall of the chamber
k_{ext}	External wall thermal conductivity
A_{ext_cond}	External conduction area
D_{ext_cond}	External wall thickness
T_{mass}	Temperature of the thermal mass
c_{p_wall}	Wall heat capacity
m_{wall}	Thermal mass
Flw_{spd}	External flow velocity
$\dot{m}_{int\_gas}$	Average internal mass flow rate

Power Accounting

For the power accounting, the block implements these equation based on the number of inlet and outlet ports.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrHeatFlwi`	Port *i* heat flow	q_i
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrHeatTrnsfr`	Heat transfer rate from wall to control volume	$-Q_{wall}$

Bus Signal			Description	Equations
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrHeatStored	Rate of heat stored in the control volume	$\left(\sum(q_i) - Q_{wall}\right)$

For example, if you configure your block with 3 input ports and 2 outlet ports, the block implements these equations

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrHeatFlw1	Inlet port 1 heat flow	q_1
		PwrHeatFlw2	Inlet port 2 heat flow	q_2
		PwrHeatFlw3	Inlet port 3 heat flow	q_3
		PwrHeatFlw4	Outlet port 4 heat flow	q_4
		PwrHeatFlw5	Outlet port 5 heat flow	q_5
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrHeatTrnsfr	Heat transfer rate from wall to control volume	$-Q_{wall}$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrHeatStored	Rate of heat stored in the control volume	$\left(\sum(q_i) - Q_{wall}\right)$

Ports

Input

C — Inlet mass flow rate, heat flow rate, mass fractions

two-way connector port

Bus containing:

- `MassFlw` — Mass flow rate through inlet, in kg/s
- `HeatFlw` — Inlet heat flow rate, in J/s

- `MassFrac` — Inlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Dependencies

To create input ports, specify the **Number of inlet ports** parameter.

`HeatTrnsfrRate` — Heat transfer
`scalar`

External heat transfer input to control volume, q_{he}, in Kg/s.

Dependencies

To create this port, select `External input` for the **Heat transfer model** parameter.

`ExtnlFlwVel` — External flow velocity
scalar

External flow velocity, Flw_{spd}, in m/s.

Dependencies

To create this port, select `External wall convection` for the **Heat transfer model** parameter.

`ExtnlTemp` — Ambient temperature, K
`scalar`

Dependencies

To create this port, select `External wall convection` for the **Heat transfer model** parameter.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
Vol	Prs		Volume pressure	Pa
	Temp		Volume temperature	K
	Enth		Volume specific enthalpy	J/kg
	Species	O2MassFrac	Oxygen mass fraction	NA
		N2MassFrac	Nitrogen mass fraction	NA
		UnbrndFuelMassFrac	Unburned gas mass fraction	NA
		CO2MassFrac	Carbon dioxide mass fraction	NA
		H2OMassFrac	Water mass fraction	NA
		COMassFrac	Carbon monoxide mass fraction	NA
		NOMassFrac	Nitric oxide mass fraction	NA
		NO2MassFrac	Nitrogen dioxide mass fraction	NA
		NOxMassFrac	Nitric oxide and nitrogen dioxide mass fraction	NA
		PmMassFrac	Particulate matter mass fraction	NA
		AirMassFrac	Air mass fraction	NA
		BrndGasMassFrac	Burned gas mass fraction	NA
HeatTrnsfr	HeatTrnsfrRate		Wall heat transfer rate	J/s
	MassFlw		Average internal mass flow rate	kg/s
	IntrnTemp		Temperature of gas inside chamber	K
PwrInfo	PwrTrnsfrd	PwrHeatFlw*i*	Port *i* heat flow	W
	PwrNotTrnsfrd	PwrHeatTrnsfr	Heat transfer rate from wall to control volume	W
	PwrStored	PwrHeatStored	Rate of heat stored in the control volume	W

C — Outlet pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the outlet control volume:

- `Prs` — Chamber pressure, in Pa
- `Temp` — Gas temperature, in K

- `Enth` — Specific enthalpy, in J/kg
- `MassFrac` — Mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Dependencies

To create outlet ports, specify the **Number of outlet ports** parameter.

Parameters

Block Options

`Number of inlet ports` — Number of ports
`1` (default) | `0` | `2` | `3` | `4`

Number of inlet ports.

Dependencies

To create inlet ports, specify the number.

`Number of outlet ports` — Number of ports
`1` (default) | `0` | `2` | `3` | `4`

Number of outlet ports.

Dependencies

To create outlet ports, specify the number.

`Heat transfer model` — Select model
`Constant` (default) | `External input` | `External wall convection`

Dependencies

Selecting `Constant` or `External wall convection` enables the **Heat Transfer** parameters.

Image type — Icon color
Cold (default) | Hot

Select color for block icon:

- Cold for blue
- Hot for red

General

Chamber volume, Vch — Volume
0.0029 (default) | scalar

Chamber volume, V_{ch}, in m^3.

Initial chamber pressure, Pinit — Pressure
101325 (default) | scalar

Initial chamber pressure, P_{vol}, in Pa.

Initial chamber temperature, Tinit — Temperature
298 (default) | scalar

Initial chamber temperature, T_{vol}, in K.

Ideal gas constant, R — Ideal gas constant
287 (default) | scalar

Ideal gas constant, R, in J/(kg*K).

Specific heat capacity, cp — Specific heat
1005 (default) | scalar

Specific heat capacity, c_p, in J/(kg·K).

Heat Transfer

Heat transfer rate, q_he — Rate
0 (default) | scalar

Constant heat transfer rate, q_{he}, in J/s.

Dependencies

To enable this parameter, select Constant for the **Heat transfer model** parameter.

External convection heat transfer coefficient, ext_tbl — Manifold external air
[40 160 740 2000] (default) | vector

External convection heat transfer coefficient, h_{ext}, in W/(m^2K).

Dependencies

To enable this parameter, select External wall convection for the **Heat transfer model** parameter.

External velocity breakpoints, ext_bpts — Manifold external air
linspace(0,180,4) (default) | vector

External velocity breakpoints, x_{ext}, in m/s.

Dependencies

To enable this parameter, select External wall convection for the **Heat transfer model** parameter.

External convection area, Aext_conv — Manifold external air
0.125 (default) | scalar

External convection area, A_{ext_conv}, in m^2.

Dependencies

To enable this parameter, select External wall convection for the **Heat transfer model** parameter.

Thermal mass, m_wall — Manifold wall general
7 (default) | scalar

Thermal mass, m_{wall}, in kg.

Dependencies

To enable this parameter, select External wall convection for the **Heat transfer model** parameter.

Wall heat capacity, cp_wall — Manifold wall general
900 (default) | scalar

Wall heat capacity, c_{p_wall}, in J/(kg·K).

Dependencies

To enable this parameter, select External wall convection for the **Heat transfer model** parameter.

Initial mass temperature, Tmass — Manifold wall general
293.15 (default) | scalar

Initial mass temperature, T_{mass}, in K.

Dependencies

To enable this parameter, select External wall convection for the **Heat transfer model** parameter.

External wall thickness, Dext_cond — Manifold wall external
0.004 (default) | scalar

External wall thickness, D_{ext_cond}, in m.

Dependencies

To enable this parameter, select External wall convection for the **Heat transfer model** parameter.

`External conduction area, Aext_cond` — Manifold wall external
`0.003` (default) | `scalar`

External conduction area, A_{ext_cond}, in m^2.

Dependencies

To enable this parameter, select `External wall convection` for the **Heat transfer model** parameter.

`External wall thermal conductivity, kint` — Manifold wall external
`25` (default) | `scalar`

External wall thermal conductivity, k_{ext}, in W/(m·K).

Dependencies

To enable this parameter, select `External wall convection` for the **Heat transfer model** parameter.

`Internal wall thickness, Dint_cond` — Manifold wall internal
`0.004` (default) | `scalar`

Internal wall thickness, D_{int_cond}, in m.

Dependencies

To enable this parameter, select `External wall convection` for the **Heat transfer model** parameter.

`Internal conduction area, Aint_cond` — Manifold wall internal
`0.003` (default) | `scalar`

Internal conduction area, A_{int_cond}, in m^2.

Dependencies

To enable this parameter, select `External wall convection` for the **Heat transfer model** parameter.

`Internal wall thermal conductivity, kint` — Manifold wall internal
`25` (default) | `scalar`

Internal wall thermal conductivity, k_{int}, in W/(m·K).

Dependencies

To enable this parameter, select `External wall convection` for the **Heat transfer model** parameter.

`Internal convection heat transfer coefficient, int_tbl` — Manifold internal air
`[40 160 740 2000]` (default) | `vector`

Internal convection heat transfer coefficient, h_{int}, in W/(m^2K).

Dependencies

To enable this parameter, select `External wall convection` for the **Heat transfer model** parameter.

`Internal mass flow rate breakpoints, int_bpts` — Manifold internal air
`linspace(0.0020,0.1100,4)` (default) | `vector`

Internal velocity breakpoints, x_{int}, in kg/s.

Dependencies

To enable this parameter, select `External wall convection` for the **Heat transfer model** parameter.

`Internal flow convection area, Aint_conv` — Manifold internal air
`0.125` (default) | `scalar`

Internal convection area, A_{int_conv}, in m^2.

Dependencies

To enable this parameter, select `External wall convection` for the **Heat transfer model** parameter.

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

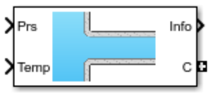
See Also

Flow Restriction | Heat Exchanger | Constant Volume Pneumatic Chamber (Simscape)

Introduced in R2017a

Flow Boundary

Flow boundary for ambient temperature and pressure
Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Fundamental Flow



Description

The Flow Boundary block implements a flow boundary that typically represents ambient temperature and pressure. Engine models require flow boundaries at the intake inlet and exhaust outlet. In dynamic engine models, flow-modifying components (for example, flow restriction, turbines, and compressors) connect to control volumes and flow boundaries.

You can specify these block configurations:

- Constant pressure and temperature
- Externally input pressure and temperature

The Flow Boundary block outputs pressure, temperature, and specific enthalpy:

$$h = c_p T$$

The block models the mass fractions as dry air, resulting in these mass fractions:

- $y_{N2} = 0.767$
- $y_{O2} = .233$

The equation uses these variables.

T	Temperature
h	Specific enthalpy
c_p	Specific heat at constant pressure
y_{N2}	Nitrogen mass fraction
y_{O2}	Oxygen mass fraction

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrBndrFlw	Heat flow rate to flow restriction	q_{orf}
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrEnv	Heat flow rate to environment	$-q_{orf}$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	*Not used*		

Ports

Input

Prs — Pressure
scalar

External input pressure, *P*, in Pa.

Dependencies

To create this port, select `External input` for the **Pressure and temperature source** parameter.

Temp — Temperature
scalar

External input temperature, *T*, in K.

Dependencies

To create this port, select `External input` for the **Pressure and temperature source** parameter.

Output

Info — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Units
`BndryPrs`			Boundary pressure	Pa
`BndryTemp`			Boundary temperature	K
`BndryEnth`			Boundary specific enthalpy	J/kg
`PwrInfo`	`PwrTrnsfrd`	`PwrBndryFlw`	Heat flow rate to flow restriction	W
	`PwrNotTrnsfrd`	`PwrEnv`	Heat flow rate to environment	W
	`PwrStored`		*Not used*	

C — Boundary pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the flow boundary:

- `Prs` — Pressure, *P*, in Pa
- `Temp` — Temperature, *T*, in K
- `Enth` — Specific enthalpy, *h*, in J/kg
- `MassFrac` — Mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Parameters

Block Options

`Pressure and temperature source` — Select source
`External input` (default) | `Constant`

Pressure and temperature source.

Dependencies

The table summarizes the parameter and port dependencies.

Value	Enables Parameters	Creates Ports
`Constant`	**Pressure, Pcnst** **Temperature, Tcnst**	None

`External input`	None	`Prs`
		
		`Temp`

`Image type` — Icon color
`Cold` (default) | `Hot`

Select color for block icon:

- `Cold` for blue
- `Hot` for red

`Pressure, Pcnst` — Constant
`101325` (default) | `scalar`

Constant pressure, *P*, in Pa.

Dependencies

To enable this parameter, select `Constant` for the **Pressure and temperature source** parameter.

`Temperature, Tcnst` — Constant
`298.15` (default) | `scalar`

Constant temperature, *T*, in K.

Dependencies

To enable this parameter, select `Constant` for the **Pressure and temperature source** parameter.

`Specific heat at constant pressure, cp` — Constant
`1005` (default) | `scalar`

Specific heat at constant pressure, in J/(kg·K).

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

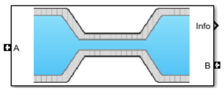
Compressor | Flow Restriction | Turbine

Introduced in R2017a

Flow Restriction

Isentropic ideal gas flow through an orifice

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Fundamental Flow



Description

The Flow Restriction block models isentropic ideal gas flow through an orifice. The block uses the conservation of mass and energy to determine the mass flow rate. The flow velocity is limited by choked flow.

You can specify these orifice area models:

- Constant
- External input
- Throttle body geometry

Equations

The Flow Restriction block implements these equations.

Calculation	Equations
Standard orifice	$\dot{m}_{orf} = \Gamma \cdot \Psi(P_{ratio})$ $P_{ratio} = \frac{P_{downstr}}{P_{upstr}}$ $\Gamma = \frac{A_{eff} \cdot P_{upstr}}{\sqrt{R \cdot T_{upstr}}}$ $P_{cr} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}}$ $\Psi = \begin{cases} \sqrt{\gamma\left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} & P_{ratio} < P_{cr} \\ \sqrt{\frac{2\gamma}{\gamma-1}\left(P_{ratio}^{\frac{2}{\gamma}} - P_{ratio}^{\frac{\gamma+1}{\gamma}}\right)} & P_{cr} \le P_{ratio} \le P_{lim} \\ \frac{P_{ratio}-1}{P_{lim}-1}\sqrt{\frac{2\gamma}{\gamma-1}\left(P_{lim}^{\frac{2}{\gamma}} - P_{lim}^{\frac{\gamma+1}{\gamma}}\right)} & P_{lim} < P_{ratio} \end{cases}$
Constituent mass flow rates	$\dot{m}_i = \dot{m}_{orf} y_{upstr,\,i}$
Constant orifice area	$A_{eff} = A_{orf\_cnst} \cdot Cd_{cnst}$

Calculation	Equations
External input orifice area	$A_{eff} = A_{orf\_ext} \cdot Cd_{ext}$
Throttle body geometry	$\theta_{thr} = Pct_{thr} \cdot \frac{90}{100}$ $A_{eff\_thr} = \frac{\pi}{4} D_{thr} 2 C_{d\_thr}(\theta_{thr})$
Heat flow rate	$q_{orf} = \dot{m}_{orf} h_{upstr}$

The equations use these variables.

A_{eff}, A_{eff_thr}	Effective orifice cross-sectional area
A_{orf_cnst}, A_{orf_ext}	Orifice area
Cd_{cnst}, Cd_{ext}	Discharge coefficient
R	Ideal gas constant
P_{cr}	Critical pressure at which choked flow occurs
γ	Ratio of specific heats
Γ	Flow function based on pressure ratio
P_{ratio}	Pressure ratio
P_{upstr}	Upstream orifice pressure
$P_{downstr}$	Downstream orifice pressure
P_{lim}	Pressure ratio limit to avoid singularities as the pressure ratio approaches 1
$y_{upstr,i}$	Upstream species mass fraction for i = O_2, N_2, unburned fuel, CO_2, H_2O, CO, NO, NO_2, PM, air, and burned gas
$\dot{m}_i$	Mass flow rate for i = O_2, N_2, unburned fuel, CO_2, H_2O, CO, NO, NO_2, PM, air, and burned gas
θ_{thr}	Throttle angle
Pct_{thr}	Percentage of throttle body that is open
C_{d_thr}	Throttle discharge coefficient
D_{thr}	Throttle body diameter at opening
$\dot{m}_{orf}$	Orifice mass flow
h_{upstr}	Upstream specific enthalpy
q_{orf}	Heat flow rate

The block uses the internal signal `FlwDir` to track the direction of the flow.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrHeatFlwIn	Heat flow rate at port A	q_{orf}
		PwrHeatFlwOut	Heat flow rate at port B	$-q_{orf}$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	*Not used*		
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	*Not used*		

Ports

Input

A — Inlet orifice pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing orifice:

- Prs — Pressure, in Pa
- Temp — Temperature, in K
- Enth — Specific enthalpy, in J/kg
- MassFrac — Inlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - O2MassFrac — Oxygen
  - N2MassFrac — Nitrogen
  - UnbrndFuelMassFrac — Unburned fuel
  - CO2MassFrac — Carbon dioxide
  - H2OMassFrac — Water
  - COMassFrac — Carbon monoxide
  - NOMassFrac — Nitric oxide
  - NO2MassFrac — Nitrogen dioxide
  - NOxMassFrac — Nitric oxide and nitrogen dioxide
  - PmMassFrac — Particulate matter
  - AirMassFrac — Air
  - BrndGasMassFrac — Burned gas

B — Outlet orifice pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing orifice:

- `Prs` — Pressure, in Pa
- `Temp` — Temperature, in K
- `Enth` — Specific enthalpy, in J/kg
- `MassFrac` — Outlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

`Area` — Orifice area
`scalar`

External area input for orifice area, A_{orf_ext}, in m^2.

Dependencies

To create this port, select `External input` for the **Orifice area model** parameter.

`ThrPct` — Throttle body percent open
`scalar`

Percentage of throttle body that is open, Pct_{thr}.

Dependencies

To create this port, select `Throttle body geometry` for the **Orifice area model** parameter.

Output

A — Inlet mass flow rate, heat flow rate, temperature
two-way connector port

Bus containing:

- `MassFlw` — Mass flow rate through inlet, in kg/s
- `HeatFlw` — Inlet heat flow rate, in J/s
- `Temp` — Inlet temperature, in K
- `MassFrac` — Inlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

B — Outlet mass flow rate, heat flow rate, temperature
two-way connector port

Bus containing:

- `MassFlw` — Outlet mass flow rate, in kg/s
- `HeatFlw` — Outlet heat flow rate, in J/s
- `Temp` — Outlet temperature, in K
- `MassFrac` — Outlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Info — Bus signal
bus

Bus signal containing these block calculations.

Signal				Description	Units
Flw	PrsAdj		DwnstrmPrs	Downstream pressure	Pa
			UpstrmPrs	Upstream pressure	Pa
			PrsRatio	Pressure ratio	NA
			DwnstrmTemp	Downstream temperature	K
			UpstrmTemp	Upstream temperature	K
	OrfMassFlw			Mass flow rate through orifice	kg/s
	Species		O2MassFlw	Oxygen mass flow rate	kg/s
			N2MassFlw	Nitrogen mass flow rate	kg/s
			UnbrndFuelMassFlw	Unburned gas mass flow rate	kg/s
			CO2MassFlw	Carbon dioxide mass flow rate	kg/s
			H2OMassFlw	Water mass flow rate	kg/s
			COMassFlw	Carbon monoxide mass flow rate	kg/s
			NOMassFlw	Nitric oxide mass flow rate	kg/s
			NO2MassFlw	Nitrogen dioxide mass flow rate	kg/s
			NOxMassFlw	Nitric oxide and nitrogen dioxide mass flow rate	kg/s
			PmMassFlw	Particulate matter mass flow rate	kg/s
			AirMassFlw	Air mass flow rate	kg/s
			BrnedGasMassFlw	Burned gas mass flow rate	kg/s
	PwrInfo	PwrTrnsfrd	PwrHeatFlwIn	Heat flow rate at port A	W
			PwrHeatFlwOut	Heat flow rate at port B	W
		PwrNotTrnsfrd		*Not used*	
		PwrStored		*Not used*	
Area	FlwArea			Cross-sectional flow area	m^2
	EffctArea			Effective orifice cross-sectional area	m^2
	ThrAng			Throttle area, if applicable	deg

Parameters

Block Options

`Orifice area model` — Select model
`Constant` (default) | `External input` | `Throttle body geometry`

Orifice area model.

Dependencies

The orifice area model enables the parameters on the **Area Parameters** tab.

`Image type` — Icon color
`Cold` (default) | `Hot`

Block icon color:

- `Cold` for blue.
- `Hot` for red.

General

`Ratio of specific heats, gamma` — Ratio
`1.3998` (default) | `scalar`

Ratio of specific heats, γ.

`Ideal gas constant, R` — Constant
`287.05` (default) | `scalar`

Ideal gas constant, R, in J/(kg·K).

`Pressure ratio linearize limit, Plim` — Limit
`0.95` (default) | `scalar`

Pressure ratio limit to avoid singularities as the pressure ratio approaches 1, P_{lim}.

Area

`Constant area value, Aorf_cnst` — Area
`.1` (default) | `scalar`

Constant area value, A_{orf_cnst}, in m^2.

Dependencies

To enable this parameter, select `Constant` for the **Orifice area model** parameter.

`Discharge coefficient, Cd_cnst` — Coefficient
`1` (default) | `scalar`

Discharge coefficient for constant area, Cd_{cnst}.

Dependencies

To enable this parameter, select `Constant` for the **Orifice area model** parameter.

`Discharge coefficient, Cd_ext` — Coefficient
`1` (default) | `scalar`

Discharge coefficient for external area input, Cd_{ext}.

Dependencies

To enable this parameter, select `External input` for the **Orifice area model** parameter.

`Throttle diameter, Dthr` — Diameter
`50` (default) | `scalar`

Throttle body diameter at opening, D_{thr}, in mm.

Dependencies

To enable this parameter, select `Throttle body geometry` for the **Orifice area model** parameter.

`Discharge coefficient table, ThrCd` — Coefficient
`[0.001; 0.735]` (default) | `vector`

Discharge coefficient table, C_{d_thr}.

Dependencies

To enable this parameter, select `Throttle body geometry` for the **Orifice area model** parameter.

`Angle breakpoints, ThrAngBpts` — Angle
`[0; 90]` (default) | `vector`

Angle breakpoints, Thr_{ang_bpts}, in deg.

Dependencies

To enable this parameter, select `Throttle body geometry` for the **Orifice area model** parameter.

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

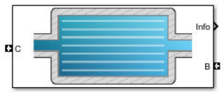
See Also
Control Volume System | Heat Exchanger

Introduced in R2017a

Heat Exchanger

Intercooler or exhaust gas recirculation (EGR) cooler

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Fundamental Flow



Description

The Heat Exchanger block models a heat exchanger, for example, an intercooler or exhaust gas recirculation (EGR) cooler. The inlet (port C) connects to an engine flow component (flow restriction, compressor, turbine, or engine block). The outlet (port B) connects to a volume (control volume or environment). Based on the upstream temperature, heat exchanger effectiveness, and cooling medium temperature, the block determines the heat transfer rate and downstream temperature.

For the heat exchanger effectiveness and cooling medium temperature, you can specify either a constant value or an external input. For example, if you specify a heat exchanger effectiveness that is:

- Equal to 1, the downstream temperature is equal to the cooling medium temperature.
- Equal to 0, there is no heat transfer to the cooling medium. The downstream temperature is equal to the upstream temperature.

The block assumes no pressure drop. To model pressure losses, use a Flow Restriction block.

Equations

The Heat Exchanger block implements equations that use these variables.

T_{upstr}	Upstream temperature
T_{dnstr}	Downstream temperature
T_{cool}	Cooling medium temperature
$T_{cool,cnst}$	Constant cooling medium temperature
$T_{cool,input}$	External input cooling medium temperature
ε	Heat exchanger effectiveness
ε_{cnst}	Constant heat exchanger effectiveness
ε_{input}	Input heat exchanger effectiveness
c_p	Specific heat at constant pressure
q_{ht}	Heat exchanger heat transfer rate
$p_{flw,in}$	Pressure at inlet
$p_{vol,out}$	Pressure at outlet
$T_{vol,out}$	Temperature at outlet
$h_{vol,out}$	Specific enthalpy at outlet

q_{in}	Heat flow rate at inlet
q_{out}	Heat flow rate at outlet
$\dot{m}$	Heat exchanger mass flow rate
$T_{flw,in}$	Temperature at inlet
T_{in}	Heat exchanger inlet temperature
T_{out}	Heat exchanger outlet temperature
h_{in}	Inlet specific enthalpy

Heat Exchanger Effectiveness

Heat exchanger effectiveness measures the effectiveness of heat transfer from the incoming hot fluid to the cooling medium:

$$\varepsilon = \frac{T_{upstr} - T_{dnstr}}{T_{upstr} - T_{cool}}$$

In an ideal heat exchanger, the downstream temperature equals the cooling temperature. The effectiveness is equal to 1.

$$T_{dnstr} = T_{cool}$$
$$\varepsilon = 1$$

The Heat Exchanger block uses the effectiveness to determine the downstream temperature and heat transfer rate.

$$T_{dnstr} = T_{upstr} - \varepsilon\left(T_{upstr} - T_{cool}\right)$$
$$q_{ht} = \dot{m}c_p\left(T_{upstr} - T_{dnstr}\right)$$

Fluid Flow

Since the block assumes no pressure drop, $P_{flw,in} = P_{vol,out}$.

The flow component connection to the heat exchanger inlet determines the direction of the mass flow. Based on the mass flow rate direction, these temperature and heat flow equations apply.

Fluid Flow	Mass Flow Rate	Temperatures and Heat Flow
Forward — From engine flow component to outlet volume	$\dot{m} \geq 0$	$T_{upstr} = T_{flw,in}$ $T_{in} = T_{upstr}$ $T_{out} = T_{dnstr}$ $q_{out} = \dot{m}c_pT_{dnstr}$
Reverse — From outlet volume to engine flow component	$\dot{m} < 0$	$T_{upstr} = T_{vol,out}$ $T_{in} = T_{dnstr}$ $T_{out} = T_{vol,out}$ $h_{in} = c_pT_{dnstr}$ $q_{out} = \dot{m}h_{vol,out}$

The block uses the internal signal `FlwDir` to track the direction of the flow.

Power Accounting

For the power accounting, the block implements these equations.

<table>
<tr><th colspan="3">Bus Signal</th><th>Description</th><th>Equations</th></tr>
<tr><td rowspan="4">PwrInfo</td><td rowspan="2">PwrTrnsfrd — Power transferred between blocks
• Positive signals indicate flow into block
• Negative signals indicate flow out of block</td><td>PwrHeatFlwIn</td><td>Heat flow rate at port C</td><td>q_{in}</td></tr>
<tr><td>PwrHeatFlwOut</td><td>Heat flow rate at port B</td><td>$-q_{out}$</td></tr>
<tr><td>PwrNotTrnsfrd — Power crossing the block boundary, but not transferred
• Positive signals indicate an input
• Negative signals indicate a loss</td><td>PwrHeatTrnsfr</td><td>Heat transfer rate to cooling medium</td><td>$-q_{ht}$</td></tr>
<tr><td colspan="2">PwrStored — Stored energy rate of change
• Positive signals indicate an increase
• Negative signals indicate a decrease</td><td colspan="2">Not used</td></tr>
</table>

Ports

Input

C — Inlet mass flow rate, heat flow rate, temperature, mass fractions
two-way connector port

Bus containing the heat exchanger:

- `MassFlwRate` — Mass flow rate at inlet, $\dot{m}$, in kg/s
- `HeatFlwRate` — Heat flow rate at inlet, q_{in}, in J/s
- `Temp` — Temperature at inlet, $T_{flw,in}$, in K
- `MassFrac` — Inlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide

  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

B — Outlet volume pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the heat exchanger:

- `Prs` — Pressure at outlet, $p_{vol,out}$, in Pa
- `Temp` — Temperature at outlet, $T_{vol,out}$, in K
- `Enth` — Specific enthalpy at outlet, $h_{vol,out}$, in J/kg
- `MassFrac` — Outlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

`Effct` — Heat exchanger effectiveness
`scalar`

Heat exchanger effectiveness, ε_{input}.

Dependencies

To create this port, set **Effectiveness model** to `External input`.

`CoolTemp` — Cooling medium temperature
scalar

Cooling medium temperature, $T_{cool,input}$.

Dependencies

To create this port, set **Cooling medium temperature input** to `External input`

Output

Info — Heat exchanger data

bus

Bus signal containing these block calculations.

Signal			Description	Units
InletTemp			Heat exchanger inlet temperature	K
OutletTemp			Heat exchanger outlet temperature	K
HeatTrnsfrRate			Heat exchanger heat transfer rate	J/s
PwrInfo	PwrTrnsfrd	PwrHeatFlwIn	Heat flow rate at port C	W
		PwrHeatFlwOut	Heat flow rate at port B	W
	PwrNotTrnsfrd	PwrHeatTrnsfr	Heat transfer rate to cooling medium	W
	PwrStored		*Not used*	

C — Inlet flow pressure, temperature, enthalpy, mass fractions

two-way connector port

Bus containing the heat exchanger:

- Prs — Pressure at inlet, $p_{flw,in}$, in Pa
- Temp — Temperature at inlet, T_{in}, in K
- Enth — Specific enthalpy at inlet, h_{in}, in J/kg
- MassFrac — Inlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - O2MassFrac — Oxygen
  - N2MassFrac — Nitrogen
  - UnbrndFuelMassFrac — Unburned fuel
  - CO2MassFrac — Carbon dioxide
  - H2OMassFrac — Water
  - COMassFrac — Carbon monoxide
  - NOMassFrac — Nitric oxide
  - NO2MassFrac — Nitrogen dioxide
  - NOxMassFrac — Nitric oxide and nitrogen dioxide
  - PmMassFrac — Particulate matter
  - AirMassFrac — Air
  - BrndGasMassFrac — Burned gas

B — Outlet volume mass flow rate, heat flow rate, temperature, mass fractions
two-way connector port

Bus containing the heat exchanger:

- `MassFlwRate` — Mass flow rate at outlet, $\dot{m}$, in kg/s
- `HeatFlwRate` — Heat flow rate at outlet, q_{out}, in J/s
- `Temp` — Temperature at outlet, T_{out}, in K
- `MassFrac` — Outlet mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Parameters

Block Options

`Effectiveness model` — Model type for heat effectiveness
`Constant` (default) | `External input`

Type of model to calculate the heat exchanger effectiveness.

Dependencies

Selecting:

- `External input` creates the `Effct` port.
- `Constant` enables the **Heat exchanger effectiveness, ep_cnst** parameter.

`Cooling medium temperature input` — Specify type
`Constant` (default) | `External input`

Cooling medium temperature input.

Dependencies

Selecting:

- `External input` creates the `CoolTemp` port.
- `Constant` enables the **Cooling medium temperature, T_cool_cnst** parameter.

`Image type` — Icon color
`Intercooler` (default) | `EGR cooler hot to cold` | `EGR cooler cold to hot`

Block icon color:

- `Intercooler` for blue, to indicate an intercooler
- `EGR cooler hot to cold` for red to blue, to indicate EGR from hot to cold
- `EGR cooler cold to hot` for blue to red, to indicate EGR from cold to hot

`Heat exchanger effectiveness, ep_cnst` — Effectiveness
`0.7` (default) | `scalar`

Constant heat exchanger effectiveness, ε_{cnst}.

Dependencies

To enable this parameter, select `Constant` for the **Effectiveness model** parameter.

`Cooling medium temperature, T_cool_cnst` — Temperature
`300` (default) | `scalar`

Constant cooling medium temperature, $T_{cool,\,cnst}$, in K.

Dependencies

To enable this parameter, select `Constant` for the **Cooling medium temperature input** parameter.

`Specific heat at constant pressure, cp` — Specific heat
`1005` (default) | `scalar`

Specific heat at constant pressure, c_p, in J/(kg*K).

References

[1] Eriksson, Lars and Nielsen, Lars. *Modeling and Control of Engines and Drivelines*. Chichester, West Sussex, United Kingdom: John Wiley & Sons Ltd, 2014.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

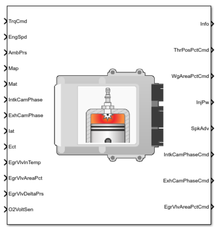
See Also
Control Volume System | Flow Restriction

Introduced in R2017a

SI Controller

Spark-ignition engine controller that uses the driver torque request

Library: Powertrain Blockset / Propulsion / Combustion Engine Controllers



Description

The SI Controller block implements a spark-ignition (SI) controller that uses the driver torque request to calculate the open-loop air, fuel, and spark actuator commands that are required to meet the driver demand.

You can use the SI Controller block in engine control design or performance, fuel economy, and emission tradeoff studies. The core engine, throttle, and turbocharger wastegate subsystems require the commands that are output from the SI Controller block.

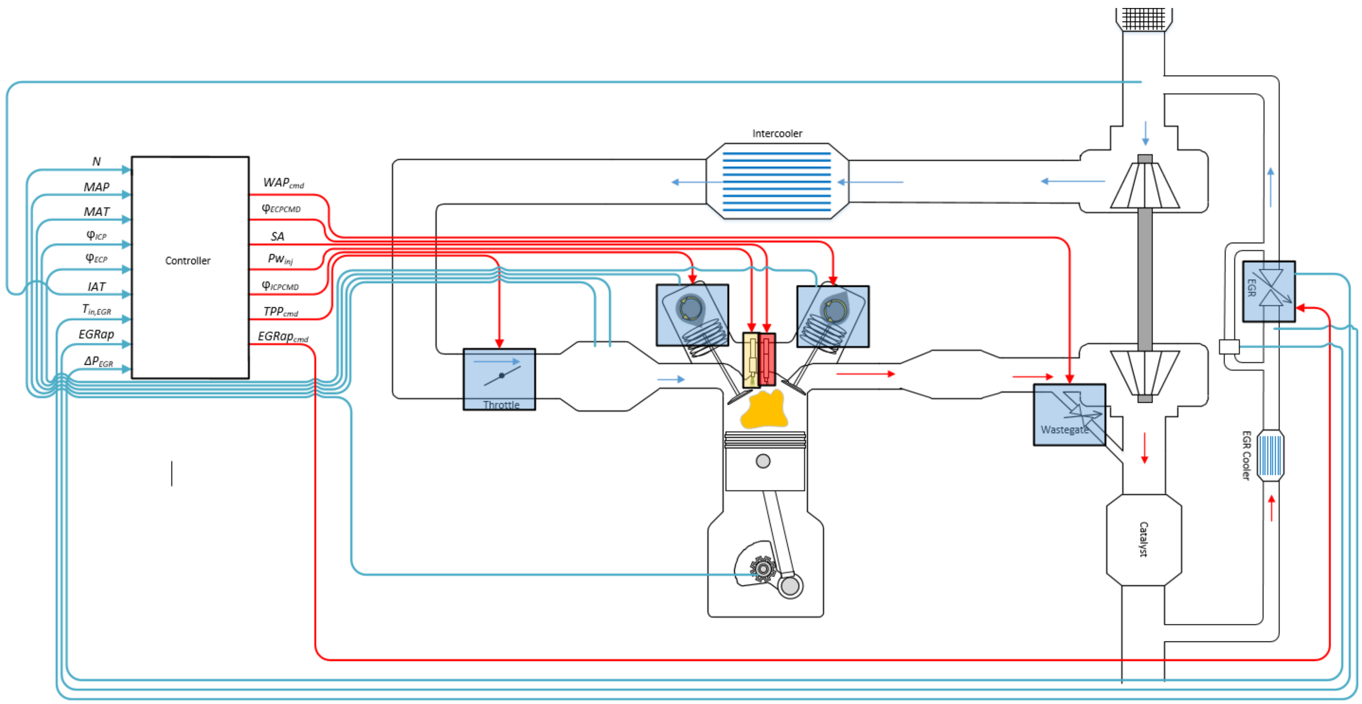
The block uses the commanded torque and engine speed to determine these open-loop actuator commands:

- Throttle position percent
- Wastegate area percent
- Injector pulse-width
- Spark advance
- Intake cam phaser angle
- Exhaust cam phaser angle
- Exhaust gas recirculation (EGR) valve area percent

The SI Controller block has two subsystems:

- The `Controller` subsystem — Determines the commands based on the commanded torque, measured engine speed, and estimated cylinder air mass.
- The `Estimator` subsystem — Determines the estimated air mass flow, torque, and exhaust gas temperature from intake manifold gas pressure, intake manifold gas temperature, engine speed, and cam phaser positions.

The figure illustrates the signal flow.



The figure uses these variables.

N	Engine speed
MAP	Cycle average intake manifold pressure
IAT	Intake air temperature
$T_{in,EGR}$	Temperature at EGR valve inlet
MAT	Cycle average intake manifold gas absolute temperature
φ_{ICP}, φ_{ICPCMD}	Intake cam phaser angle and intake cam phaser angle command, respectively
φ_{ECP}, φ_{ECPCMD}	Exhaust cam phaser angle and exhaust cam phaser angle command, respectively
$EGRap$, $EGRap_{cmd}$	EGR valve area percent and EGR valve area percent command, respectively
ΔP_{EGR}	Pressure difference at EGR valve inlet and outlet
WAP_{cmd}	Turbocharger wastegate area percent command
SA	Spark advance
Pw_{inj}	Fuel injector pulse-width
TPP_{cmd}	Throttle position percent command

The Model-Based Calibration Toolbox was used to develop the tables that are available with the Powertrain Blockset.

Controller

Air

The block determines the commanded engine load (that is, normalized cylinder air mass) from a lookup table that is a function of commanded torque and measured engine speed.

$$L_{cmd} = f_{Lcmd}(T_{cmd}, N)$$

To achieve the commanded load, the controller sets the throttle position percent and turbocharger wastegate area percent using feed forward lookup tables. The lookup tables are functions of the commanded load and measured engine speed.

$$TAP_{cmd} = f_{TAPcmd}(L_{cmd}, N)$$

$$TPP_{cmd} = f_{TPPcmd}(TAP_{cmd})$$

$$WAP_{cmd} = f_{WAPcmd}(L_{cmd}, N)$$

To determine the cam phaser angle commands, the block uses lookup tables that are functions of estimated engine load and measured engine speed.

$$\varphi_{ICPCMD} = f_{ICPCMD}(L_{est}, N)$$

$$\varphi_{ECPCMD} = f_{ECPCMD}(L_{est}, N)$$

The block calculates the desired engine load using this equation.

$$L_{est} = \frac{CpsR_{air}T_{std}\dot{m}_{air,est}}{P_{std}V_dN}$$

The equations use these variables.

L_{est}	Estimated engine load
L_{cmd}	Commanded engine load
N	Engine speed
T_{cmd}	Commanded engine torque
TAP_{cmd}	Throttle area percent command
TPP_{cmd}	Throttle position percent command
WAP_{cmd}	Turbocharger wastegate area percent command
Cps	Crankshaft revolutions per power stroke
P_{std}	Standard pressure
T_{std}	Standard temperature
R_{air}	Ideal gas constant for air and burned gas mixture
V_d	Displaced volume
$\dot{m}_{air,est}$	Estimated engine air mass flow

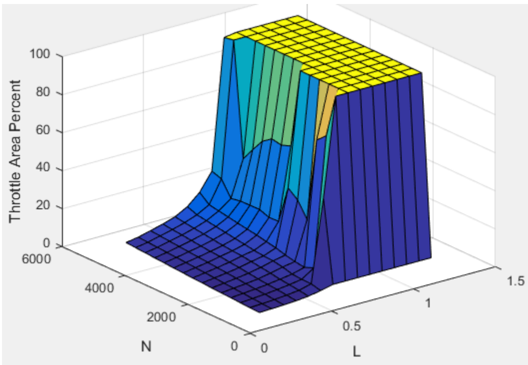
The controller subsystem uses these lookup tables for the air calculations.

- The throttle area percent command lookup table, f_{TAPcmd}, is a function of commanded load and engine speed

  $$TAP_{cmd} = f_{TAPcmd}(L_{cmd}, N)$$

  where:

- TAP_{cmd} is throttle area percentage command, in percent.
- L_{cmd}=L is commanded engine load, dimensionless.
- N is engine speed, in rpm.



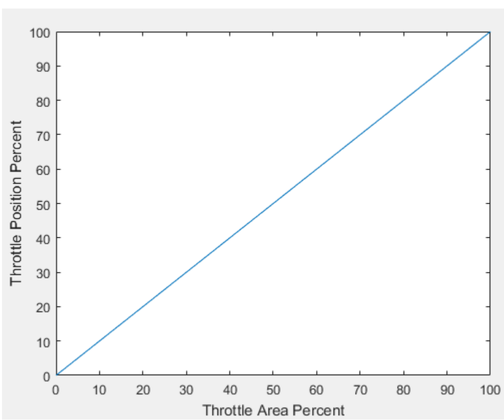
- To account for the non-linearity of the throttle position to throttle area, the throttle position percent lookup table linearizes the open-loop air mass flow control.

  The throttle position percent command lookup table, f_{TPPcmd}, is a function of the throttle area percentage command

  $$TPP_{cmd} = f_{TPPcmd}(TAP_{cmd})$$

  where:

  - TPP_{cmd} is throttle position percentage command, in percent.
  - TAP_{cmd} is throttle area percentage command, in percent.



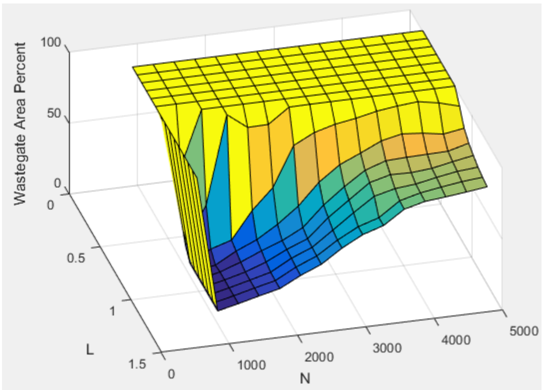
- The wastegate area percent command lookup table, f_{WAPcmd}, is a function of the commanded engine load and engine speed

  $$WAP_{cmd} = f_{WAPcmd}(L_{cmd}, N)$$

  where:

  - WAP_{cmd} is wastegate area percentage command, in percent.
  - L_{cmd}=L is commanded engine load, dimensionless.

- N is engine speed, in rpm.

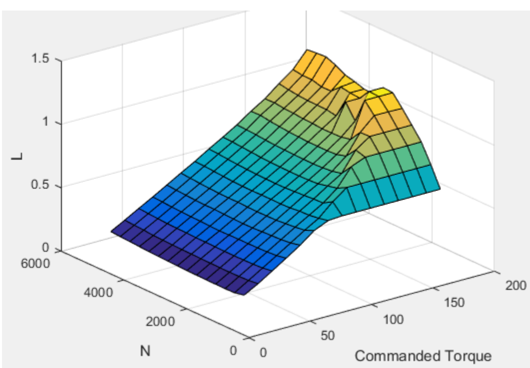


- The commanded engine load lookup table, f_{Lcmd}, is a function of the commanded torque and engine speed

  $$L_{cmd} = f_{Lcmd}(T_{cmd}, N)$$

  where:

  - L_{cmd}=L is commanded engine load, dimensionless.
  - T_{cmd} is commanded torque, in N·m.
  - N is engine speed, in rpm.

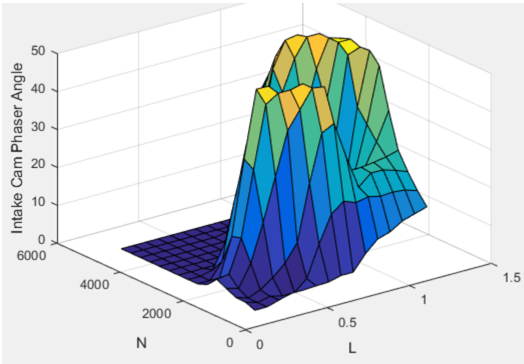


- The intake cam phaser angle command lookup table, f_{ICPCMD}, is a function of the engine load and engine speed

  $$\varphi_{ICPCMD} = f_{ICPCMD}(L_{est}, N)$$

  where:

  - φ_{ICPCMD} is commanded intake cam phaser angle, in degrees crank advance.
  - L_{est}=L is estimated engine load, dimensionless.
  - N is engine speed, in rpm.

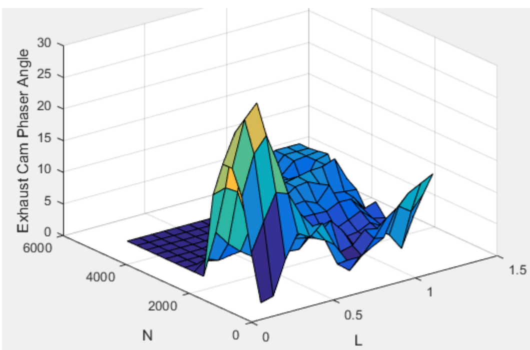


- The exhaust cam phaser angle command lookup table, f_{ECPCMD}, is a function of the engine load and engine speed

  $$\varphi_{ECPCMD} = f_{ECPCMD}(L_{est}, N)$$

  where:

  - φ_{ECPCMD} is commanded exhaust cam phaser angle, in degrees crank retard.
  - L_{est}=L is estimated engine load, dimensionless.
  - N is engine speed, in rpm.



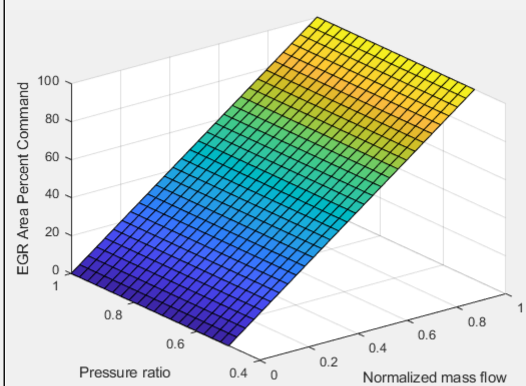
EGR

EGR is typically expressed as a percent of total intake port flow.

$$EGR_{pct} = 100\frac{\dot{m}_{EGR}}{\dot{m}_{EGR} + \dot{m}_{air}}$$

To calculate the EGR area percent command, the block uses equations and a lookup table.

Equations	$\dot{m}_{EGRstd,cmd} = \dot{m}_{EGR,cmd}\frac{P_{std}}{P_{in,EGR}}\sqrt{\frac{T_{in,EGR}}{T_{std}}}$ $\dot{m}_{EGRstd,max} = f_{EGRstd,max}\left(\frac{P_{out,EGR}}{P_{in,EGR}}\right)$ $\dot{m}_{EGR,cmd} = EGR_{pct,cmd}\dot{m}_{intk,est}$

Lookup table	The EGR area percent command, $EGRap_{cmd}$, lookup table is a function of the normalized mass flow and pressure ratio $$EGRap_{cmd} = f_{EGRap,cmd}\left(\frac{\dot{m}_{EGRstd,cmd}}{\dot{m}_{EGRstd,max}}, \frac{P_{out,EGR}}{P_{in,EGR}}\right)$$ where: • $EGRap_{cmd}$ is commanded EGR area percent, dimensionless. • $\frac{\dot{m}_{EGRstd,cmd}}{\dot{m}_{EGRstd,max}}$ is the normalized mass flow, dimensionless. • $\frac{P_{out,EGR}}{P_{in,EGR}}$ is the pressure ratio, dimensionless. 

The equations and table use these variables.

$EGRap$, $EGRap_{cmd}$	EGR valve area percent and EGR valve area percent command, respectively
$EGR_{pct,cmd}$	EGR percent command
$\dot{m}_{EGRstd,cmd}$	Commanded standard mass flow
$\dot{m}_{EGRstd,max}$	Maximum standard mass flow
$\dot{m}_{EGR,cmd}$	Commanded mass flow
$\dot{m}_{intk,est}$	Estimated intake port mass flow
T_{std}, P_{std}	Standard temperature and pressure
$T_{in,EGR}$	Temperature at EGR valve inlet
$P_{out,EGR}$, $P_{in,EGR}$	Pressure at EGR valve inlet and outlet, respectively

Fuel

The air-fuel ratio (AFR) impacts three-way-catalyst (TWC) conversion efficiency, torque production, and combustion temperature. The engine controller manages AFR by commanding injector pulse-width from a desired relative AFR. The relative AFR, λ_{cmd}, is the ratio between the commanded AFR and the stoichiometric AFR of the fuel.

$$\lambda_{cmd} = \frac{AFR_{cmd}}{AFR_{stoich}}$$

$$AFR_{cmd} = \frac{\dot{m}_{air,\,est}}{\dot{m}_{fuel,\,cmd}}$$

The SI Controller block accounts for the extra fuel delivered to the SI engine during startup. If the engine speed is greater than the startup engine cranking speed, the SI Controller block enriches the optimal AFR, lambda, with an exponentially decaying delta lambda. To initialize the delta lambda, the block uses the engine coolant temperature at startup. The delta lambda exponentially decays to zero based on a time constant that is a function of the engine coolant temperature.

You can configure the block for open-loop and closed-loop AFR control.

To	Use	Controls > Fuel > Closed-loop feedback Parameter Setting
• Assess the dynamic and steady-state accuracy of the controller airflow estimation and fuel delivery.	(default) Open-loop control	`off`
• Hold the average AFR close to stoichiometric AFR to maintain a high TWC conversion efficiency.	Closed-loop control	`on`

Open-Loop Control

To create an input port for the commanded AFR (lambda), on the **Controls** > **Fuel** > **Open-loop fuel** pane, select **Input lambda**.

You can manually tune the catalyst for maximum efficiency during open-loop AFR control with or without dither. If you want to implement dither during open-loop control, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Dither**.

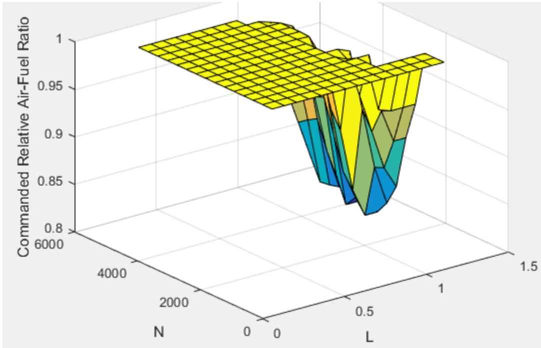
By default, the block is configured to use a lookup table for the commanded AFR.

The commanded lambda, λ_{cmd}, lookup table is a function of estimated engine load and measured engine speed

$$\lambda_{cmd} = f_{\lambda cmd}(L_{est}, N)$$

where:

- λ_{cmd} is commanded relative AFR, dimensionless.
- L_{est}=L is estimated engine load, dimensionless.
- N is engine speed, in rpm.



The block calculates the estimated fuel mass flow rate using the commanded lambda, λ_{cmd}, stoichiometric AFR, and estimated air mass flow rate.

$$\dot{m}_{fuel,cmd} = \frac{\dot{m}_{air,est}}{AFR_{cmd}} = \frac{\dot{m}_{air,est}}{\lambda_{cmd}AFR_{stoich}}$$

The block assumes that the battery voltage and fuel pressure are at nominal settings where pulse-width correction is not necessary. The commanded fuel injector pulse-width is proportional to the fuel mass per injection. The fuel mass per injection is calculated from the commanded fuel mass flow rate, engine speed, and the number of cylinders.

$$Pw_{inj} = \begin{cases} \dfrac{\dot{m}_{fuel,cmd}Cps(\frac{60s}{min})\left(\frac{1000mg}{g}\right)\left(\frac{1000g}{kg}\right)}{NS_{inj}N_{cyl}} & \text{when } Trq_{cmd} > 0 \\ 0 & \text{when } Trq_{cmd} \le 0 \end{cases}$$

Closed-Loop Control

TWC converters are most efficient when the exhaust AFR is near the stoichiometric AFR, where the air and fuel burn most completely. Around this ideal point, the AFR is within the *catalyst window* in which the catalyst is most efficient at converting carbon monoxide, hydrocarbons, and nitrogen oxides to non-harmful exhaust products. Empirical studies show that oscillating the AFR around stoichiometry at an optimized AFR frequency, amplitude, and bias widens the TWC window, increasing catalyst conversion efficiency in the presence of unavoidable disturbances.

To keep production hardware costs down, AFR control systems include inexpensive switching oxygen sensors positioned in the engine exhaust stream upstream and downstream of the catalyst. The oxygen sensors have a narrow range. Essentially, they switch between too lean (i.e., more air is available than is required to burn the available fuel) and too rich (i.e., more air is available than is required to burn the available fuel).

The block implements a period-based method to control the average AFR at a value within the catalyst window for maximum conversion efficiency. Period-based AFR control is independent of the transport delay across the engine from the fuel injection point to the sensor measurement point. For more information about the method, see Developing a Period-Based Air-Fuel Ratio Controller Using a Low-Cost Switching Sensor.

Spark

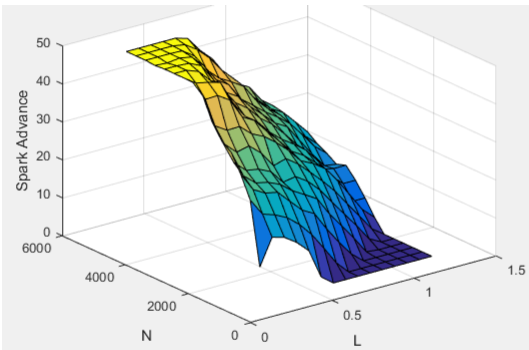
Spark advance is the crank angle before top dead center (BTDC) of the power stroke when the spark is delivered. The spark advance has an impact on engine efficiency, torque, exhaust temperature, knock, and emissions.

The spark advance lookup table is a function of estimated load and engine speed.

$$SA = f_{SA}(L_{est}, N)$$

where:

- SA is spark advance, in crank advance degrees.
- L_{est}=L is estimated engine load, dimensionless.
- N is engine speed, in rpm.



The equations use these variables.

L_{est}	Estimated engine load, based on normalized cylinder air mass
N	Engine speed
f_{SA}	Lookup table for spark advance
N	Spark advance

Idle Speed

When the commanded torque is below a threshold value, the idle speed controller regulates the engine speed.

If	Idle Speed Controller
$Trq_{cmd,input} < Trq_{idlecmd,enable}$	Enabled
$Trq_{idlecmd,enable} \leq Trq_{cmd,input}$	Not enabled

The idle speed controller uses a discrete PI controller to regulate the target idle speed by commanding a torque.

The PI controller uses this transfer function:

$$C_{idle}(z) = K_{p,\,idle} + K_{i,\,idle}\frac{t_s}{z-1}$$

The idle speed commanded torque must be less than the maximum commanded torque:

$0 \leq Trq_{idlecomd} \leq Trq_{idlecmd,max}$

Idle speed control is active under these conditions. If the commanded input torque drops below the threshold for enabling the idle speed controller ($Trq_{cmd,input} < Trq_{idlecmd,enable}$), the commanded engine torque is given by:

$Trq_{cmd} = \max(Trq_{cmd,input}, Trq_{idlecmd})$.

The equations use these variables.

Trq_{cmd}	Commanded engine torque
$Trq_{cmd,input}$	Input commanded engine torque
$Trq_{idlecmd,enable}$	Threshold for enabling idle speed controller
$Trq_{idlecmd}$	Idle speed controller commanded torque
$Trq_{idlecmd,max}$	Maximum commanded torque
N_{idle}	Base idle speed
$K_{p,idle}$	Idle speed controller proportional gain
$K_{i,idle}$	Idle speed controller integral gain

Speed Limiter

To prevent over revving the engine, the block implements an engine speed limit controller that limits the engine speed to the value specified by the **Rev-limiter speed threshold** parameter on the **Controls** > **Idle Speed** tab.

If the engine speed, N, exceeds the engine speed limit, N_{lim}, the block sets the commanded engine torque to 0.

To smoothly transition the torque command to 0 as the engine speed approaches the speed limit, the block implements a lookup table multiplier. The lookup table multiplies the torque command by a value that ranges from 0 (engine speed exceeds limit) to 1 (engine speed does not exceed the limit).

Estimator

The estimator subsystem determines the estimated air mass flow, torque, EGR mass flow, and exhaust temperature based on sensor feedback and calibration parameters.

$\dot{m}_{air,\,est}$	Estimated engine air mass flow
Trq_{est}	Estimated engine torque
$T_{exh,est}$	Estimated engine exhaust temperature
$\dot{m}_{EGR,\,est}$	Estimated low-pressure EGR mass flow

Air Mass Flow

To calculate engine air mass flow, configure the SI engine to use either of these air mass flow models.

Air Mass Flow Model	Description
"SI Engine Speed-Density Air Mass Flow Model"	Uses the speed-density equation to calculate the engine air mass flow, relating the engine air mass flow to the intake manifold pressure and engine speed. Consider using this air mass flow model in engines with fixed valvetrain designs.

Air Mass Flow Model	Description
"SI Engine Dual-Independent Cam Phaser Air Mass Flow Model"	To calculate the engine air mass flow, the dual-independent cam phaser model uses: • Empirical calibration parameters developed from engine mapping measurements • Desktop calibration parameters derived from engine computer-aided design (CAD) data In contrast to typical embedded air mass flow calculations based on direct air mass flow measurement with an air mass flow (MAF) sensor, this air mass flow model offers: • Elimination of MAF sensors in dual cam-phased valvetrain applications • Reasonable accuracy with changes in altitude • Semiphysical modeling approach • Bounded behavior • Suitable execution time for electronic control unit (ECU) implementation • Systematic development of a relatively small number of calibration parameters

To determine the estimated air mass flow, the block uses the intake air mass fraction. The EGR mass fraction at the intake port lags the mass fraction near the EGR valve outlet. To model the lag, the block uses a first order system with a time constant.

$$y_{intk,\,EGR,\,est} = \frac{\dot{m}_{EGR,\,est}}{\dot{m}_{intk,\,est}} \frac{t_s z}{\tau_{EGR} z + t_s - \tau_{EGR}}$$

The remainder of the gas is air.

$$y_{intk,\,air,\,est} = 1 - y_{intk,\,EGR,\,est}$$

The equations use these variables.

$y_{intk,EGR,est}$	Estimated intake manifold EGR mass fraction
$y_{intk,air,est}$	Estimated intake manifold air mass fraction
$\dot{m}_{EGR,\,est}$	Estimated low-pressure EGR mass flow
$\dot{m}_{intk,\,est}$	Estimated intake port mass flow
τ_{EGR}	EGR time constant

Torque

To calculate the brake torque, configure the SI engine to use either of these torque models.

Brake Torque Model	Description
"SI Engine Torque Structure Model"	For the structured brake torque calculation, the SI engine uses tables for the inner torque, friction torque, optimal spark, spark efficiency, and lambda efficiency. If you select **Crank angle pressure and torque** on the block **Torque** tab, you can: • Simulate advanced closed-loop engine controls in desktop simulations and on HIL bench, based on cylinder pressure recorded from a model or laboratory test as a function of crank angle. • Simulate driveline vibrations downstream of the engine due to high-frequency crankshaft torsionals. • Simulate engine misfires due to lean operation or spark plug fouling by using the injector pulse width input. • Simulate cylinder deactivation effect (closed intake and exhaust valves, no injected fuel) on individual cylinder pressures, mean-value airflow, mean-value torque, and crank-angle-based torque. • Simulate the fuel-cut effect on individual cylinder pressure, mean-value torque, and crank-angle-based torque.
"SI Engine Simple Torque Model"	For the simple brake torque calculation, the SI engine block uses a torque lookup table map that is a function of engine speed and load.

EGR

The controller estimates low-pressure mass flow, EGR valve inlet pressure, and EGR valve outlet pressure using an algorithm developed by F. Liu and J. Pfeiffer. The estimator requires measured EGR valve differential pressure, EGR valve area percent, intake air temperature, and EGR valve inlet temperature.

To estimate the EGR valve commands, the block uses:

- Equations

$$\dot{m}_{air,std} = \dot{m}_{air,est}\frac{P_{std}}{P_{amb}}\sqrt{\frac{IAT}{T_{std}}}$$

$$P_{in,EGR} = P_{out,EGR} + \Delta P_{EGR}$$

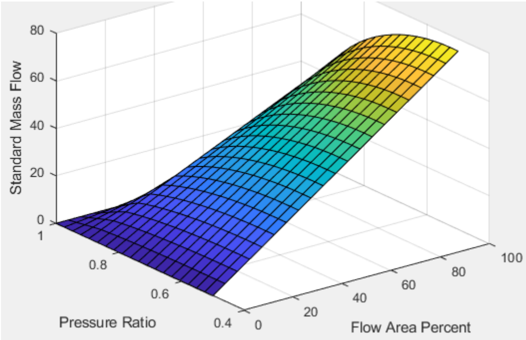
$$\dot{m}_{EGR,est} = \dot{m}_{EGR,std}\frac{P_{in,EGR}}{P_{std}}\sqrt{\frac{T_{std}}{T_{in,EGR}}}$$

- Tables
  - The EGR valve standard mass flow lookup table is a function of EGR valve area percent and the pressure ratio

$$\dot{m}_{EGR,std} = f_{EGR,std}\left(EGRap, \frac{P_{out,EGR}}{P_{in,EGR}}\right)$$

where:

- $\dot{m}_{EGR,std}$ is EGR valve standard mass flow, dimensionless.
- $EGRap$ is EGR valve flow area percent, in percent.
- $\frac{P_{out,EGR}}{P_{in,EGR}}$ is the pressure ratio, dimensionless.

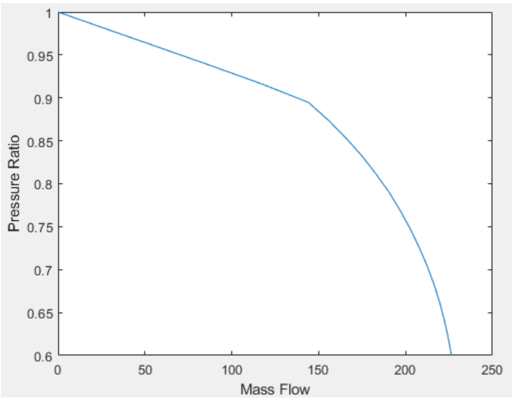


- The pressure ratio is a function of the standard mass flow

$$\frac{P_{out,EGR}}{P_{amb}} = f_{intksys,pr}(\dot{m}_{air,std})$$

where:

- $\dot{m}_{air,std}$ is standard mass flow, in g/s.
- $\frac{P_{out,EGR}}{P_{amb}}$ is pressure ratio, dimensionless.



The equations use these variables.

EGRap	EGR valve area percent command
IAT	Intake air temperature

$\dot{m}_{air,\,std}$, $\dot{m}_{EGR,\,std}$	Standard air and EGR valve mass flow, respectively
$\dot{m}_{air,\,est}$,$\dot{m}_{EGR,\,est}$	Estimated air and EGR valve mass flow, respectively
T_{std}, P_{std}	Standard temperature and pressure
T_{amb}, P_{amb}	Ambient temperature and pressure
ΔP_{EGR}	Pressure difference at EGR valve inlet and outlet
$T_{in,EGR}$, $T_{out,EGR}$	Temperature at EGR valve inlet and outlet, respectively
$P_{in,EGR}$, $P_{out,EGR}$	Pressure at EGR valve inlet and outlet, respectively

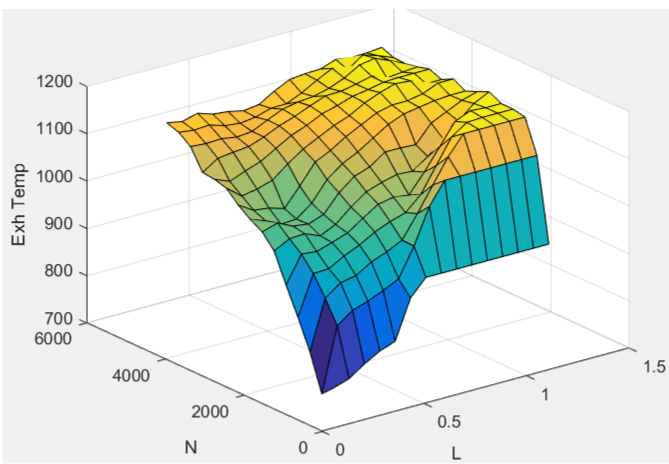
Exhaust Temperature

The exhaust temperature lookup table, f_{Texh}, is a function of engine load and engine speed

$$T_{exh} = f_{Texh}(L, N)$$

where:

- T_{exh} is engine exhaust temperature, in K.
- L is normalized cylinder air mass or engine load, dimensionless.
- N is engine speed, in rpm.



Ports

Input

TrqCmd — Commanded engine torque
scalar

Commanded engine torque, $Trq_{cmd,input}$, in N·m.

EngSpd — Measured engine speed
scalar

Measured engine speed, N, in rpm.

`AmbPrs` — Measured absolute ambient pressure
`scalar`

Measured ambient pressure, P_{Amb}, in Pa.

`Map` — Measured intake manifold absolute pressure
`scalar`

Measured intake manifold absolute pressureMAP, in Pa.

`Mat` — Measured intake manifold absolute temperature
`scalar`

Measured intake manifold absolute temperature, MAT, in K.

`IntkCamPhase` — Intake cam phaser angle
`scalar`

Intake cam phaser angle, φ_{ICP}, in degCrkAdv, or degrees crank advance.

`ExhCamPhase` — Exhaust cam phaser angle
`scalar`

Exhaust cam phaser angle, φ_{ECP}, in degCrkRet, or degrees crank retard.

`Iat` — Intake air temperature
`scalar`

Intake air temperature, IAT, in K.

`Ect` — Engine cooling temperature
`scalar`

Engine cooling temperature, $T_{coolant}$, in K.

`EgrVlvInTemp` — EGR valve inlet temperature
`scalar`

EGR valve inlet temperature, $T_{in,EGR}$, in K.

`EgrVlvAreaPct` — EGR valve area percent
`scalar`

EGR valve area percent, $EGRap$, in %.

`EgrVlvDeltaPrs` — EGR valve delta pressure
`scalar`

EGR valve delta pressure, ΔP_{EGR}, in Pa.

`O2VoltSen` — Oxygen sensor voltage
`scalar`

Oxygen sensor voltage for closed-loop air-fuel-ratio (lambda) control, in mV.

To configure the block to use closed-loop air-fuel-ratio control, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

`LambdaCmd` — Commanded AFR, lambda
`scalar`

Commanded air-fuel-ratio (lambda), λ_{cmd}, dimensionless.

Dependencies

To create this port, on the **Fuel** tab, on the **Open-loop fuel** pane, select **Input lambda**.

`IgSw` — Ignition switch
`Boolean`

State of the vehicle ignition switch, dimensionless.

Dependencies

To create this port, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

`ESSEnable` — Engine Stop-Start Enable
`Boolean`

Command to enable or disable the stop-start logic, dimensionless.

Dependencies

To create this port, on the **Stop-Start** tab, select **Enable Engine Stop-Start**. Select **External Enable Port**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Variable	Units
`TrqCmd`	Engine torque	Trq_{cmd}	N·m
`LdCmd`	Commanded load	L_{cmd}	N/A
`ThrPosCmd`	Throttle area percent command	TAP_{cmd}	%
`WgAreaPctCmd`	Wastegate area percent command	WAP_{cmd}	%
`InjPw`	Fuel injector pulse-width	Pw_{inj}	ms
`SpkAdv`	Spark advance	SA	degBTDC
`IntkCamPhaseCmd`	Intake cam phaser angle command	φ_{ICPCMD}	degCrkAdv
`ExhCamPhaseCmd`	Exhaust cam phaser angle command	φ_{ECPCMD}	degCrkRet
`EgrVlvAreaPctCmd`	Exhaust cam phaser angle command	$EGRap_{cmd}$	%
`FuelMassFlwCmd`	EGR valve area percent command	$\dot{m}_{fuel,cmd}$	kg/s
`AfrCmd`	Commanded air-fuel ratio	AFR_{cmd}	N/A

Signal	Description	Variable	Units
EstEngTrq	Estimated engine torque	Trq_{est}	N·m
EstNrmlzdAirCharg	Estimated normalized cylinder air mass	N/A	N/A
EstIntkPortMassFlw	Estimated intake port air mass flow rate	$\dot{m}_{intk,\,est}$	kg/s
EstIntkAirMassFlw	Estimated air mass flow rate	$\dot{m}_{air,\,est}$	kg/s
EstEgrMassFlw	Estimated low-pressure EGR mass flow rate	$\dot{m}_{EGR,\,est}$	kg/s
EstExhManGasTemp	Estimated exhaust manifold gas temperature	$T_{exh,est}$	K
EngRevLimAct	Flag that indicates if rev-limiter control is active	N/A	N/A
ClsdLpFuelMult	Fuel injector pulse-width multiplier for closed-loop AFR control	Pw_{inj_mult}	N/A

ThrPosPctCmd — Throttle area percent command
scalar

Throttle area percent command, TAP_{cmd}.

WgAreaPctCmd — Wastegate area percent command
scalar

Wastegate area percent command, WAP_{cmd}.

InjPw — Fuel injector pulse-width
scalar

Fuel injector pulse-width, Pw_{inj}, in ms.

SpkAdv — Spark advance
scalar

Spark advance, SA, in degrees crank angle before top dead center (degBTDC).

IntkCamPhaseCmd — Intake cam phaser angle command
scalar

Intake cam phaser angle command, φ_{ICPCMD}.

ExhCamPhaseCmd — Exhaust cam phaser angle command
scalar

Exhaust cam phaser angle command, φ_{ECPCMD}.

EgrVlvAreaPctCmd — EGR valve area percent command
scalar

EGR valve area percent command, $EGRap_{cmd}$, in %.

Parameters

Configuration

`Air mass flow estimation model` — Select air mass flow estimation model

`Dual Variable Cam Phasing` (default) | `Simple Speed-Density`

To calculate engine air mass flow, configure the SI engine to use either of these air mass flow models.

Air Mass Flow Model	Description
"SI Engine Speed-Density Air Mass Flow Model"	Uses the speed-density equation to calculate the engine air mass flow, relating the engine air mass flow to the intake manifold pressure and engine speed. Consider using this air mass flow model in engines with fixed valvetrain designs.
"SI Engine Dual-Independent Cam Phaser Air Mass Flow Model"	To calculate the engine air mass flow, the dual-independent cam phaser model uses: • Empirical calibration parameters developed from engine mapping measurements • Desktop calibration parameters derived from engine computer-aided design (CAD) data In contrast to typical embedded air mass flow calculations based on direct air mass flow measurement with an air mass flow (MAF) sensor, this air mass flow model offers: • Elimination of MAF sensors in dual cam-phased valvetrain applications • Reasonable accuracy with changes in altitude • Semiphysical modeling approach • Bounded behavior • Suitable execution time for electronic control unit (ECU) implementation • Systematic development of a relatively small number of calibration parameters

Dependencies

The table summarizes the parameter dependencies.

Air Mass Flow Estimation Model	Enables Parameters on Estimation > Air Tab
Dual Variable Cam Phasing	**Cylinder volume at intake valve close table, f_vivc** **Cylinder volume intake cam phase breakpoints, f_vivc_icp_bpt** **Cylinder trapped mass correction factor, f_tm_corr** **Normalized density breakpoints, f_tm_corr_nd_bpt** **Engine speed breakpoints, f_tm_corr_n_bpt** **Air mass flow, f_mdot_air** **Exhaust cam phase breakpoints, f_mdot_air_ecp_bpt** **Trapped mass flow breakpoints, f_mdot_trpd_bpt** **Air mass flow correction factor, f_mdot_air_corr** **Engine load breakpoints for air mass flow correction, f_mdot_air_corr_ld_bpt** **Engine speed breakpoints for air mass flow correction, f_mdot_air_n_bpt**
Simple Speed-Density	**Speed-density volumetric efficiency, f_nv** **Speed-density intake manifold pressure breakpoints, f_nv_prs_bpt** **Speed-density engine speed breakpoints, f_nv_n_bpt**

Torque estimation model — Select torque estimation model
Torque Structure (default) | Simple Torque Lookup

To calculate the brake torque, configure the SI engine to use either of these torque models.

Brake Torque Model	Description
"SI Engine Torque Structure Model"	For the structured brake torque calculation, the SI engine uses tables for the inner torque, friction torque, optimal spark, spark efficiency, and lambda efficiency. If you select **Crank angle pressure and torque** on the block **Torque** tab, you can: • Simulate advanced closed-loop engine controls in desktop simulations and on HIL bench, based on cylinder pressure recorded from a model or laboratory test as a function of crank angle. • Simulate driveline vibrations downstream of the engine due to high-frequency crankshaft torsionals. • Simulate engine misfires due to lean operation or spark plug fouling by using the injector pulse width input. • Simulate cylinder deactivation effect (closed intake and exhaust valves, no injected fuel) on individual cylinder pressures, mean-value airflow, mean-value torque, and crank-angle-based torque. • Simulate the fuel-cut effect on individual cylinder pressure, mean-value torque, and crank-angle-based torque.
"SI Engine Simple Torque Model"	For the simple brake torque calculation, the SI engine block uses a torque lookup table map that is a function of engine speed and load.

Dependencies

The table summarizes the parameter dependencies.

Torque Estimation Model	Enables Parameters on Estimation > Torque Tab
Torque Structure	**Inner torque table, f_tq_inr** **Friction torque table, f_tq_fric** **Engine temperature modifier on friction torque, f_fric_temp_mod** **Engine temperature modifier breakpoints, f_fric_temp_bpt** **Pumping torque table, f_tq_pump** **Optimal spark table, f_sa_opt** **Inner torque load breakpoints, f_tq_inr_l_bpt** **Inner torque speed breakpoints, f_tq_inr_n_bpt** **Spark efficiency table, f_m_sa** **Spark retard from optimal, f_del_sa_bpt** **Lambda efficiency, f_m_lam** **Lambda breakpoints, f_m_lam_bpt**
Simple Torque Lookup	**Torque table, f_tq_nl** **Torque table load breakpoints, f_tq_nl_l_bpt** **Torque table speed breakpoints, f_tq_nl_n_bpt**

Controls

Air

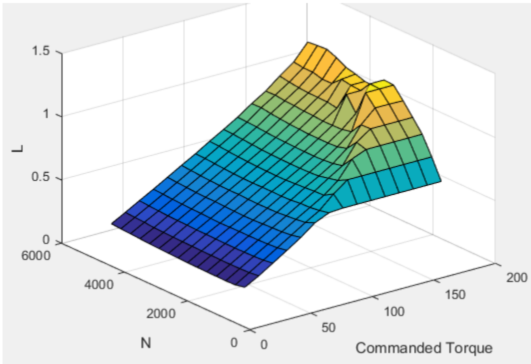
Engine commanded load table, f_lcmd — Lookup table
array

The commanded engine load lookup table, f_{Lcmd}, is a function of the commanded torque and engine speed

$$L_{cmd} = f_{Lcmd}(T_{cmd}, N)$$

where:

- L_{cmd}=L is commanded engine load, dimensionless.
- T_{cmd} is commanded torque, in N·m.
- N is engine speed, in rpm.



`Torque command breakpoints, f_lcmd_tq_bpt` — Breakpoints
`[15 26.43 37.86 49.29 60.71 72.14 83.57 95 106.4 117.9 129.3 140.7 152.1 163.6 175]` (default) | `vector`

Torque command breakpoints, in N·m.

`Speed breakpoints, f_lcmd_n_bpt` — Breakpoints
`[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000]` (default) | `vector`

Speed breakpoints, in rpm.

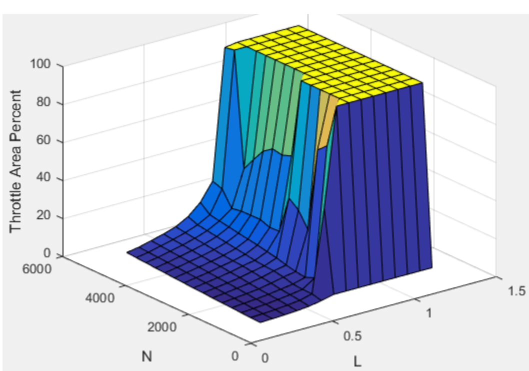
`Throttle area percent, f_tap` — Lookup table, %
`array`

The throttle area percent command lookup table, f_{TAPcmd}, is a function of commanded load and engine speed

$$TAP_{cmd} = f_{TAPcmd}(L_{cmd}, N)$$

where:

- TAP_{cmd} is throttle area percentage command, in percent.
- L_{cmd}=L is commanded engine load, dimensionless.
- N is engine speed, in rpm.



Throttle area percent load breakpoints, f_tap_ld_bpt — Breakpoints
[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25] (default) | vector

Throttle area percent load breakpoints, dimensionless.

Throttle area percent speed breakpoints, f_tap_n_bpt — Breakpoints
[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000] (default) | vector

Throttle area percent speed breakpoints, in rpm.

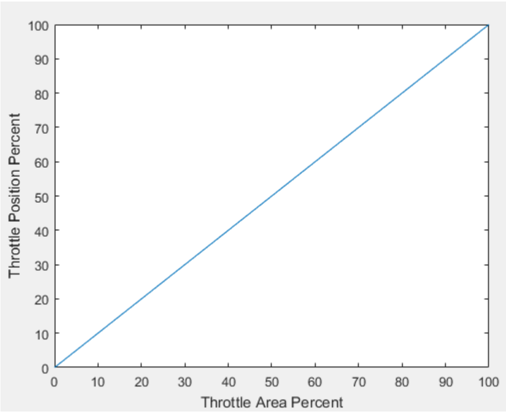
Throttle area percent to position percent table, f_tpp — Lookup table
[0 100] (default) | vector

The throttle position percent command lookup table, f_{TPPcmd}, is a function of the throttle area percentage command

$$TPP_{cmd} = f_{TPPcmd}(TAP_{cmd})$$

where:

- TPP_{cmd} is throttle position percentage command, in percent.
- TAP_{cmd} is throttle area percentage command, in percent.



Throttle area percent to position percent area breakpoints, f_tpp_tap_bpt — Breakpoints
[0 100] (default) | vector

Throttle area percent to position percent area breakpoints, dimensionless.

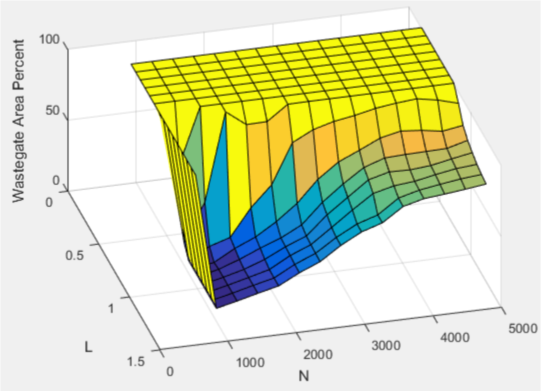
Wastegate area percent, f_wap — Lookup table, %
array

The wastegate area percent command lookup table, f_{WAPcmd}, is a function of the commanded engine load and engine speed

$$WAP_{cmd} = f_{WAPcmd}(L_{cmd}, N)$$

where:

- WAP_{cmd} is wastegate area percentage command, in percent.
- L_{cmd}=L is commanded engine load, dimensionless.
- N is engine speed, in rpm.



`Load breakpoints, f_wap_ld_bpt` — Breakpoints
`[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25]` (default) | `vector`

Load breakpoints, dimensionless.

`Speed breakpoints, f_wap_n_bpt` — Breakpoints, rpm
`[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000]` (default) | `vector`

Speed breakpoints, in rpm.

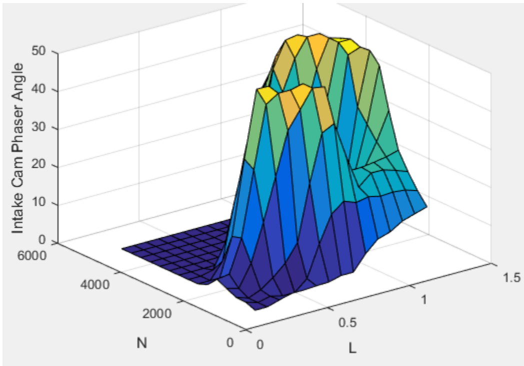
`Intake cam phaser angle, f_icp` — Lookup table
`array`

The intake cam phaser angle command lookup table, f_{ICPCMD}, is a function of the engine load and engine speed

$$\varphi_{ICPCMD} = f_{ICPCMD}(L_{est}, N)$$

where:

- φ_{ICPCMD} is commanded intake cam phaser angle, in degrees crank advance.
- L_{est}=L is estimated engine load, dimensionless.
- N is engine speed, in rpm.



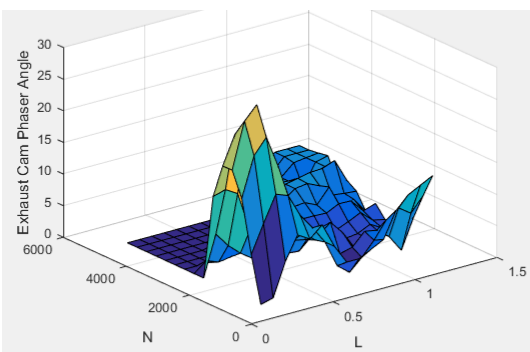
`Exhaust cam phaser angle, f_ecp` — Lookup table
`array`

The exhaust cam phaser angle command lookup table, f_{ECPCMD}, is a function of the engine load and engine speed

$$\varphi_{ECPCMD} = f_{ECPCMD}(L_{est}, N)$$

where:

- φ_{ECPCMD} is commanded exhaust cam phaser angle, in degrees crank retard.
- L_{est}=L is estimated engine load, dimensionless.
- N is engine speed, in rpm.



`Load breakpoints, f_cp_ld_bpt` — Breakpoints
`[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25]` (default) | `vector`

Load breakpoints, dimensionless.

`Speed breakpoints, f_cp_n_bpt` — Breakpoints
`[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000]` (default) | `vector`

Speed breakpoints, in rpm.

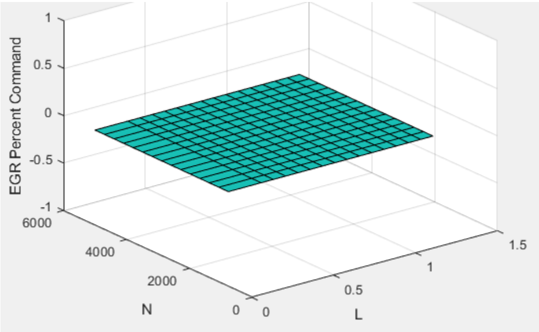
`Commanded EGR percent, f_egrpct_cmd` — Lookup table
`array`

The EGR percent command, $EGR_{pct,cmd}$, lookup table is a function of estimated engine load and engine speed

$$EGR_{pct,\,cmd} = f_{EGRpct,\,cmd}(L_{est}, N)$$

where:

- $EGR_{pct,cmd}$ is commanded EGR percent, dimensionless.
- L_{est}=L is estimated engine load, dimensionless.
- N is engine speed, in rpm.



`Load breakpoints, f_egrpct_ld_bpt` — Breakpoints
`[0 0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25]` (default) | `vector`

Engine load breakpoints, L, dimensionless.

`Speed breakpoints, f_egrpct_n_bpt` — Breakpoints
`[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000]` (default) | `vector`

Engine speed breakpoints, N, in rpm.

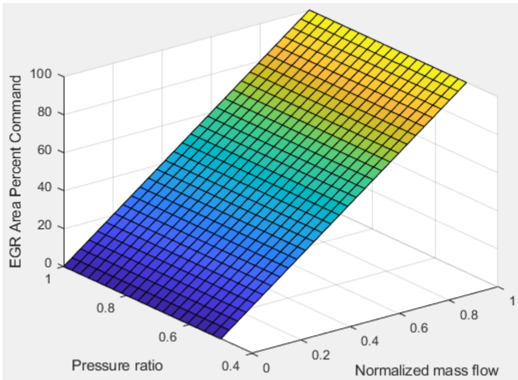
`EGR valve area percent, f_egr_areapct_cmd` — Lookup table
`array`

The EGR area percent command, $EGRap_{cmd}$, lookup table is a function of the normalized mass flow and pressure ratio

$$EGRap_{cmd} = f_{EGRap,\,cmd}\left(\frac{\dot{m}_{EGRstd,\,cmd}}{\dot{m}_{EGRstd,\,max}}, \frac{P_{out,\,EGR}}{P_{in,\,EGR}}\right)$$

where:

- $EGRap_{cmd}$ is commanded EGR area percent, dimensionless.
- $\frac{\dot{m}_{EGRstd,\,cmd}}{\dot{m}_{EGRstd,\,max}}$ is the normalized mass flow, dimensionless.
- $\frac{P_{out,\,EGR}}{P_{in,\,EGR}}$ is the pressure ratio, dimensionless.



`Open EGR valve standard flow, f_egr_max_stdflow` — Breakpoints
`[74.87 74.87 74.74 74.39 73.81 72.98 71.91 70.58 68.97 67.06 64.84 62.25 59.27 55.81 51.79 47.07 36.33 24.22 12.11 0]` (default) | `vector`

Maximum standard EGR valve mass flow breakpoints, $\dot{m}_{EGRstd,max}$, in N·m.

`Normalized EGR valve standard flow breakpoints, f_egr_areapct_nrmlzdflow_bpt` — Breakpoints
`[0 0.03448 0.06897 0.1034 0.1379 0.1724 0.2069 0.2414 0.2759 0.3103 0.3448 0.3793 0.4138 0.4483 0.4828 0.5172 0.5517 0.5862 0.6207 0.6552 0.6897 0.7241 0.7586 0.7931 0.8276 0.8621 0.8966 0.931 0.9655 1]` (default) | `vector`

Normalized mass flow breakpoints, $\frac{\dot{m}_{EGRstd,cmd}}{\dot{m}_{EGRstd,max}}$, dimensionless.

`EGR valve pressure ratio breakpoints, f_egr_areapct_pr_bpt` — Breakpoints
`vector`

Pressure ratio breakpoints, $\frac{P_{out,EGR}}{P_{in,EGR}}$, dimensionless.

Fuel

`Injector slope, Sinj` — Slope
`6.452` (default) | `scalar`

Fuel injector slope, S_{inj}, in mg/ms.

`Stoichiometric air-fuel ratio, afr_stoich` — Ratio
`14.6` (default) | `scalar`

Stoichiometric air-fuel ratio, AFR_{stoich}.

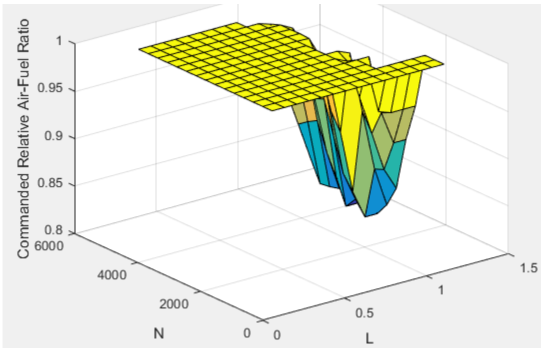
`Relative air-fuel ratio lambda, f_lamcmd` — Air-fuel-ratio (AFR) lookup table
`array`

The commanded lambda, λ_{cmd}, lookup table is a function of estimated engine load and measured engine speed

$$\lambda_{cmd} = f_{\lambda cmd}(L_{est}, N)$$

where:

- λ_{cmd} is commanded relative AFR, dimensionless.
- L_{est}=L is estimated engine load, dimensionless.
- N is engine speed, in rpm.



Dependencies

To create this parameter, on the **Fuel** tab, on the **Open-loop fuel** pane, clear **Input lambda**.

`Load breakpoints, f_lamcmd_ld_bpt` — Breakpoints
`[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25]` (default) | `vector`

Load breakpoints, dimensionless.

Dependencies

To create this parameter, on the **Fuel** tab, on the **Open-loop fuel** pane, clear **Input lambda**.

`Speed breakpoints, f_lamcmd_n_bpt` — Breakpoints
`[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000]` (default) | `vector`

Speed breakpoints, in rpm.

Dependencies

To create this parameter, on the **Fuel** tab, on the **Open-loop fuel** pane, clear **Input lambda**.

`Engine startup lambda enrichment delta vs coolant temperature, f_startup_lambda_delta` — Lookup table
`[0.5 0.3 0.2 0]` (default) | `vector`

Engine startup lambda enrichment delta as a function of coolant temperature, dimensionless.

The SI Controller block uses this parameter to account for the extra fuel delivered to the spark-ignition (SI) engine during startup. If the engine speed is greater than the **Engine cranking speed** parameter, the SI Controller block enriches the optimal relative air-fuel ratio (lambda) with an exponentially decaying delta lambda. To initialize the delta lambda, the block uses the **Engine startup lambda enrichment delta vs coolant temperature** parameter to create a lambda enrichment table that is a function of the engine coolant temperature. The delta lambda exponentially decays to zero based on a time constant specified with the **Engine startup lambda enrichment delta time constant vs coolant temperature** parameter.

Dependencies

To create this parameter, on the **Fuel** tab, on the **Open-loop fuel** pane, clear **Input lambda**.

Engine startup lambda enrichment delta time constant vs coolant temperature, f_startup_lambda_delta_timecnst — Lambda time constant

`[90 40 12 0]` (default) | `vector`

Engine startup lambda enrichment delta time constant versus coolant temperature, in s.

The SI Controller block uses this parameter to account for the extra fuel delivered to the spark-ignition (SI) engine during startup. If the engine speed is greater than the **Engine cranking speed** parameter, the SI Controller block enriches the optimal relative air-fuel ratio (lambda) with an exponentially decaying delta lambda. To initialize the delta lambda, the block uses the **Engine startup lambda enrichment delta vs coolant temperature** parameter to create a lambda enrichment table that is a function of the engine coolant temperature. The delta lambda exponentially decays to zero based on a time constant specified with the **Engine startup lambda enrichment delta time constant vs coolant temperature** parameter.

Dependencies

To create this parameter, on the **Fuel** tab, on the **Open-loop fuel** pane, clear **Input lambda**.

Engine startup coolant temperature breakpoints, f_startup_ect_bpt — Breakpoints

`[-40 0 20 50]` (default) | `vector`

Engine startup coolant temperature breakpoints, in C.

The SI Controller block uses this parameter to account for the extra fuel delivered to the spark-ignition (SI) engine during startup. If the engine speed is greater than the **Engine cranking speed** parameter, the SI Controller block enriches the optimal relative air-fuel ratio (lambda) with an exponentially decaying delta lambda. To initialize the delta lambda, the block uses the **Engine startup lambda enrichment delta vs coolant temperature** parameter to create a lambda enrichment table that is a function of the engine coolant temperature. The delta lambda exponentially decays to zero based on a time constant specified with the **Engine startup lambda enrichment delta time constant vs coolant temperature** parameter.

Dependencies

To create this parameter, on the **Fuel** tab, on the **Open-loop fuel** pane, clear **Input lambda**.

Closed-loop feedback — Minimize commanded AFR error

`off` (default) | `on`

Select option to minimize the commanded air-fuel-ratio (lambda), λ_{cmd} error.

Dependencies

Selecting this parameter enables these parameters:

- **Closed-loop fuel proportional gain, ClsdLpFuelPGain**
- **Closed-loop fuel integral gain, ClsdLpFuelIGain**

- **Closed-loop fuel integrator limit, ClsdLpFuelIntgLmt**
- **Lambda dither amplitude, LambdaDitherAmp**
- **Lambda dither frequency, LambdaDitherFrq**
- **Oxygen sensor stoichiometric reset voltage, O2ResetStoichVoltSen**
- **Oxygen sensor minimum voltage reset, O2ResetMinVoltSen**
- **Oxygen sensor maximum voltage reset, O2ResetMaxVoltSen**
- **Oxygen sensor voltage learn update period, O2LearnUpdatePerSen**
- **Oxygen sensor voltage amplitude minimum, O2AmpMinVoltSen**
- **Oxygen sensor ready voltage, O2ReadyVoltSen**
- **Oxygen sensor not ready voltage, O2NotReadyVoltSen**

`Dither` — Model catalytic conversion efficiency
`off` (default) | `on`

Configure the block to model dither. For open-loop analysis, select this option to tune for maximum catalytic conversion efficiency.

Dependencies

By default, selecting **Closed-loop feedback** configures the block to model dither.

To enable this parameter for open-loop air-fuel-ratio (lambda) commands, clear **Closed-loop feedback**.

Selecting this parameter enables these parameters:

- **Lambda dither amplitude, LambdaDitherAmp**
- **Lambda dither frequency, LambdaDitherFrq**

`Closed-loop fuel proportional gain, ClsdLpFuelPGain` — Proportional gain
`0.005` (default) | `scalar`

Closed-loop fuel proportional gain, dimensionless.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

`Closed-loop fuel integral gain, ClsdLpFuelIGain` — Integral gain
`0.05` (default) | `scalar`

Closed-loop fuel integral gain, dimensionless.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

`Closed-loop fuel integrator limit, ClsdLpFuelIntgLmt` — Integrator limit
`0.2` (default) | `scalar`

Closed-loop fuel integrator limit, dimensionless.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

Lambda dither amplitude, LambdaDitherAmp — Amplitude
0.03 (default) | scalar

Lambda dither amplitude, dimensionless.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select either **Closed-loop feedback** or **Dither**.

Lambda dither frequency, LambdaDitherFrq — Frequency
0.75 (default) | scalar

Lambda dither frequency, in Hz.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select either **Closed-loop feedback** or **Dither**.

Oxygen sensor stoichiometric reset voltage, O2ResetStoichVoltSen — Closed-loop AFR control
2500 (default) | scalar

Oxygen sensor stoichiometric reset voltage, O2ResetStoichVoltSen, in mV.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

Oxygen sensor minimum voltage reset, O2ResetMinVoltSen — Closed-loop AFR control
0 (default) | scalar

Oxygen sensor minimum voltage reset, O2ResetMinVoltSen, in mV.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

Oxygen sensor maximum voltage reset, O2ResetMaxVoltSen — Closed-loop AFR control
5000 (default) | scalar

Oxygen sensor maximum voltage reset, O2ResetMaxVoltSen, in mV.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

Oxygen sensor voltage learn update period, O2LearnUpdatePerSen — Closed-loop AFR control

4 (default) | scalar

Oxygen sensor voltage learn update period, O2LearnUpdatePerSen, in mV.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

Oxygen sensor voltage amplitude minimum, O2AmpMinVoltSen — Closed-loop AFR control

250 (default) | scalar

Oxygen sensor voltage amplitude minimum, O2AmpMinVoltSen, in mV.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

Oxygen sensor ready voltage, O2ReadyVoltSen — Closed-loop AFR control

1150 (default) | scalar

Oxygen sensor ready voltage, O2ReadyVoltSen, in mV.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

Oxygen sensor not ready voltage, O2NotReadyVoltSen — Closed-loop AFR control

1950 (default) | scalar

Oxygen sensor not ready voltage, O2NotReadyVoltSen, in mV.

Dependencies

To enable this parameter, on the **Fuel** tab, on the **Closed-loop fuel** pane, select **Closed-loop feedback**.

Spark

Spark advance table, f_sa — Lookup table

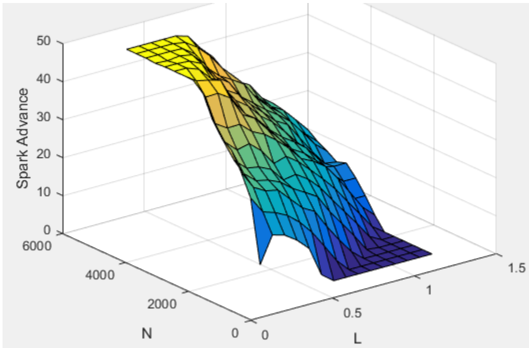
array

The spark advance lookup table is a function of estimated load and engine speed.

$$SA = f_{SA}(L_{est}, N)$$

where:

- SA is spark advance, in crank advance degrees.
- L_{est}=L is estimated engine load, dimensionless.
- N is engine speed, in rpm.



Load breakpoints, f_sa_ld_bpt — Breakpoints
[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25] (default) | vector

Load breakpoints, dimensionless.

Speed breakpoints, f_sa_n_bpt — Breakpoints
[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000] (default) | vector

Speed breakpoints, in rpm.

Idle Speed

Target idle speed, N_idle — Speed
750 (default) | scalar

Target idle speed, N_{idle}, in rpm.

Enable torque command limit, Trq_idlecmd_enable — Torque
1 (default) | scalar

Torque to enable the idle speed controller, $Trq_{idlecmd,enable}$, in N·m.

Maximum torque command, Trq_idlecmd_max — Torque
50 (default) | scalar

Maximum idle controller commanded torque, $Trq_{idlecmd,max}$, in N·m.

Proportional gain, Kp_idle — PI Controller
0.05 (default) | scalar

Proportional gain for idle speed control, $K_{p,idle}$, in N·m/rpm.

Integral gain, Ki_idle — PI Controller
0.2 (default) | scalar

Integral gain for idle speed control, $K_{i,idle}$, in N·m/(rpm·s).

Rev-limiter speed threshold — Engine speed limit
scalar

Engine speed limit, N_{lim}, in rpm.

If the engine speed, N, exceeds the engine speed limit, N_{lim}, the block sets the commanded engine torque to 0.

To smoothly transition the torque command to 0 as the engine speed approaches the speed limit, the block implements a lookup table multiplier. The lookup table multiplies the torque command by a value that ranges from 0 (engine speed exceeds limit) to 1 (engine speed does not exceed the limit).

Engine cranking speed, CrankSpeed — Engine speed
150 (default) | scalar

Engine cranking speed, in rpm.

Stop-Start

Enable Engine Stop-Start — Select to enable the engine stop-start logic
off (default) | on

Select to enable the engine stop-start logic. Selecting this option will activate additional parameters to modify the behavior of the Engine Stop-Start block.

External Enable Port — Create input port
off (default) | on

Select to add a port to the engine controller block which enables or disables the stop-start logic.

Dependencies

To enable this parameter, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

Engine stop time, EngStopTime [s] — Engine stop time
5 (default) | scalar

Engine stop time for the stop-start logic, in s.

Dependencies

To enable this parameter, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

Catalyst light off time, CatLightOffTime [s] — Catalyst light off time
0 (default) | scalar

Catalyst light off time for the stop-start logic, in s.

Dependencies

To enable this parameter, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

Sample time, Ts [s] — Sample time
0.01 (default) | scalar

Sample time for the stop-start logic, in s.

Dependencies

To enable this parameter, on the **Stop-Start** tab, select **Enable Engine Stop-Start**.

Estimation

Air

`Number of cylinders, NCyl` — Engine cylinders
`4` (default) | `scalar`

Number of engine cylinders, N_{cyl}.

`Crank revolutions per power stroke, Cps` — Revolutions per stroke
`2` (default) | `scalar`

Crankshaft revolutions per power stroke, Cps, in rev/stroke.

`Total displaced volume, Vd` — Volume
`0.0015` (default) | `scalar`

Displaced volume, V_d, in m^3.

`Ideal gas constant air, Rair` — Constant
`287` (default) | `scalar`

Ideal gas constant, R_{air}, in J/(kg·K).

`Air standard pressure, Pstd` — Pressure
`101325` (default) | `scalar`

Standard air pressure, P_{std}, in Pa.

`Air standard temperature, Tstd` — Temperature
`293.15` (default) | `scalar`

Standard air temperature, T_{std}, in K.

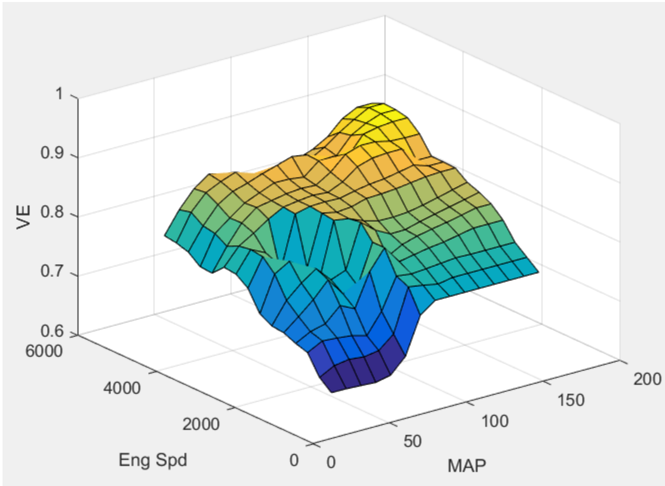
`Speed-density volumetric efficiency, f_nv` — Lookup table
`array`

The engine volumetric efficiency lookup table, f_{η_v}, is a function of intake manifold absolute pressure and engine speed

$$\eta_v = f_{\eta_v}(MAP, N)$$

where:

- η_v is engine volumetric efficiency, dimensionless.
- MAP is intake manifold absolute pressure, in KPa.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Simple Speed-Density`.

`Speed-density intake manifold pressure breakpoints, f_nv_prs_bpt` — Breakpoints
`[31 40.64 50.29 59.93 69.57 79.21 88.86 98.5 108.1 117.8 127.4 137.1 146.7 156.4 166]` (default) | `vector`

Intake manifold pressure breakpoints for speed-density volumetric efficiency lookup table, in KPa.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Simple Speed-Density`.

`Speed-density engine speed breakpoints, f_nv_n_bpt` — Breakpoints
`[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000]` (default) | `vector`

Engine speed breakpoints for speed-density volumetric efficiency lookup table, in rpm.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Simple Speed-Density`.

`Cylinder volume at intake valve close table, f_vivc` — 2-D lookup table
`array`

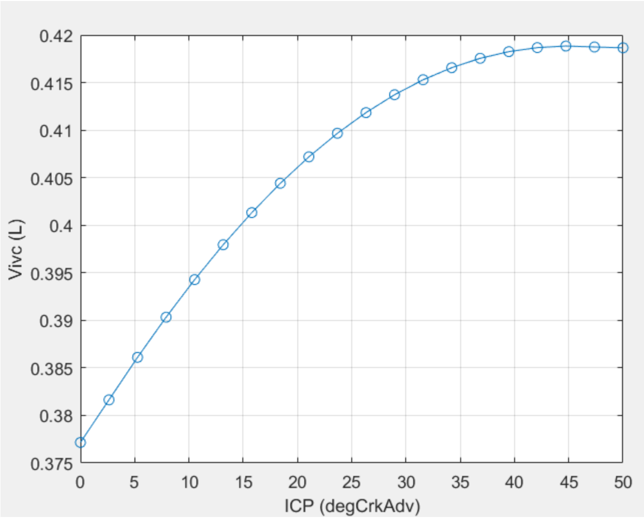
The cylinder volume at intake valve close table (IVC), f_{Vivc} is a function of the intake cam phaser angle

$$V_{IVC} = f_{Vivc}(\varphi_{ICP})$$

where:

- V_{IVC} is cylinder volume at IVC, in L.

- φ_{ICP} is intake cam phaser angle, in crank advance degrees.



Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Engine speed breakpoints, f_tm_corr_n_bpt` — Breakpoints

`[750 973.7 1197 1421 1645 1868 2092 2316 2539 2763 2987 3211 3434 3658 3882 4105 4329 4553 4776 5000]` (default) | `vector`

Engine speed breakpoints, in rpm.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Cylinder volume intake cam phase breakpoints, f_vivc_icp_bpt` — Breakpoints

`[0 2.632 5.263 7.895 10.53 13.16 15.79 18.42 21.05 23.68 26.32 28.95 31.58 34.21 36.84 39.47 42.11 44.74 47.37 50]` (default) | `vector`

Cylinder volume at intake valve close table breakpoints.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Cylinder trapped mass correction factor, f_tm_corr` — Lookup table

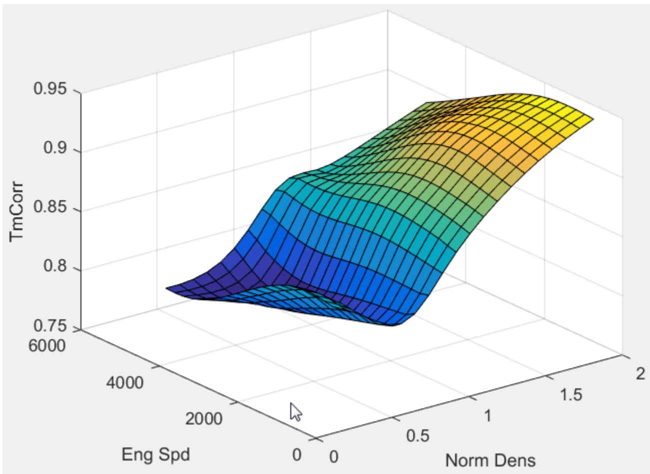
`array`

The trapped mass correction factor table, f_{TMcorr}, is a function of the normalized density and engine speed

$$TM_{corr} = f_{TMcorr}(\rho_{norm}, \quad N)$$

where:

- TM_{corr}, is trapped mass correction multiplier, dimensionless.
- ρ_{norm} is normalized density, dimensionless.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Normalized density breakpoints, f_tm_corr_nd_bpt` — Breakpoints

`[0.3 0.3895 0.4789 0.5684 0.6579 0.7474 0.8368 0.9263 1.016 1.105 1.195 1.284 1.374 1.463 1.553 1.642 1.732 1.821 1.911 2]` (default) | `vector`

Normalized density breakpoints.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Intake mass flow, f_mdot_intk` — Lookup table

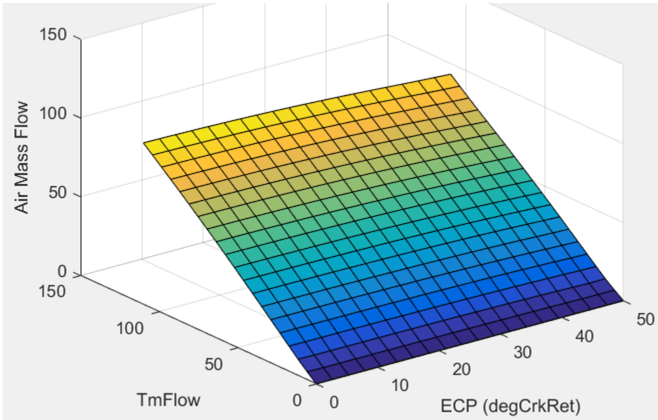
`array`

The phaser intake mass flow model lookup table is a function of exhaust cam phaser angles and trapped air mass flow

$$\dot{m}_{intkideal} = f_{intkideal}(\varphi_{ECP}, TM_{flow})$$

where:

- $\dot{m}_{intkideal}$ is engine intake port mass flow at arbitrary cam phaser angles, in g/s.
- φ_{ECP} is exhaust cam phaser angle, in degrees crank retard.
- TM_{flow} is flow rate equivalent to corrected trapped mass at the current engine speed, in g/s.



Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Exhaust cam phase breakpoints, f_mdot_air_ecp_bpt` — Breakpoints

`[0 2.632 5.263 7.895 10.53 13.16 15.79 18.42 21.05 23.68 26.32 28.95 31.58 34.21 36.84 39.47 42.11 44.74 47.37 50]` (default) | `vector`

Exhaust cam phaser breakpoints for air mass flow lookup table.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Trapped mass flow breakpoints, f_mdot_trpd_bpt` — Breakpoints

`[0 5.79 11.58 17.37 23.16 28.95 34.74 40.53 46.32 52.11 57.89 63.68 69.47 75.26 81.05 86.84 92.63 98.42 104.2 110]` (default) | `vector`

Trapped mass flow breakpoints for air mass flow lookup table.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Air mass flow correction factor, f_mdot_air_corr` — Lookup table

`array`

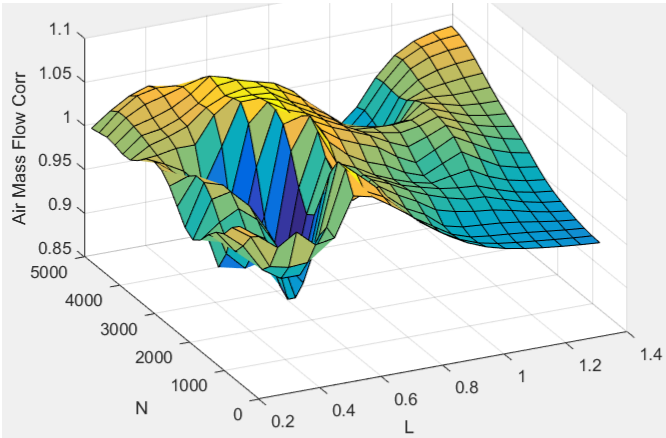
The intake air mass flow correction lookup table, $f_{aircorr}$, is a function of ideal load and engine speed

$$\dot{m}_{air} = \dot{m}_{intkideal} f_{aircorr}(L_{ideal}, N)$$

where:

- L_{ideal} is engine load (normalized cylinder air mass) at arbitrary cam phaser angles, uncorrected for final steady-state cam phaser angles, dimensionless.
- N is engine speed, in rpm.
- $\dot{m}_{air}$ is engine intake air mass flow final correction at steady-state cam phaser angles, in g/s.

- $\dot{m}_{intkideal}$ is engine intake port mass flow at arbitrary cam phaser angles, in g/s.



Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Engine load breakpoints for air mass flow correction, f_mdot_air_corr_ld_bpt` — Breakpoints

`vector`

Engine load breakpoints for air mass flow final correction.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`Engine speed breakpoints for air mass flow correction, f_mdot_air_n_bpt` — Breakpoints

`[750 973.7 1197 1421 1645 1868 2092 2316 2539 2763 2987 3211 3434 3658 3882 4105 4329 4553 4776 5000]` (default) | `vector`

Engine speed breakpoints for air mass flow final correction.

Dependencies

To enable this parameter, for the **Air mass flow estimation model** parameter, select `Dual Variable Cam Phasing`.

`EGR flow time constant, tau_egr` — Constant

`0.2` (default) | `scalar`

EGR flow time constant, τ_{EGR}, in s.

`Intake system pressure ratio table, f_intksys_stdflow_pr` — Table

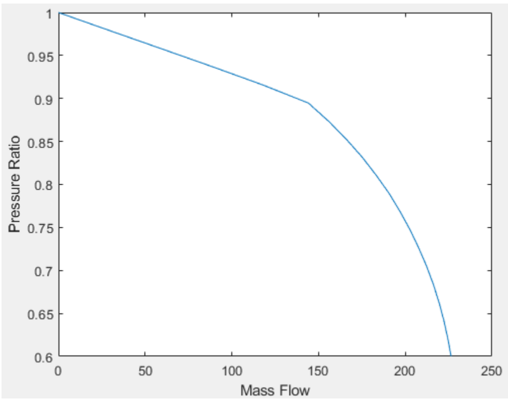
`array`

The pressure ratio is a function of the standard mass flow

$$\frac{P_{out,EGR}}{P_{amb}} = f_{intksys,pr}(\dot{m}_{air,std})$$

where:

- $\dot{m}_{air,std}$ is standard mass flow, in g/s.
- $\frac{P_{out,EGR}}{P_{amb}}$ is pressure ratio, dimensionless.



Standard mass flow rate breakpoints for intake pressure ratio, f_intksys_stdflow_bpt — Breakpoints
[0 29.67 59.34 89.01 117.8 144.1 155.7 166 175.2 183.3 190.7 197 202.7 207.7 212.2 216.1 219.4 222.2 224.5 226.4] (default) | vector

Standard mass flow, $\dot{m}_{air,std}$, in g/s.

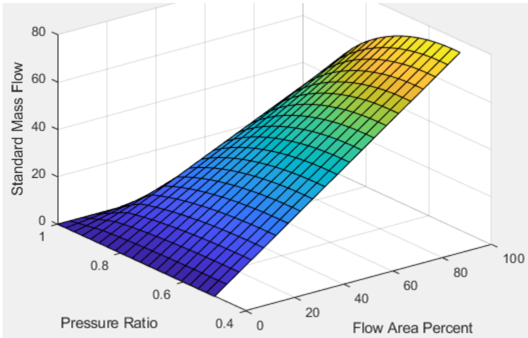
EGR valve standard mass flow rate, f_egr_stdflow — Table
array

The EGR valve standard mass flow lookup table is a function of EGR valve area percent and the pressure ratio

$$\dot{m}_{EGR,std} = f_{EGR,std}\left(EGRap, \frac{P_{out,EGR}}{P_{in,EGR}}\right)$$

where:

- $\dot{m}_{EGR,std}$ is EGR valve standard mass flow, dimensionless.
- $EGRap$ is EGR valve flow area percent, in percent.
- $\frac{P_{out,EGR}}{P_{in,EGR}}$ is the pressure ratio, dimensionless.



`EGR valve standard flow pressure ratio breakpoints, f_egr_stdflow_pr_bpt` — Breakpoints
`vector`

EGR valve standard flow pressure ratio, $\frac{P_{out,EGR}}{P_{in,EGR}}$, dimensionless.

`EGR valve standard flow area percent breakpoints, f_egr_stdflow_egrap_bpt` — Breakpoints
`[0;5;10;15;20;25;30;35;40;45;50;55;60;65;70;75;80;85;90;95;100]` (default) | `vector`

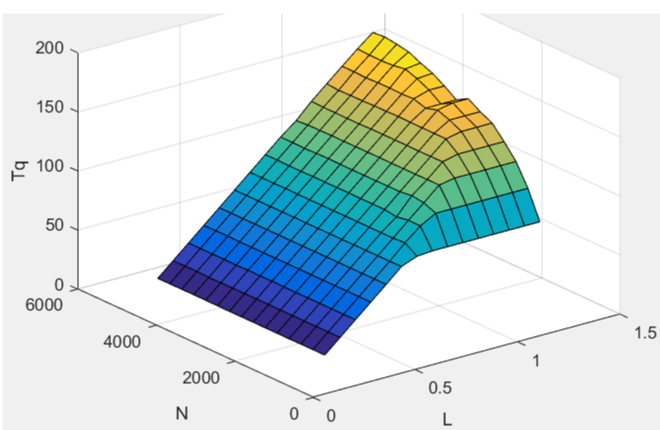
EGR valve flow area percent, *EGRap*, in percent.

Torque

`Torque table, f_tq_nl` — Lookup table
`[L x N] array`

For the simple torque lookup table model, the SI engine uses a lookup table map that is a function of engine speed and load, $T_{brake} = f_{TnL}(L, N)$, where:

- T_{brake} is engine brake torque after accounting for spark advance, AFR, and friction effects, in N·m.
- L is engine load, as a normalized cylinder air mass, dimensionless.
- N is engine speed, in rpm.



The simple torque lookup model assumes that the calibration has negative torque values to indicate the non-firing engine load (L) versus speed (N) condition. The calibrated table (L-by-N) contains the non-firing data in the first table row (1-by-N). When the fuel delivered to the engine is zero, the model uses the data in the first table row (1-by-N) at or above 100 AFR. 100 AFR results from fuel cutoff or very lean operation where combustion cannot occur.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table load breakpoints, f_tq_nl_l_bpt` — Breakpoints

`[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25]` (default) | `vector` | `[1 x L] vector`

Engine load breakpoints, *L*, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table speed breakpoints, f_tq_nl_n_bpt` — Breakpoints

`[750 1053.57142857143 1357.14285714286 1660.71428571429 1964.28571428571 2267.85714285714 2571.42857142857 2875 3178.57142857143 3482.14285714286 3785.71428571429 4089.28571428571 4392.85714285714 4696.42857142857 5000]` (default) | `vector` | `[1 x N] vector`

Engine speed breakpoints, *N*, in rpm.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Crank angle pressure and torque` — Enable Crank angle signals

`off` (default) | `on`

If you select **Crank angle pressure and torque** on the block **Torque** tab, you can:

- Simulate advanced closed-loop engine controls in desktop simulations and on HIL bench, based on cylinder pressure recorded from a model or laboratory test as a function of crank angle.
- Simulate driveline vibrations downstream of the engine due to high-frequency crankshaft torsionals.
- Simulate engine misfires due to lean operation or spark plug fouling by using the injector pulse width input.
- Simulate cylinder deactivation effect (closed intake and exhaust valves, no injected fuel) on individual cylinder pressures, mean-value airflow, mean-value torque, and crank-angle-based torque.
- Simulate the fuel-cut effect on individual cylinder pressure, mean-value torque, and crank-angle-based torque.

Dependencies

To enable this parameter, set **Torque model** to `Torque Structure`.

`Cylinder pressure, f_crk_prs` — Cylinder pressure table

`L x M x N` array

Cylinder pressure table *Prs*, as a function of speed *N*, load *L*, and crank angle *M*, in Pa.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`. Select **Crank angle pressure and torque**.

`Brake torque, f_crk_btq` — Brake torque table

`L x M x N` array

Brake torque table T_{brake}, as a function of speed *N*, load *L*, and crank angle *M*, in N·m.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`. Select **Crank angle pressure and torque**.

`Speed breakpoints, f_crk_n_bpt` — Speed breakpoints

`[750 5000]` (default) | `1 x N` vector

Speed breakpoints, *N*, in rpm.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`. Select **Crank angle pressure and torque**.

`Load breakpoints, f_crk_l_bpt` — Load breakpoints

`[0.2 1.4]` (default) | `1 x L` vector

Load breakpoints, *L*. No dimension.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`. Select **Crank angle pressure and torque**.

`Crank angle breakpoints, f_crk_ang_bpt` — Crank angle breakpoints

`[60 660]` (default) | `1 x M` vector

Crank angle breakpoints, *M*, in deg.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`. Select **Crank angle pressure and torque**.

`TDC compression angles by cylinder, f_crk_tdc_ang` — TDC compression angles by cylinder

`[0 540 180 360]` (default) | vector

Top dead center (TDC) compression angles by cylinder, in deg.

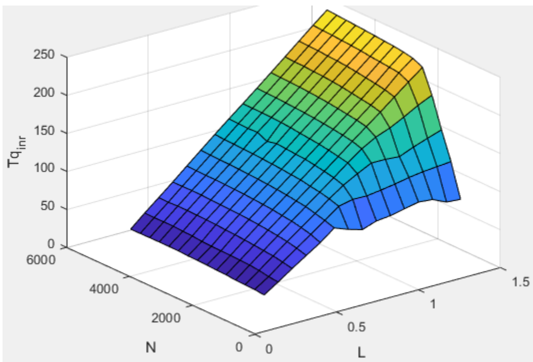
Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`. Select **Crank angle pressure and torque**.

`Inner torque table, f_tq_inr` — Lookup table
`array`

The inner torque lookup table, f_{Tqinr}, is a function of engine speed and engine load, $Tq_{inr} = f_{Tqinr}(L, N)$, where:

- Tq_{inr} is inner torque based on gross indicated mean effective pressure, in N·m.
- L is engine load at arbitrary cam phaser angles, corrected for final steady-state cam phaser angles, dimensionless.
- N is engine speed, in rpm.



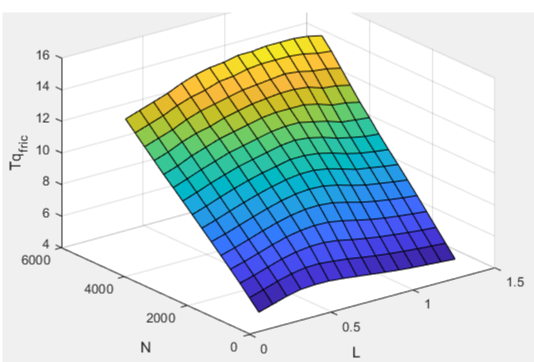
Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Friction torque table, f_tq_fric` — Lookup table
`array`

The friction torque lookup table, f_{Tfric}, is a function of engine speed and engine load, $T_{fric} = f_{Tfric}(L, N)$, where:

- T_{fric} is friction torque offset to inner torque, in N·m.
- L is engine load at arbitrary cam phaser angles, corrected for final steady-state cam phaser angles, dimensionless.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Engine temperature modifier on friction torque, f_fric_temp_mod` — Lookup table

`[3.96 3.22 2.56 2.26 2.11 2 1.9 1.83 1.76 1.7 1.65 1.6 1.55 1.49 1.44 1.41 1.38 1.35 1.32 1.3 1.27 1.25 1.24 1.21 1.2 1.18 1.16 1.15 1.13 1.12 1.11 1.1 1.09 1.08 1.07 1.06 1.05 1.05 1.04 1.03 1.02 1.02 1.01 1.01 1 1 1 0.999 0.997 0.995 0.993 0.991 0.989 0.987]` (default) | `vector` | `vector`

Engine temperature modifier on friction torque, $f_{fric,temp}$, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Engine temperature modifier breakpoints, f_fric_temp_bpt` — Breakpoints

`[274 276 278 280 282 284 286 288 290 292 294 296 298 300 302 304 306 308 310 312 314 316 318 320 322 324 326 328 330 332 334 336 338 340 342 344 346 348 350 352 354 356 358 360 362 364 366 368 370 372 374 376 378 380]` (default) | `vector` | `vector`

Engine temperature modifier breakpoints, in K.

Dependencies

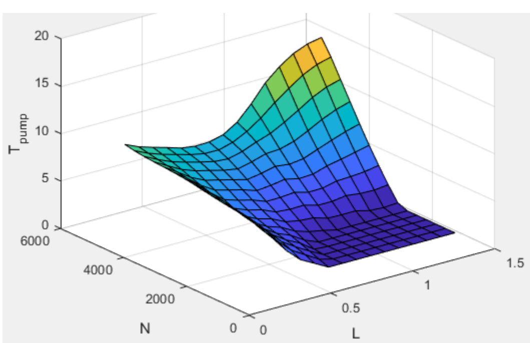
To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Pumping work table, f_tq_pump` — Lookup table

`array`

The pumping work lookup table, f_{Tpump}, is a function of engine load and engine speed, $T_{pump}=f_{Tpump}(L,N)$, where:

- T_{pump} is pumping work, in N·m.
- L is engine load, as a normalized cylinder air mass, dimensionless.
- N is engine speed, in rpm.



Dependencies

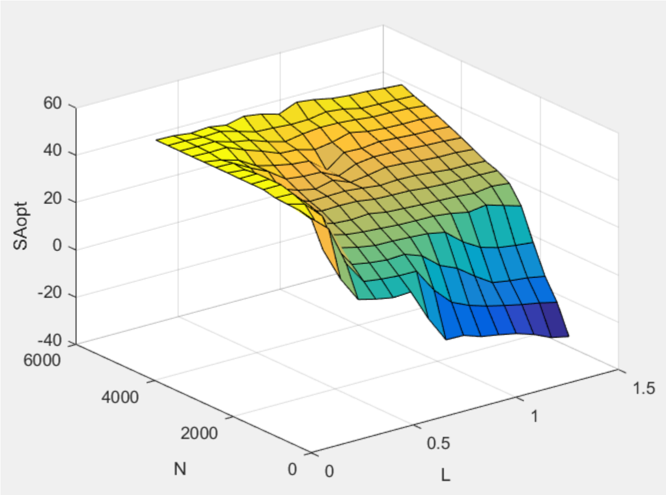
To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Optimal spark table, f_sa_opt` — Lookup table

`array`

The optimal spark lookup table, f_{SAopt}, is a function of engine speed and engine load, $SA_{opt} = f_{SAopt}(L, N)$, where:

- SA_{opt} is optimal spark advance timing for maximum inner torque at stoichiometric air-fuel ratio (AFR), in deg.
- L is engine load at arbitrary cam phaser angles, corrected for final steady-state cam phaser angles, dimensionless.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Inner torque load breakpoints, f_tq_inr_l_bpt` — Breakpoints

`[0.2 0.28571 0.37143 0.45714 0.54286 0.62857 0.71429 0.8 0.88571 0.97143 1.0571 1.1429 1.2286 1.3143 1.4]` (default) | `vector`

Inner torque load breakpoints, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Inner torque speed breakpoints, f_tq_inr_n_bpt` — Breakpoints

`[750 1053.5714 1357.1429 1660.7143 1964.2857 2267.8571 2571.4286 2875 3178.5714 3482.1429 3785.7143 4089.2857 4392.8571 4696.4286 5000]` (default) | `vector`

Inner torque speed breakpoints, in rpm.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Spark efficiency table, f_m_sa` — Lookup table

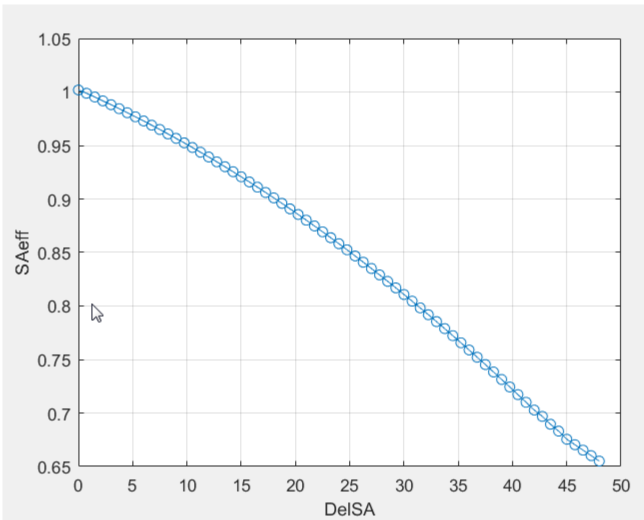
`array`

The spark efficiency lookup table, f_{Msa}, is a function of the spark retard from optimal

$$M_{sa} = f_{Msa}(\Delta SA)$$
$$\Delta SA = SA_{opt} - SA$$

where:

- M_{sa} is the spark retard efficiency multiplier, dimensionless.
- $\Delta SA$is the spark retard timing distance from optimal spark advance, in deg.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Spark retard from optimal, f_del_sa_bpt` — Breakpoints

`[0 0.75 1.5 2.25 3 3.75 4.5 5.25 6 6.75 7.5 8.25 9 9.75 10.5 11.25 12 12.75 13.5 14.25 15 15.75 16.5 17.25 18 18.75 19.5 20.25 21 21.75 22.5 23.25 24 24.75 25.5 26.25 27 27.75 28.5 29.25 30 30.75 31.5 32.25 33 33.75 34.5 35.25 36 36.75 37.5 38.25 39 39.75 40.5 41.25 42 42.75 43.5 44.25 45 45.75 46.5 47.25 48]` (default) | `vector`

Spark retard from optimal inner torque timing breakpoints, in deg.

Dependencies

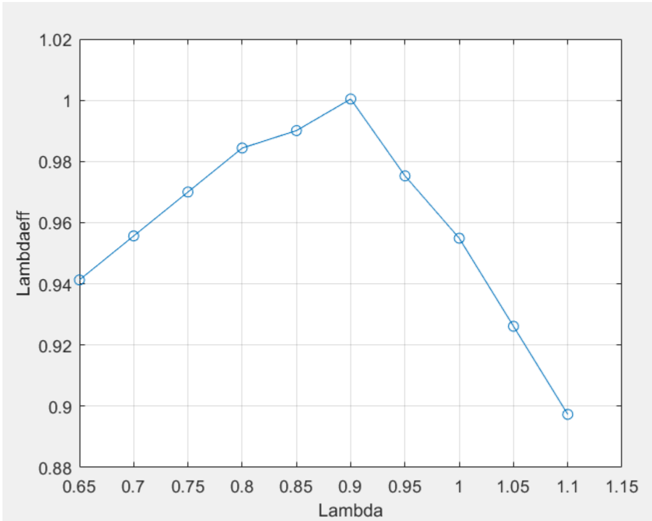
To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Lambda efficiency, f_m_lam` — Lookup table

`array`

The lambda efficiency lookup table, $f_{M\lambda}$, is a function of lambda, $M_\lambda = f_{M\lambda}(\lambda)$, where:

- M_λ is the lambda multiplier on inner torque to account for the air-fuel ratio (AFR) effect, dimensionless.
- λ is lambda, AFR normalized to stoichiometric fuel AFR, dimensionless.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Lambda breakpoints, f_m_lam_bpt` — Breakpoints

`[0.65 0.7 0.75 0.8 0.85 0.9 0.95 1 1.05 1.1]` (default) | `vector`

Lambda effect on inner torque lambda breakpoints, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

Exhaust

`Exhaust temperature table, f_t_exh` — Lookup table

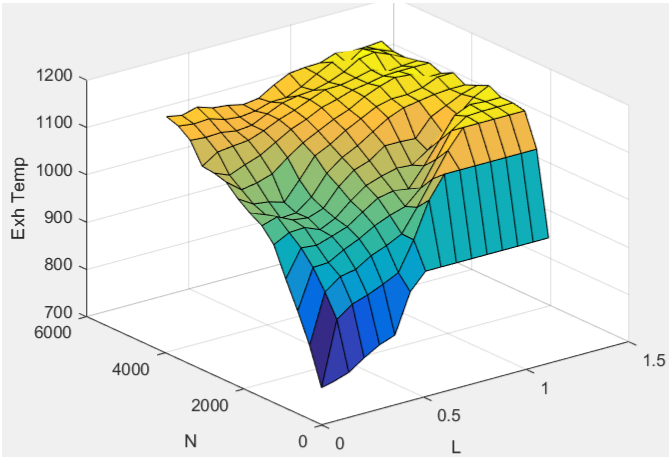
`array`

The exhaust temperature lookup table, f_{Texh}, is a function of engine load and engine speed

$$T_{exh} = f_{Texh}(L, N)$$

where:

- T_{exh} is engine exhaust temperature, in K.
- L is normalized cylinder air mass or engine load, dimensionless.
- N is engine speed, in rpm.



Load breakpoints, `f_t_exh_l_bpt` — Breakpoints
`[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25]` (default) | `vector`

Engine load breakpoints used for exhaust temperature lookup table.

Speed breakpoints, `f_t_exh_n_bpt` — Breakpoints
`[750 1054 1357 1661 1964 2268 2571 2875 3179 3482 3786 4089 4393 4696 5000]` (default) | `vector`

Engine speed breakpoints used for exhaust temperature lookup table, in rpm.

References

[1] Gerhardt, J., Hönninger, H., and Bischof, H., *A New Approach to Functional and Software Structure for Engine Management Systems — BOSCH ME7*. SAE Technical Paper 980801, 1998.

[2] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

[3] Leone, T. Christenson, E., Stein, R., *Comparison of Variable Camshaft Timing Strategies at Part Load*. SAE Technical Paper 960584, 1996, doi:10.4271/960584.

[4] Liu, F. and Pfeiffer, J., *Estimation Algorithms for Low Pressure Cooled EGR in Spark-Ignition Engines*. SAE Int. J. Engines 8(4):2015, doi:10.4271/2015-01-1620.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

SI Core Engine | Mapped SI Engine

Topics
“Engine Calibration Maps”

External Websites

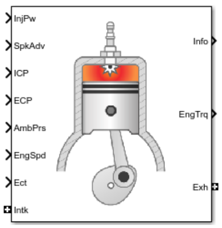
Developing a Period-Based Air-Fuel Ratio Controller Using a Low-Cost Switching Sensor

Introduced in R2017a

SI Core Engine

Spark-ignition engine from intake to exhaust port

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Core Engine



Description

The SI Core Engine block implements a spark-ignition (SI) engine from intake to exhaust port. You can use the block in larger vehicle models, hardware-in-the-loop (HIL) engine control design, or vehicle-level fuel economy and performance simulations.

The SI Core Engine block calculates:

- Brake torque
- Fuel flow
- Port gas mass flow, including exhaust gas recirculation (EGR)
- Air-fuel ratio (AFR)
- Exhaust temperature and exhaust mass flow rate
- Engine-out (EO) exhaust emissions
  - Hydrocarbon (HC)
  - Carbon monoxide (CO)
  - Nitric oxide and nitrogen dioxide (NOx)
  - Carbon dioxide (CO_2)
  - Particulate matter (PM)

Air Mass Flow

To calculate engine air mass flow, configure the SI engine to use either of these air mass flow models.

Air Mass Flow Model	Description
"SI Engine Speed-Density Air Mass Flow Model"	Uses the speed-density equation to calculate the engine air mass flow, relating the engine air mass flow to the intake manifold pressure and engine speed. Consider using this air mass flow model in engines with fixed valvetrain designs.

Air Mass Flow Model	Description
"SI Engine Dual-Independent Cam Phaser Air Mass Flow Model"	To calculate the engine air mass flow, the dual-independent cam phaser model uses: • Empirical calibration parameters developed from engine mapping measurements • Desktop calibration parameters derived from engine computer-aided design (CAD) data In contrast to typical embedded air mass flow calculations based on direct air mass flow measurement with an air mass flow (MAF) sensor, this air mass flow model offers: • Elimination of MAF sensors in dual cam-phased valvetrain applications • Reasonable accuracy with changes in altitude • Semiphysical modeling approach • Bounded behavior • Suitable execution time for electronic control unit (ECU) implementation • Systematic development of a relatively small number of calibration parameters

Brake Torque

To calculate the brake torque, configure the SI engine to use either of these torque models.

Brake Torque Model	Description
"SI Engine Torque Structure Model"	For the structured brake torque calculation, the SI engine uses tables for the inner torque, friction torque, optimal spark, spark efficiency, and lambda efficiency. If you select **Crank angle pressure and torque** on the block **Torque** tab, you can: • Simulate advanced closed-loop engine controls in desktop simulations and on HIL bench, based on cylinder pressure recorded from a model or laboratory test as a function of crank angle. • Simulate driveline vibrations downstream of the engine due to high-frequency crankshaft torsionals. • Simulate engine misfires due to lean operation or spark plug fouling by using the injector pulse width input. • Simulate cylinder deactivation effect (closed intake and exhaust valves, no injected fuel) on individual cylinder pressures, mean-value airflow, mean-value torque, and crank-angle-based torque. • Simulate the fuel-cut effect on individual cylinder pressure, mean-value torque, and crank-angle-based torque.
"SI Engine Simple Torque Model"	For the simple brake torque calculation, the SI engine block uses a torque lookup table map that is a function of engine speed and load.

Fuel Flow

To calculate the fuel flow, the SI Core Engine block uses fuel injector characteristics and fuel injector pulse-width.

$$\dot{m}_{fuel} = \frac{NS_{inj}Pw_{inj}N_{cyl}}{Cps\left(\frac{60s}{\min}\right)\left(\frac{1000mg}{g}\right)}$$

To calculate the fuel economy for high-fidelity models, the block uses the volumetric fuel flow.

$$Q_{fuel} = \frac{\dot{m}_{fuel}}{\left(\frac{1000kg}{m^3}\right)Sg_{fuel}}$$

The equation uses these variables.

$\dot{m}_{fuel}$	Fuel mass flow, g/s
ω	Engine rotational speed, rad/s
Cps	Crankshaft revolutions per power stroke, rev/stroke
S_{inj}	Fuel injector slope, mg/ms
Pw_{inj}	Fuel injector pulse-width, ms

N_{cyl}	Number of engine cylinders
N	Engine speed, rpm
Sg_{fuel}	Specific gravity of fuel
Q_{fuel}	Volumetric fuel flow

The block uses the internal signal `FlwDir` to track the direction of the flow.

Air-Fuel Ratio

To calculate the air-fuel (AFR) ratio, the CI Core Engine and SI Core Engine blocks implement this equation.

$$AFR = \frac{\dot{m}_{air}}{\dot{m}_{fuel}}$$

The CI Core Engine uses this equation to calculate the relative AFR.

$$\lambda = \frac{AFR}{AFR_S}$$

To calculate the exhaust gas recirculation (EGR), the blocks implement this equation. The calculation expresses the EGR as a percent of the total intake port flow.

$$EGR_{pct} = 100\frac{\dot{m}_{intk,\,b}}{\dot{m}_{intk}} = 100y_{intk,\,b}$$

The equations use these variables.

AFR	Air-fuel ratio
AFR_s	Stoichiometric air-fuel ratio
$\dot{m}_{intk}$	Engine air mass flow
$\dot{m}_{fuel}$	Fuel mass flow
λ	Relative AFR
$y_{intk,b}$	Intake burned mass fraction
EGR_{pct}	EGR percent
$\dot{m}_{intk,\,b}$	Recirculated burned gas mass flow rate

Exhaust

The block calculates the:

- Exhaust gas temperature
- Exhaust gas-specific enthalpy
- Exhaust gas mass flow rate
- Engine-out (EO) exhaust emissions:
  - Hydrocarbon (HC)
  - Carbon monoxide (CO)

- Nitric oxide and nitrogen dioxide (NOx)
- Carbon dioxide (CO_2)
- Particulate matter (PM)

The exhaust temperature determines the specific enthalpy.

$$h_{exh} = Cp_{exh}T_{exh}$$

The exhaust mass flow rate is the sum of the intake port air mass flow and the fuel mass flow.

$$\dot{m}_{exh} = \dot{m}_{intake} + \dot{m}_{fuel}$$

To calculate the exhaust emissions, the block multiplies the emission mass fraction by the exhaust mass flow rate. To determine the emission mass fractions, the block uses lookup tables that are functions of the engine torque and speed.

$$y_{exh,\,i} = f_{i\_frac}(T_{brake}, N)$$
$$\dot{m}_{exh,\,i} = \dot{m}_{exh}y_{exh,\,i}$$

The fraction of air and fuel entering the intake port, injected fuel, and stoichiometric AFR determine the air mass fraction that exits the exhaust.

$$y_{exh,\,air} = \max\left[y_{in,\,air} - \frac{\dot{m}_{fuel} + y_{in,\,fuel}\dot{m}_{intake}}{\dot{m}_{fuel} + \dot{m}_{intake}}AFR_s\right]$$

If the engine is operating at the stoichiometric or fuel rich AFR, no air exits the exhaust. Unburned hydrocarbons and burned gas comprise the remainder of the exhaust gas. This equation determines the exhaust burned gas mass fraction.

$$y_{exh,\,b} = \max\left[(1 - y_{exh,\,air} - y_{exh,\,HC}), 0\right]$$

The equations use these variables.

T_{exh}	Engine exhaust temperature
h_{exh}	Exhaust manifold inlet-specific enthalpy
Cp_{exh}	Exhaust gas specific heat
$\dot{m}_{intk}$	Intake port air mass flow rate
$\dot{m}_{fuel}$	Fuel mass flow rate
$\dot{m}_{exh}$	Exhaust mass flow rate
$y_{in,\,fuel}$	Intake fuel mass fraction
$y_{exh,i}$	Exhaust mass fraction for i = CO_2, CO, HC, NOx, air, burned gas, and PM
$\dot{m}_{exh,\,i}$	Exhaust mass flow rate for i = CO_2, CO, HC, NOx, air, burned gas, and PM
T_{brake}	Engine brake torque
N	Engine speed
$y_{exh,air}$	Exhaust air mass fraction
$y_{exh,b}$	Exhaust air burned mass fraction

Power Accounting

For the power accounting, the block implements equations that depend on **Torque model**.

When you set **Torque model** to `Simple Torque Lookup`, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrIntkHeatFlw`	Intake heat flow	$\dot{m}_{intk}h_{intk}$
		`PwrExhHeatFlw`	Exhaust heat flow	$-\dot{m}_{exh}h_{exh}$
		`PwrCrkshft`	Crankshaft power	$-T_{brake}\omega$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFuel`	Fuel input power	$\dot{m}_{fuel}LHV$
		`PwrLoss`	All losses	$T_{brake}\omega - \dot{m}_{fuel}LHV - \dot{m}_{intk}h_{intk} + \dot{m}_{exh}h_{exh}$

Bus Signal			Description	Equations
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	*Not used*		

When you set **Torque model** to `Torque Structure`, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrIntkHeatFlw`	Intake heat flow	$\dot{m}_{intk}h_{intk}$
		`PwrExhHeatFlw`	Exhaust heat flow	$-\dot{m}_{exh}h_{exh}$
		`PwrCrkshft`	Crankshaft power	$-T_{brake}\omega$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFuel`	Fuel input power	$\dot{m}_{fuel}LHV$
		`PwrFricLoss`	Friction loss	$-T_{fric}\omega$
		`PwrPumpLoss`	Pumping loss	$-T_{pump}\omega$
		`PwrHeatTrnsfrLoss`	Heat transfer loss	$T_{brake}\omega - \dot{m}_{fuel}LHV - \dot{m}_{intk}h_{intk} + \dot{m}_{exh}h_{exh} + T_{fric}\omega + T_{pump}\omega$

Bus Signal		Description	Equations
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	*Not used*	

h_{exh}	Exhaust manifold inlet-specific enthalpy
h_{intk}	Intake port specific enthalpy
$\dot{m}_{intk}$	Intake port air mass flow rate
$\dot{m}_{fuel}$	Fuel mass flow rate
$\dot{m}_{exh}$	Exhaust mass flow rate
ω	Engine speed
T_{brake}	Brake torque
T_{pump}	Engine pumping work offset to inner torque
T_{fric}	Engine friction torque
LHV	Fuel lower heating value

Ports

Input

`InjPw` — Fuel injector pulse-width

`scalar`

Fuel injector pulse-width, Pw_{inj}, in ms.

`SpkAdv` — Spark advance

`scalar`

Spark advance, SA, in degrees crank angle before top dead center (degBTDC).

Dependencies

To create this port, for the **Torque model** parameter, select `Torque Structure`.

`ICP` — Intake cam phase angle command

`scalar`

Intake cam phase angle command, φ_{ICPCMD}, in degCrkAdv, or degrees crank advance.

Dependencies

To create this port, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

ECP — Exhaust cam phase angle command
`scalar`

Exhaust cam phase angle command, φ_{ECPCMD}, in degCrkRet, or degrees crank retard.

Dependencies

To create this port, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`AmbPrs` — Ambient pressure
`scalar`

Ambient pressure, P_{Amb}, in Pa.

Dependencies

To create this port, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

EngSpd — Engine speed
`scalar`

Engine speed, N, in rpm.

`Ect` — Engine cooling temperature
`scalar`

Engine cooling temperature, $T_{coolant}$, in K.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intk` — Intake port pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the upstream:

- `Prs` — Pressure, in Pa
- `Temp` — Temperature, in K
- `Enth` — Specific enthalpy, in J/kg
- `MassFrac` — Intake port mass fractions, dimensionless. EGR mass flow at the intake port is burned gas.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen

    - `UnbrndFuelMassFrac` — Unburned fuel
    - `CO2MassFrac` — Carbon dioxide
    - `H2OMassFrac` — Water
    - `COMassFrac` — Carbon monoxide
    - `NOMassFrac` — Nitric oxide
    - `NO2MassFrac` — Nitrogen dioxide
    - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
    - `PmMassFrac` — Particulate matter
    - `AirMassFrac` — Air
    - `BrndGasMassFrac` — Burned gas

Exh — Exhaust port pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the exhaust:

- `Prs` — Pressure, in Pa
- `Temp` — Temperature, in K
- `Enth` — Specific enthalpy, in J/kg
- `MassFrac` — Exhaust port mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

    - `O2MassFrac` — Oxygen
    - `N2MassFrac` — Nitrogen
    - `UnbrndFuelMassFrac` — Unburned fuel
    - `CO2MassFrac` — Carbon dioxide
    - `H2OMassFrac` — Water
    - `COMassFrac` — Carbon monoxide
    - `NOMassFrac` — Nitric oxide
    - `NO2MassFrac` — Nitrogen dioxide
    - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
    - `PmMassFrac` — Particulate matter
    - `AirMassFrac` — Air
    - `BrndGasMassFrac` — Burned gas

Output

`Info` — Bus signal
bus

Bus signal that contains these block calculations.

Signal	Description	Variable	Units
IntkGasMassFlw	Engine intake air mass flow	$\dot{m}_{air}$	kg/s
IntkAirMassFlw	Engine intake port mass flow	$\dot{m}_{intk}$	kg/s
NrmlzdAirChrg	Engine load (that is, normalized cylinder air mass) corrected for final steady-state cam phase angles	L	N/A
Afr	Air-fuel ratio at engine exhaust port	AFR	N/A
FuelMassFlw	Fuel flow into engine	$\dot{m}_{fuel}$	kg/s
FuelVolFlw	Volumetric fuel flow	Q_{fuel}	m^3/s
ExhManGasTemp	Exhaust gas temperature at exhaust manifold inlet	T_{exh}	K
EngTrq	Engine brake torque	T_{brake}	N·m
EngSpd	Engine speed	N	rpm
IntkCamPhase	Intake cam phaser angle	φ_{ICP} i	degrees crank advance
ExhCamPhase	Exhaust cam phaser angle	φ_{ECP}	degrees crank retard
CrkAng	Engine crankshaft absolute angle	$\int_0^{(360)Cps} EngSpd\frac{180}{30}d\theta$ where Cps is crankshaft revolutions per power stroke	degrees crank angle
EgrPct	EGR percent	EGR_{pct}	N/A
EoAir	EO air mass flow rate	$\dot{m}_{exh}$	kg/s
EoBrndGas	EO burned gas mass flow rate	$y_{exh,b}$	kg/s
EoHC	EO hydrocarbon emission mass flow rate	$y_{exh,HC}$	kg/s
EoCO	EO carbon monoxide emission mass flow rate	$y_{exh,CO}$	kg/s
EoNOx	EO nitric oxide and nitrogen dioxide emissions mass flow rate	$y_{exh,NOx}$	kg/s
EoCO2	EO carbon dioxide emission mass flow rate	$y_{exh,CO2}$	kg/s

Signal			Description	Variable	Units
`EoPm`			EO particulate matter emission mass flow rate	$y_{exh,PM}$	kg/s
`CylPrs`			Cylinder pressure	N/A	Pa
`EngTrqCrk`			Crank-angle based engine torque	N/A	N·m
`PwrInfo`	`PwrTrnsfrd`	`PwrIntkHeatFlw`	Intake heat flow	$\dot{m}_{intk}h_{intk}$	W
		`PwrExhHeatFlw`	Exhaust heat flow	$-\dot{m}_{exh}h_{exh}$	W
		`PwrCrkshft`	Crankshaft power	$-T_{brake}\omega$	W
	`PwrNotTrnsfrd`	`PwrFuel`	Fuel input power	$\dot{m}_{fuel}LHV$	W
		`PwrLoss`	For **Torque model** set to `Simple Torque Lookup`: All losses	$T_{brake}\omega - \dot{m}_{fuel}LHV - \dot{m}_{intk}h_{intk} + \dot{m}_{exh}h_{exh}$	W
		`PwrFricLoss`	For **Torque model** set to `Torque Structure`: Friction loss	$-T_{fric}\omega$	W
		`PwrPumpLoss`	For **Torque model** set to `Torque Structure`: Pumping loss	$-T_{pump}\omega$	W
		`PwrHeatTrnsfrLoss`	For **Torque model** set to `Torque Structure`: Heat transfer loss	$T_{brake}\omega - \dot{m}_{fuel}LHV - \dot{m}_{intk}h_{intk} + \dot{m}_{exh}h_{exh} + T_{fric}\omega + T_{pump}\omega$	W
	`PwrStored`	*Not used*			

`EngTrq` — Engine brake torque
`scalar`

Engine brake torque, T_{brake}, in N·m.

`Intk` — Intake port mass flow rate, heat flow rate, temperature, mass fraction
two-way connector port

Bus containing:

- `MassFlwRate` — Intake port mass flow rate, in kg/s
- `HeatFlwRate` — Intake port heat flow rate, in J/s
- `Temp` — Intake port temperature, in K
- `MassFrac` — Intake port mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

- `O2MassFrac` — Oxygen
- `N2MassFrac` — Nitrogen
- `UnbrndFuelMassFrac` — Unburned fuel
- `CO2MassFrac` — Carbon dioxide
- `H2OMassFrac` — Water
- `COMassFrac` — Carbon monoxide
- `NOMassFrac` — Nitric oxide
- `NO2MassFrac` — Nitrogen dioxide
- `NOxMassFrac` — Nitric oxide and nitrogen dioxide
- `PmMassFrac` — Particulate matter
- `AirMassFrac` — Air
- `BrndGasMassFrac` — Burned gas

Exh — Exhaust port mass flow rate, heat flow rate, temperature, mass fraction
two-way connector port

Bus containing:

- `MassFlwRate` — Exhaust port mass flow rate, in kg/s
- `HeatFlwRate` — Exhaust heat flow rate, in J/s
- `Temp` — Exhaust temperature, in K
- `MassFrac` — Exhaust port mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

Parameters

Block Options

`Air mass flow model` — Select air mass flow model
`Dual-Independent Variable Cam Phasing` (default) | `Simple Speed-Density`

To calculate engine air mass flow, configure the SI engine to use either of these air mass flow models.

Air Mass Flow Model	Description
"SI Engine Speed-Density Air Mass Flow Model"	Uses the speed-density equation to calculate the engine air mass flow, relating the engine air mass flow to the intake manifold pressure and engine speed. Consider using this air mass flow model in engines with fixed valvetrain designs.
"SI Engine Dual-Independent Cam Phaser Air Mass Flow Model"	To calculate the engine air mass flow, the dual-independent cam phaser model uses: • Empirical calibration parameters developed from engine mapping measurements • Desktop calibration parameters derived from engine computer-aided design (CAD) data In contrast to typical embedded air mass flow calculations based on direct air mass flow measurement with an air mass flow (MAF) sensor, this air mass flow model offers: • Elimination of MAF sensors in dual cam-phased valvetrain applications • Reasonable accuracy with changes in altitude • Semiphysical modeling approach • Bounded behavior • Suitable execution time for electronic control unit (ECU) implementation • Systematic development of a relatively small number of calibration parameters

Dependencies

The table summarizes the parameter dependencies.

Air Mass Flow Model	Enables Parameters
Dual-Independent Variable Cam Phasing	**Cylinder volume at intake valve close table, f_vivc** **Cylinder volume intake cam phase breakpoints, f_vivc_icp_bpt** **Cylinder trapped mass correction factor, f_tm_corr** **Normalized density breakpoints, f_tm_corr_nd_bpt** **Engine speed breakpoints, f_tm_corr_n_bpt** **Air mass flow, f_mdot_air** **Exhaust cam phase breakpoints, f_mdot_air_ecp_bpt** **Trapped mass flow breakpoints, f_mdot_trpd_bpt** **Air mass flow correction factor, f_mdot_air_corr** **Engine load breakpoints for air mass flow correction, f_mdot_air_corr_ld_bpt** **Engine speed breakpoints for air mass flow correction, f_mdot_air_n_bpt**
Simple Speed Density	**Speed-density volumetric efficiency, f_nv** **Speed-density intake manifold pressure breakpoints, f_nv_prs_bpt** **Speed-density engine speed breakpoints, f_nv_n_bpt**

Torque model — Select torque model
Torque Structure (default) | Simple Torque Lookup

To calculate the brake torque, configure the SI engine to use either of these torque models.

Brake Torque Model	Description
"SI Engine Torque Structure Model"	For the structured brake torque calculation, the SI engine uses tables for the inner torque, friction torque, optimal spark, spark efficiency, and lambda efficiency. If you select **Crank angle pressure and torque** on the block **Torque** tab, you can: • Simulate advanced closed-loop engine controls in desktop simulations and on HIL bench, based on cylinder pressure recorded from a model or laboratory test as a function of crank angle. • Simulate driveline vibrations downstream of the engine due to high-frequency crankshaft torsionals. • Simulate engine misfires due to lean operation or spark plug fouling by using the injector pulse width input. • Simulate cylinder deactivation effect (closed intake and exhaust valves, no injected fuel) on individual cylinder pressures, mean-value airflow, mean-value torque, and crank-angle-based torque. • Simulate the fuel-cut effect on individual cylinder pressure, mean-value torque, and crank-angle-based torque.
"SI Engine Simple Torque Model"	For the simple brake torque calculation, the SI engine block uses a torque lookup table map that is a function of engine speed and load.

Dependencies

The table summarizes the parameter dependencies.

Torque Model	Enables Parameters
Torque Structure	**Inner torque table, f_tq_inr** **Friction torque table, f_tq_fric** **Engine temperature modifier on friction torque, f_fric_temp_mod** **Engine temperature modifier breakpoints, f_fric_temp_bpt** **Pumping work table, f_tq_pump** **Optimal spark table, f_sa_opt** **Inner torque load breakpoints, f_tq_inr_l_bpt** **Inner torque speed breakpoints, f_tq_inr_n_bpt** **Spark efficiency table, f_m_sa** **Spark retard from optimal, f_del_sa_bpt** **Lambda efficiency, f_m_lam** **Lambda breakpoints, f_m_lam_bpt**
Simple Torque Lookup	**Torque table, f_tq_nl** **Torque table load breakpoints, f_tq_nl_l_bpt** **Torque table speed breakpoints, f_tq_nl_n_bpt**

Air

Number of cylinders, NCyl — Engine cylinders
4 (default) | scalar

Number of engine cylinders, N_{cyl}.

Crank revolutions per power stroke, Cps — Revolutions per stroke
2 (default) | scalar

Crankshaft revolutions per power stroke, Cps, in rev/stroke.

Total displaced volume, Vd — Volume
0.0015 (default) | scalar

Displaced volume, V_d, in m^3.

Ideal gas constant air, Rair — Constant
287 (default) | scalar

Ideal gas constant, R_{air}, in J/(kg·K).

Air standard pressure, Pstd — Pressure
101325 (default) | scalar

Standard air pressure, P_{std}, in Pa.

`Air standard temperature, Tstd` — Temperature
`293.15` (default) | `scalar`

Standard air temperature, T_{std}, in K.

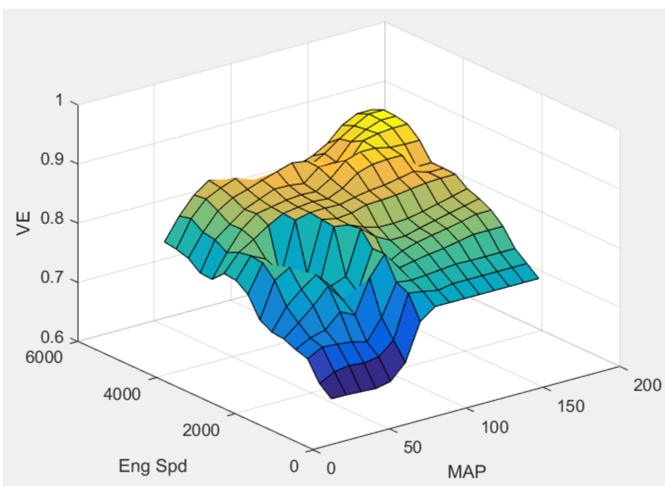
`Speed-density volumetric efficiency, f_nv` — Lookup table
`array`

The engine volumetric efficiency lookup table, f_{η_v}, is a function of intake manifold absolute pressure and engine speed

$$\eta_v = f_{\eta_v}(MAP, N)$$

where:

- η_v is engine volumetric efficiency, dimensionless.
- MAP is intake manifold absolute pressure, in KPa.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Simple Speed-Density`.

`Speed-density intake manifold pressure breakpoints, f_nv_prs_bpt` — Breakpoints
`[31 40.6428571428571 50.2857142857143 59.9285714285714 69.5714285714286 79.2142857142857 88.8571428571429 98.5 108.142857142857 117.785714285714 127.428571428571 137.071428571429 146.714285714286 156.357142857143 166]` (default) | `array`

Intake manifold pressure breakpoints for speed-density volumetric efficiency lookup table, in KPa.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Simple Speed-Density`.

Speed-density engine speed breakpoints, `f_nv_n_bpt` — Breakpoints
`[750 1053.57142857143 1357.14285714286 1660.71428571429 1964.28571428571 2267.85714285714 2571.42857142857 2875 3178.57142857143 3482.14285714286 3785.71428571429 4089.28571428571 4392.85714285714 4696.42857142857 5000]` (default) | `array`

Engine speed breakpoints for speed-density volumetric efficiency lookup table, in rpm.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Simple Speed-Density`.

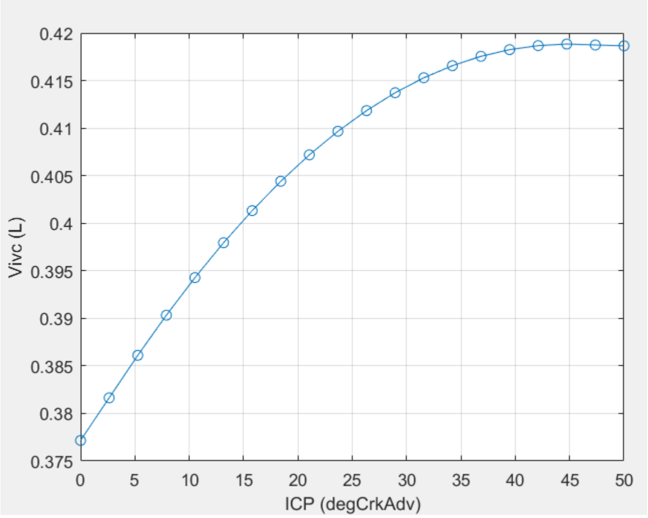
Cylinder volume at intake valve close table, `f_vivc` — 2-D lookup table
`array`

The cylinder volume at intake valve close table (IVC), f_{Vivc} is a function of the intake cam phaser angle

$$V_{IVC} = f_{Vivc}(\varphi_{ICP})$$

where:

- V_{IVC} is cylinder volume at IVC, in L.
- φ_{ICP} is intake cam phaser angle, in crank advance degrees.



Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

Cylinder volume intake cam phase breakpoints, `f_vivc_icp_bpt` — Breakpoints
`[0 2.6316 5.2632 7.8947 10.5263 13.1579 15.7895 18.4211 21.0526 23.6842 26.3158 28.9474 31.5789 34.2105 36.8421 39.4737 42.1053 44.7368 47.3684 50]` (default) | `vector`

Cylinder volume intake cam phase breakpoints, in L.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Cylinder trapped mass correction factor, f_tm_corr` — Lookup table

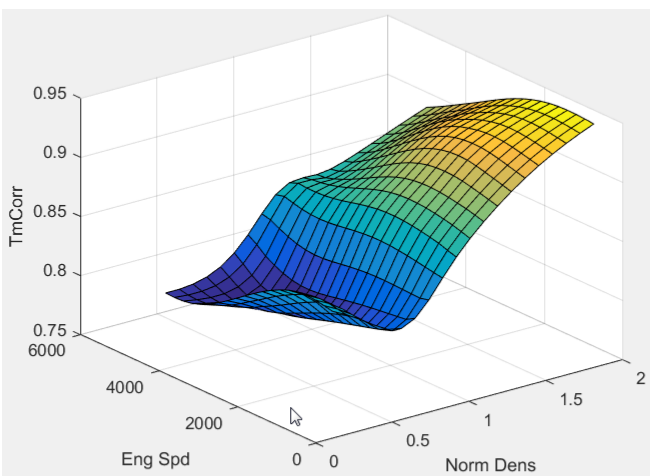
`array`

The trapped mass correction factor table, f_{TMcorr}, is a function of the normalized density and engine speed

$$TM_{corr} = f_{TMcorr}(\rho_{norm}, \quad N)$$

where:

- TM_{corr}, is trapped mass correction multiplier, dimensionless.
- ρ_{norm} is normalized density, dimensionless.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Normalized density breakpoints, f_tm_corr_nd_bpt` — Breakpoints

`[0.3 0.38947 0.47895 0.56842 0.65789 0.74737 0.83684 0.92632 1.0158 1.1053 1.1947 1.2842 1.3737 1.4632 1.5526 1.6421 1.7316 1.8211 1.9105 2]` (default) | `vector`

Normalized density breakpoints, dimensionless.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Engine speed breakpoints, f_tm_corr_n_bpt` — Breakpoints
`[750 973.6842 1197.3684 1421.0526 1644.7368 1868.4211 2092.1053 2315.7895 2539.4737 2763.1579 2986.8421 3210.5263 3434.2105 3657.8947 3881.5789 4105.2632 4328.9474 4552.6316 4776.3158 5000]` (default) | `vector`

Engine speed breakpoints, in rpm.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

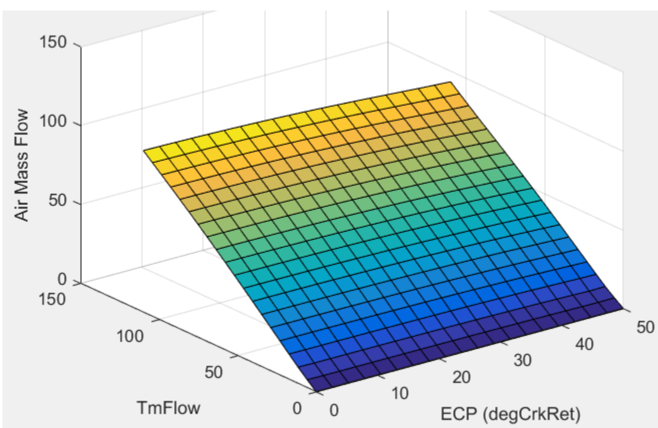
`Intake mass flow, f_mdot_intk` — Lookup table
`array`

The phaser intake mass flow model lookup table is a function of exhaust cam phaser angles and trapped air mass flow

$$\dot{m}_{intkideal} = f_{intkideal}(\varphi_{ECP}, TM_{flow})$$

where:

- $\dot{m}_{intkideal}$ is engine intake port mass flow at arbitrary cam phaser angles, in g/s.
- φ_{ECP} is exhaust cam phaser angle, in degrees crank retard.
- TM_{flow} is flow rate equivalent to corrected trapped mass at the current engine speed, in g/s.



Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Exhaust cam phase breakpoints, f_mdot_air_ecp_bpt` — Breakpoints
`[0 2.6316 5.2632 7.8947 10.5263 13.1579 15.7895 18.4211 21.0526 23.6842 26.3158 28.9474 31.5789 34.2105 36.8421 39.4737 42.1053 44.7368 47.3684 50]` (default) | `vector`

Exhaust cam phaser breakpoints for air mass flow lookup table, in degrees crank retard.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Trapped mass flow breakpoints, f_mdot_trpd_bpt` — Breakpoints

`[0 5.7895 11.5789 17.3684 23.1579 28.9474 34.7368 40.5263 46.3158 52.1053 57.8947 63.6842 69.4737 75.2632 81.0526 86.8421 92.6316 98.4211 104.2105 110]` (default) | `vector`

Trapped mass flow breakpoints for air mass flow lookup table, in g/s.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Air mass flow correction factor, f_mdot_air_corr` — Lookup table

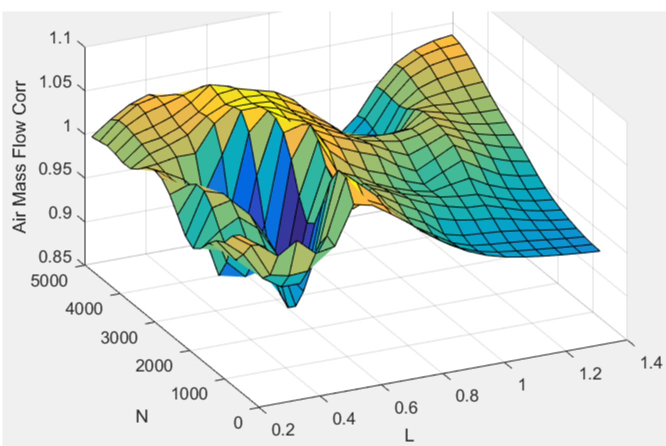
`array`

The intake air mass flow correction lookup table, $f_{aircorr}$, is a function of ideal load and engine speed

$$\dot{m}_{air} = \dot{m}_{intkideal} f_{aircorr}(L_{ideal}, N)$$

where:

- L_{ideal} is engine load (normalized cylinder air mass) at arbitrary cam phaser angles, uncorrected for final steady-state cam phaser angles, dimensionless.
- N is engine speed, in rpm.
- $\dot{m}_{air}$ is engine intake air mass flow final correction at steady-state cam phaser angles, in g/s.
- $\dot{m}_{intkideal}$ is engine intake port mass flow at arbitrary cam phaser angles, in g/s.



Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Engine load breakpoints for air mass flow correction, f_mdot_air_corr_ld_bpt` — Breakpoints
`vector`

Engine load breakpoints for air mass flow final correction, dimensionless.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Engine speed breakpoints for air mass flow correction, f_mdot_air_n_bpt` — Breakpoints
`vector`

Engine speed breakpoints for air mass flow final correction, in rpm.

Dependencies

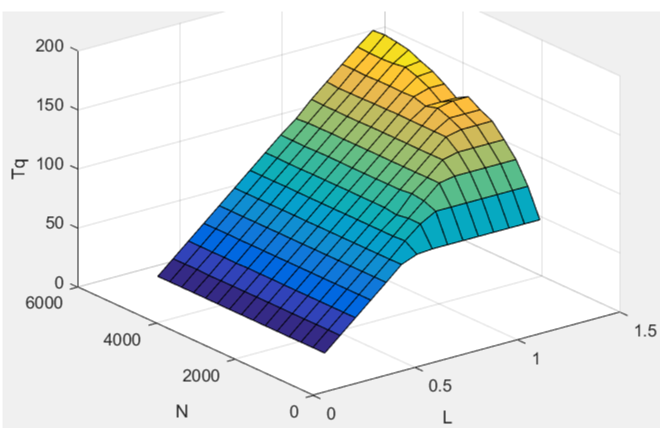
To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

Torque

`Torque table, f_tq_nl` — Lookup table
`[L x N] array`

For the simple torque lookup table model, the SI engine uses a lookup table map that is a function of engine speed and load, $T_{brake} = f_{TnL}(L, N)$, where:

- T_{brake} is engine brake torque after accounting for spark advance, AFR, and friction effects, in N·m.
- L is engine load, as a normalized cylinder air mass, dimensionless.
- N is engine speed, in rpm.



The simple torque lookup model assumes that the calibration has negative torque values to indicate the non-firing engine load (L) versus speed (N) condition. The calibrated table (L-by-N) contains the non-firing data in the first table row (1-by-N). When the fuel delivered to the engine is zero, the model uses the data in the first table row (1-by-N) at or above 100 AFR. 100 AFR results from fuel cutoff or very lean operation where combustion cannot occur.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table load breakpoints, f_tq_nl_l_bpt` — Breakpoints

`[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25]` (default) | `vector` | `[1 x L] vector`

Engine load breakpoints, *L*, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table speed breakpoints, f_tq_nl_n_bpt` — Breakpoints

`[750 1053.57142857143 1357.14285714286 1660.71428571429 1964.28571428571 2267.85714285714 2571.42857142857 2875 3178.57142857143 3482.14285714286 3785.71428571429 4089.28571428571 4392.85714285714 4696.42857142857 5000]` (default) | `vector` | `[1 x N] vector`

Engine speed breakpoints, *N*, in rpm.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Crank angle pressure and torque` — Enable Crank angle signals

`off` (default) | `on`

If you select **Crank angle pressure and torque** on the block **Torque** tab, you can:

- Simulate advanced closed-loop engine controls in desktop simulations and on HIL bench, based on cylinder pressure recorded from a model or laboratory test as a function of crank angle.
- Simulate driveline vibrations downstream of the engine due to high-frequency crankshaft torsionals.
- Simulate engine misfires due to lean operation or spark plug fouling by using the injector pulse width input.
- Simulate cylinder deactivation effect (closed intake and exhaust valves, no injected fuel) on individual cylinder pressures, mean-value airflow, mean-value torque, and crank-angle-based torque.
- Simulate the fuel-cut effect on individual cylinder pressure, mean-value torque, and crank-angle-based torque.

Dependencies

To enable this parameter, set **Torque model** to `Torque Structure`.

`Cylinder pressure, f_crk_prs` — Cylinder pressure table

`L x M x N` array

Cylinder pressure table *Prs*, as a function of speed *N*, load *L*, and crank angle *M*, in Pa.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`. Select **Crank angle pressure and torque**.

Brake torque, f_crk_btq — Brake torque table
L x M x N array

Brake torque table T_{brake}, as a function of speed N, load L, and crank angle M, in N·m.

Dependencies

To enable this parameter, for the **Torque model** parameter, select Torque Structure. Select **Crank angle pressure and torque**.

Speed breakpoints, f_crk_n_bpt — Speed breakpoints
[750 5000] (default) | 1 x N vector

Speed breakpoints, N, in rpm.

Dependencies

To enable this parameter, for the **Torque model** parameter, select Torque Structure. Select **Crank angle pressure and torque**.

Load breakpoints, f_crk_l_bpt — Load breakpoints
[0.2 1.4] (default) | 1 x L vector

Load breakpoints, L. No dimension.

Dependencies

To enable this parameter, for the **Torque model** parameter, select Torque Structure. Select **Crank angle pressure and torque**.

Crank angle breakpoints, f_crk_ang_bpt — Crank angle breakpoints
[60 660] (default) | 1 x M vector

Crank angle breakpoints, M, in deg.

Dependencies

To enable this parameter, for the **Torque model** parameter, select Torque Structure. Select **Crank angle pressure and torque**.

TDC compression angles by cylinder, f_crk_tdc_ang — TDC compression angles by cylinder
[0 540 180 360] (default) | vector

Top dead center (TDC) compression angles by cylinder, in deg.

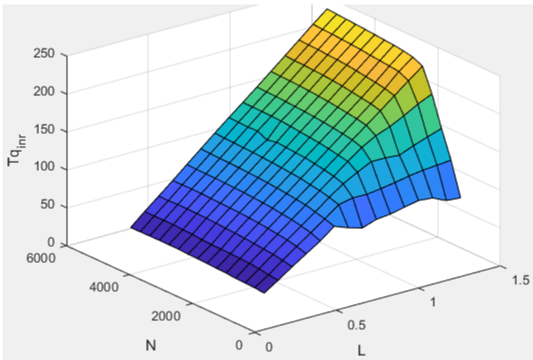
Dependencies

To enable this parameter, for the **Torque model** parameter, select Torque Structure. Select **Crank angle pressure and torque**.

Inner torque table, f_tq_inr — Lookup table
array

The inner torque lookup table, f_{Tqinr}, is a function of engine speed and engine load, $Tq_{inr} = f_{Tqinr}(L, N)$, where:

- Tq_{inr} is inner torque based on gross indicated mean effective pressure, in N·m.
- L is engine load at arbitrary cam phaser angles, corrected for final steady-state cam phaser angles, dimensionless.
- N is engine speed, in rpm.



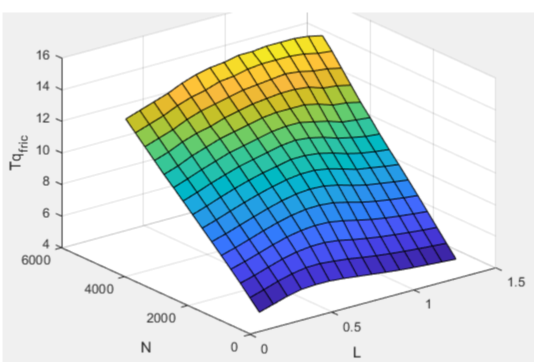
Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Friction torque table, f_tq_fric` — Lookup table
`array`

The friction torque lookup table, f_{Tfric}, is a function of engine speed and engine load, $T_{fric} = f_{Tfric}(L, N)$, where:

- T_{fric} is friction torque offset to inner torque, in N·m.
- L is engine load at arbitrary cam phaser angles, corrected for final steady-state cam phaser angles, dimensionless.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Engine temperature modifier on friction torque, f_fric_temp_mod` — Lookup table
`[3.96 3.22 2.56 2.26 2.11 2 1.9 1.83 1.76 1.7 1.65 1.6 1.55 1.49 1.44 1.41 1.38 1.35 1.32 1.3 1.27 1.25 1.24 1.21 1.2 1.18 1.16 1.15 1.13 1.12 1.11 1.1`

1.09 1.08 1.07 1.06 1.05 1.05 1.04 1.03 1.02 1.02 1.01 1.01 1 1 1 0.999 0.997 0.995 0.993 0.991 0.989 0.987] (default) | vector | vector

Engine temperature modifier on friction torque, $f_{fric,temp}$, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

Engine temperature modifier breakpoints, f_fric_temp_bpt — Breakpoints

[274 276 278 280 282 284 286 288 290 292 294 296 298 300 302 304 306 308 310 312 314 316 318 320 322 324 326 328 330 332 334 336 338 340 342 344 346 348 350 352 354 356 358 360 362 364 366 368 370 372 374 376 378 380] (default) | vector | vector

Engine temperature modifier breakpoints, in K.

Dependencies

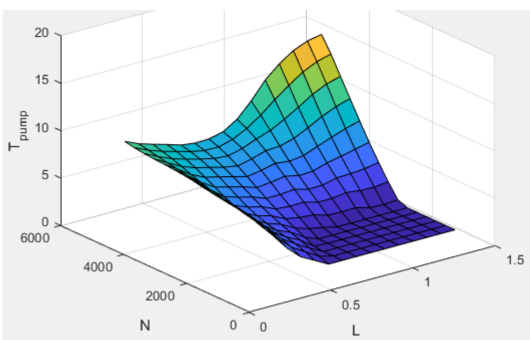
To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

Pumping work table, f_tq_pump — Lookup table

array

The pumping work lookup table, f_{Tpump}, is a function of engine load and engine speed, $T_{pump}=f_{Tpump}(L,N)$, where:

- T_{pump} is pumping work, in N·m.
- L is engine load, as a normalized cylinder air mass, dimensionless.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

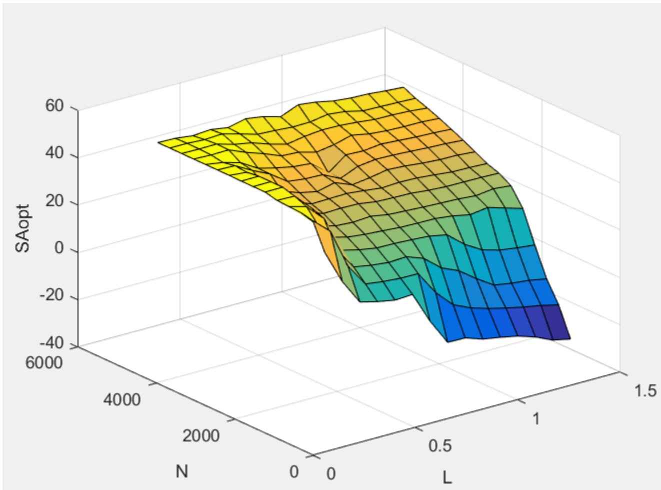
Optimal spark table, f_sa_opt — Lookup table

array

The optimal spark lookup table, f_{SAopt}, is a function of engine speed and engine load, $SA_{opt} = f_{SAopt}(L,N)$, where:

- SA_{opt} is optimal spark advance timing for maximum inner torque at stoichiometric air-fuel ratio (AFR), in deg.

- L is engine load at arbitrary cam phaser angles, corrected for final steady-state cam phaser angles, dimensionless.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Inner torque load breakpoints, f_tq_inr_l_bpt` — Breakpoints

`[0.2 0.28571 0.37143 0.45714 0.54286 0.62857 0.71429 0.8 0.88571 0.97143 1.0571 1.1429 1.2286 1.3143 1.4]` (default) | `vector`

Inner torque load breakpoints, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Inner torque speed breakpoints, f_tq_inr_n_bpt` — Breakpoints

`[750 1053.5714 1357.1429 1660.7143 1964.2857 2267.8571 2571.4286 2875 3178.5714 3482.1429 3785.7143 4089.2857 4392.8571 4696.4286 5000]` (default) | `vector`

Inner torque speed breakpoints, in rpm.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Spark efficiency table, f_m_sa` — Lookup table

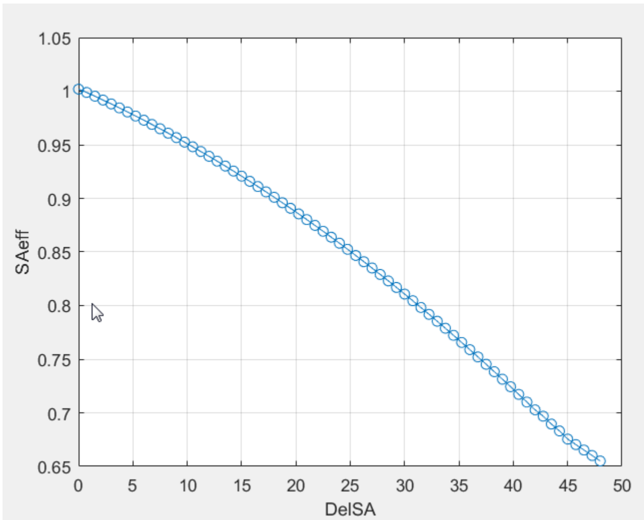
`array`

The spark efficiency lookup table, f_{Msa}, is a function of the spark retard from optimal

$$M_{sa} = f_{Msa}(\Delta SA)$$
$$\Delta SA = SA_{opt} - SA$$

where:

- M_{sa} is the spark retard efficiency multiplier, dimensionless.
- $\Delta SA$is the spark retard timing distance from optimal spark advance, in deg.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Spark retard from optimal, f_del_sa_bpt` — Breakpoints

`[0 0.75 1.5 2.25 3 3.75 4.5 5.25 6 6.75 7.5 8.25 9 9.75 10.5 11.25 12 12.75 13.5 14.25 15 15.75 16.5 17.25 18 18.75 19.5 20.25 21 21.75 22.5 23.25 24 24.75 25.5 26.25 27 27.75 28.5 29.25 30 30.75 31.5 32.25 33 33.75 34.5 35.25 36 36.75 37.5 38.25 39 39.75 40.5 41.25 42 42.75 43.5 44.25 45 45.75 46.5 47.25 48]` (default) | `vector`

Spark retard from optimal inner torque timing breakpoints, in deg.

Dependencies

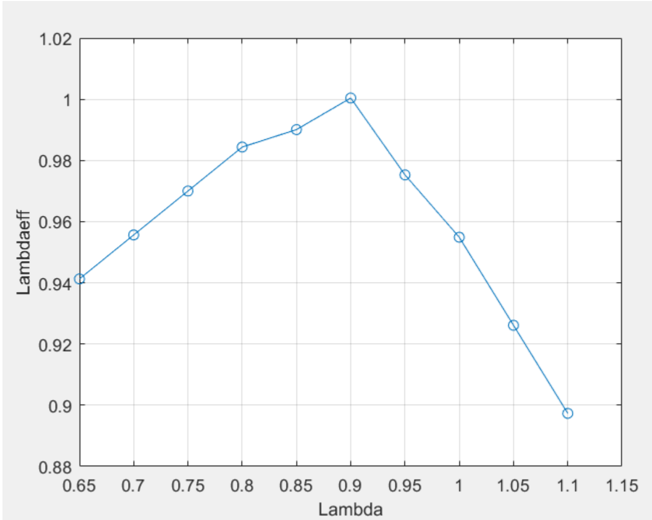
To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Lambda efficiency, f_m_lam` — Lookup table

`array`

The lambda efficiency lookup table, $f_{M\lambda}$, is a function of lambda, $M_\lambda = f_{M\lambda}(\lambda)$, where:

- M_λ is the lambda multiplier on inner torque to account for the air-fuel ratio (AFR) effect, dimensionless.
- λ is lambda, AFR normalized to stoichiometric fuel AFR, dimensionless.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Lambda breakpoints, f_m_lam_bpt` — Breakpoints

`[0.65 0.7 0.75 0.8 0.85 0.9 0.95 1 1.05 1.1]` (default) | `vector`

Lambda effect on inner torque lambda breakpoints, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

Exhaust

`Exhaust temperature table, f_t_exh` — Lookup table

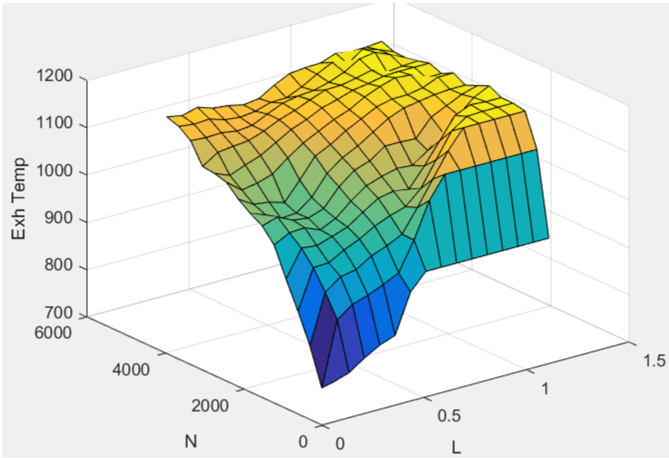
`array`

The exhaust temperature lookup table, f_{Texh}, is a function of engine load and engine speed

$$T_{exh} = f_{Texh}(L, N)$$

where:

- T_{exh} is engine exhaust temperature, in K.
- L is normalized cylinder air mass or engine load, dimensionless.
- N is engine speed, in rpm.



`Load breakpoints, f_t_exh_l_bpt` — Breakpoints
`[0.2 0.275 0.35 0.425 0.5 0.575 0.65 0.725 0.8 0.875 0.95 1.025 1.1 1.175 1.25]` (default) | `vector`

Engine load breakpoints used for exhaust temperature lookup table, dimensionless.

`Speed breakpoints, f_t_exh_n_bpt` — Breakpoints
`[750 1053.57142857143 1357.14285714286 1660.71428571429 1964.28571428571 2267.85714285714 2571.42857142857 2875 3178.57142857143 3482.14285714286 3785.71428571429 4089.28571428571 4392.85714285714 4696.42857142857 5000]` (default) | `vector`

Engine speed breakpoints used for exhaust temperature lookup table, in rpm.

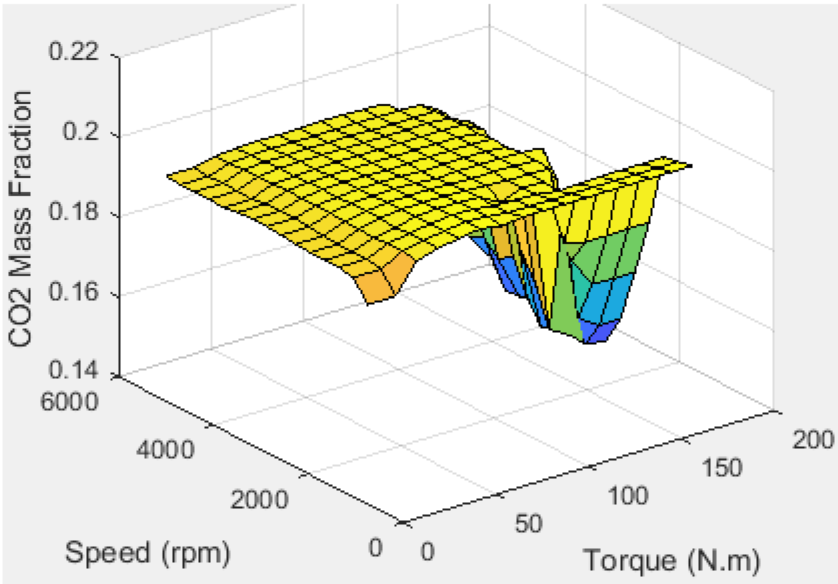
`Exhaust gas specific heat at constant pressure, cp_exh` — Specific heat
`1005` (default) | `scalar`

Exhaust gas-specific heat, Cp_{exh}, in J/(kg·K).

`CO2 mass fraction table, f_CO2_frac` — Carbon dioxide (CO_2) emission lookup table
`array`

The SI Core Engine CO_2 emission mass fraction lookup table is a function of engine torque and engine speed, *CO2 Mass Fraction* = ƒ(*Speed*, *Torque*), where:

- *CO2 Mass Fraction* is the CO_2 emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.



Dependencies

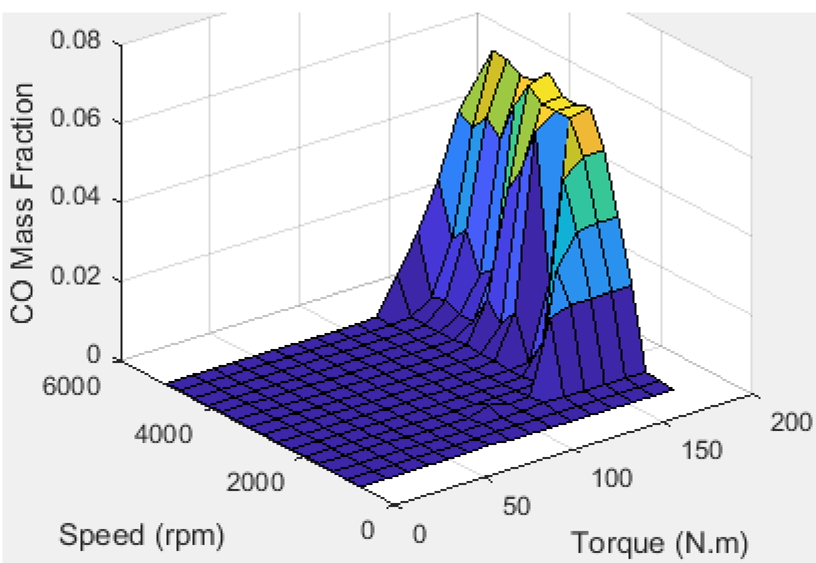
To enable this parameter, on the **Exhaust** tab, select **CO2**.

`CO mass fraction table, f_CO_frac` — Carbon monoxide (CO) emission lookup table

`array`

The SI Core Engine CO emission mass fraction lookup table is a function of engine torque and engine speed, *CO Mass Fraction* = ƒ(*Speed*, *Torque*), where:

- *CO Mass Fraction* is the CO emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.



Dependencies

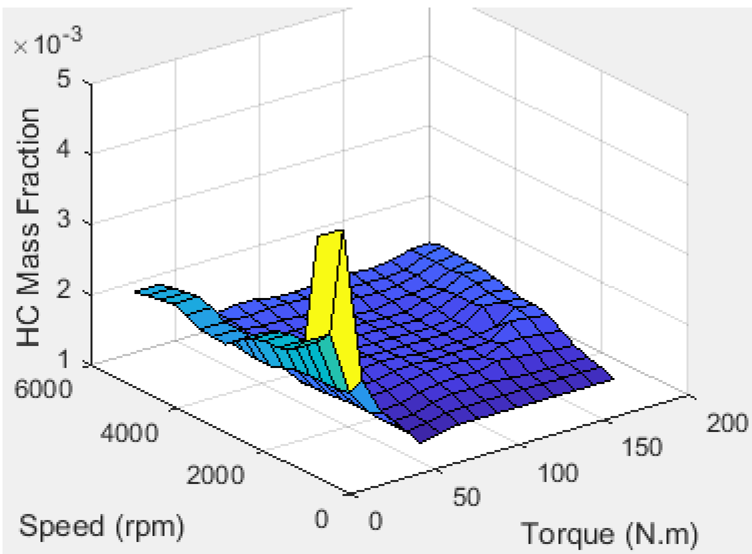
To enable this parameter, on the **Exhaust** tab, select **CO**.

`HC mass fraction table, f_HC_frac` — Hydrocarbon (HC) emission lookup table

`array`

The SI Core Engine HC emission mass fraction lookup table is a function of engine torque and engine speed, *HC Mass Fraction* = *f*(*Speed*, *Torque*), where:

- *HC Mass Fraction* is the HC emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.



Dependencies

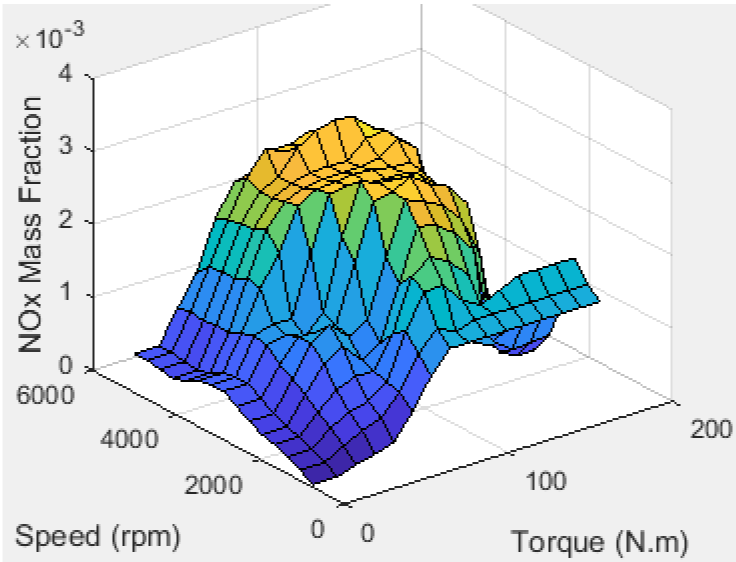
To enable this parameter, on the **Exhaust** tab, select **HC**.

`NOx mass fraction table, f_NOx_frac` — Nitric oxide and nitrogen dioxide (NOx) emission lookup table

`array`

The SI Core Engine NOx emission mass fraction lookup table is a function of engine torque and engine speed, *NOx Mass Fraction* = *f*(*Speed*, *Torque*), where:

- *NOx Mass Fraction* is the NOx emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.



Dependencies

To enable this parameter, on the **Exhaust** tab, select **NOx**.

`PM mass fraction table, f_PM_frac` — Particulate matter (PM) emission lookup table

`array`

The SI Core Engine PM emission mass fraction lookup table is a function of engine torque and engine speed where:

- *PM* is the PM emission mass fraction, dimensionless.
- *Speed* is engine speed, in rpm.
- *Torque* is engine torque, in N·m.

Dependencies

To enable this parameter, on the **Exhaust** tab, select **PM**.

`Engine speed breakpoints, f_exhfrac_n_bpt` — Breakpoints

`[750 1053.57142857143 1357.14285714286 1660.71428571429 1964.28571428571 2267.85714285714 2571.42857142857 2875 3178.57142857143 3482.14285714286 3785.71428571429 4089.28571428571 4392.85714285714 4696.42857142857 5000]` (default) | `vector`

Engine speed breakpoints used for the emission mass fractions lookup tables, in rpm.

Dependencies

To enable this parameter, on the **Exhaust** tab, select **CO2**, **CO**, **NOx**, **HC**, or **PM**.

`Engine torque breakpoints, f_exhfrac_trq_bpt` — Breakpoints

`[0 15 26.4285714285714 37.8571428571429 49.2857142857143 60.7142857142857 72.1428571428571 83.5714285714286 95 106.428571428571 117.857142857143 129.285714285714 140.714285714286 152.142857142857 163.571428571429 175]` (default) | `vector`

Engine torque breakpoints used for the emission mass fractions lookup tables, in N·m.

Dependencies

To enable this parameter, on the **Exhaust** tab, select **CO2**, **CO**, **NOx**, **HC**, or **PM**.

Fuel

`Injector slope, Sinj` — Slope
`6.45161290322581` (default) | `scalar`

Fuel injector slope, S_{inj}, mg/ms.

`Stoichiometric air-fuel ratio, afr_stoich` — Air-fuel ratio
`14.6` (default) | `scalar`

Air-fuel ratio, *AFR*.

`Fuel lower heating value, fuel_lhv` — Heating value
`46e6` (default) | `scalar`

Fuel lower heating value, *LHV*, in J/kg.

`Fuel specific gravity, fuel_sg` — Specific gravity
`0.745` (default) | `scalar`

Specific gravity of fuel, Sg_{fuel}, dimensionless.

References

[1] Gerhardt, J., Hönninger, H., and Bischof, H., *A New Approach to Functional and Software Structure for Engine Management Systems — BOSCH ME7*. SAE Technical Paper 980801, 1998.

[2] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
SI Controller | Mapped SI Engine

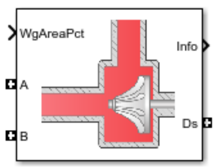
Topics
"SI Core Engine Air Mass Flow and Torque Production"
"Engine Calibration Maps"

Introduced in R2017a

Turbine

Turbine for boosted engines

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Boost

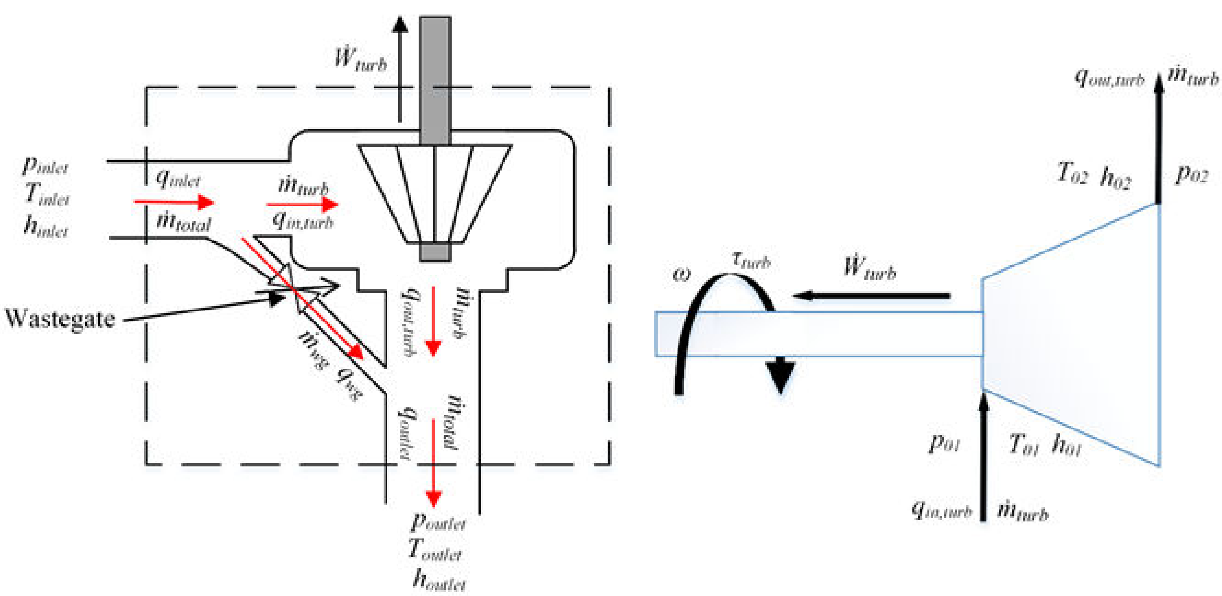


Description

The Turbine block uses the conservation of mass and energy to calculate mass and heat flow rates for turbines with either fixed or variable geometry. You can configure the block with a wastegate valve to bypass the turbine. The block uses two-way ports to connect to the inlet and outlet control volumes and the drive shaft. You can specify the lookup tables to calculate the mass flow rate and turbine efficiency. Typically, turbine manufacturers provide the mass flow rate and efficiency tables as a function of corrected speed and pressure ratio. The block does not support reverse mass flow.

If you have Model-Based Calibration Toolbox, click **Calibrate Performance Maps** to virtually calibrate the mass flow rate and turbine efficiency lookup tables using measured data.

The mass flows from the inlet control volume to outlet control volume.



The Turbine block implements equations to model the performance, wastegate flow, and combined flow.

Virtual Calibration

If you have Model-Based Calibration Toolbox, click **Calibrate Performance Maps** to virtually calibrate the corrected mass flow rate and turbine efficiency lookup tables using measured data. The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import turbine data</td><td>Import this turbine data from a file. For more information, see “Using Data” (Model-Based Calibration Toolbox).
<table>
<tr><th>Turbine type</th><th>Data</th></tr>
<tr><td><code>Fixed geometry</code></td><td>

Speed, Spd, in rad/s
Corrected mass flow rate, MassFlwRate, in kg/s
Pressure ratio, PrsRatio, dimensionless
Efficiency, Eff, dimensionless

The speed, corrected mass flow rate, pressure ratio, and efficiency are in the 2nd-5th columns of the data file, respectively. The first and second rows of the data file provide the variable names and units. For example, use this format.
<table>
<tr><td>Name:</td><td>Spd</td><td>MassFlwRate</td><td>PrsRatio</td><td>Eff</td></tr>
<tr><td>Unit:</td><td>rad/s</td><td>kg/s</td><td></td><td></td></tr>
<tr><td>Data:</td><td><code>8373.3</code></td><td><code>0.02</code></td><td><code>1.21</code></td><td><code>0.44</code></td></tr>
<tr><td></td><td>...</td><td>...</td><td>...</td><td>...</td></tr>
</table>
</td></tr>
<tr><td><code>Variable geometry</code></td><td>

Speed, Spd, in rad/s
Corrected mass flow rate, MassFlwRate, kg/s
Rack position, RackPos, dimensionless
Pressure ratio, PrsRatio, dimensionless
Efficiency, Eff, dimensionless

Include data for several test points at each rack position operating point.

The speed, corrected mass flow rate, rack position, pressure ratio, and efficiency are in the 2nd-6th columns of the data file, respectively. The first and second rows of the data file provide the variable names and units. For example, use this format.
<table>
<tr><td>Name:</td><td>Spd</td><td>MassFlwRate</td><td>RackPos</td><td>PrsRatio</td><td>Eff</td></tr>
<tr><td>Unit:</td><td>rad/s</td><td>kg/s</td><td></td><td></td><td></td></tr>
<tr><td>Data:</td><td><code>8373.3</code></td><td><code>0.02</code></td><td><code>1</code></td><td><code>1.21</code></td><td><code>0.44</code></td></tr>
<tr><td></td><td>...</td><td>...</td><td></td><td>...</td><td>...</td></tr>
</table>
</td></tr>
</table>
Model-Based Calibration Toolbox limits the speed and pressure ratio breakpoint values to the maximum values in the file.</td></tr>
</table>

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td></td><td>To filter or edit the data, select Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
<tr><td>Generate response models</td><td>Model-Based Calibration Toolbox fits the imported data and generates response models.
<table>
<tr><th>Turbine type</th><th>Description</th></tr>
<tr><td><code>Fixed geometry</code></td><td>
<table>
<tr><th>Data</th><th>Response Model</th></tr>
<tr><td>Corrected mass flow rate</td><td>Square root turbine flow model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
<tr><td>Efficiency</td><td>Blade speed ratio (BSR) model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
</table>
</td></tr>
<tr><td><code>Variable geometry</code></td><td>Model-Based Calibration Toolbox uses a point-by-point test plan to fit the data. For each rack position, the block uses these response models to fit the corrected mass flow rate and efficiency data.
<table>
<tr><th>Data</th><th>Response Model</th></tr>
<tr><td>Corrected mass flow rate</td><td>Square root turbine flow model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
<tr><td>Efficiency</td><td>Blade speed ratio (BSR) model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
</table>
</td></tr>
</table>
To assess or adjust the response model fit, select Edit in Application. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</td></tr>
<tr><td>Generate calibration</td><td>Model-Based Calibration Toolbox calibrates the response model and generates calibrated tables.
<table>
<tr><th>Turbine type</th><th>Description</th></tr>
<tr><td><code>Fixed geometry</code></td><td>Model-Based Calibration Toolbox uses the response models for the corrected mass flow rate and efficiency tables.</td></tr>
<tr><td><code>Variable geometry</code></td><td>Model-Based Calibration Toolbox fills the corrected mass flow rate and efficiency tables for each rack position. Model-Based Calibration Toolbox then combines the rack position-dependent tables into 3D lookup tables for corrected mass flow rate and efficiency.</td></tr>
</table>
To assess or adjust the calibration, select Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</td></tr>
</table>

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Update block parameters</td><td>Update these corrected mass flow rate and efficiency parameters with the calibration.
<table>
<tr><th>Turbine type</th><th>Parameters</th></tr>
<tr><td><code>Fixed geometry</code></td><td>Corrected mass flow rate table, mdot_corrfx_tbl
Efficiency table, eta_turbfx_tbl
Corrected speed breakpoints, w_corrfx_bpts1
Pressure ratio breakpoints, Pr_fx_bpts2</td></tr>
<tr><td><code>Variable geometry</code></td><td>Corrected mass flow rate table, mdot_corrvr_tbl
Efficiency table, eta_turbvr_tbl
Corrected speed breakpoints, w_corrvr_bpts2
Pressure ratio breakpoints, Pr_vr_bpts2
Rack breakpoints, L_rack_bpts3</td></tr>
</table>
</td></tr>
</table>

Thermodynamics

The block uses these equations to model the thermodynamics.

Calculation	Equations
Forward mass flow	$\dot{m}_{turb} > 0$ $p_{01} = p_{inlet}$ $p_{02} = p_{outlet}$ $T_{01} = T_{inlet}$ $h_{01} = h_{inlet}$
First law of thermodynamics	$\dot{W}_{turb} = \dot{m}_{turb} c_p (T_{01} - T_{02})$
Isentropic efficiency	$\eta_{turb} = \frac{h_{01} - h_{02}}{h_{01} - h_{02s}} = \frac{T_{01} - T_{02}}{T_{01} - T_{02s}}$
Isentropic outlet temperature, assuming ideal gas, and constant specific heats	$T_{02s} = T_{01} \left(\frac{p_{02}}{p_{01}}\right)^{\frac{\gamma - 1}{\gamma}}$
Specific heat ratio	$\gamma = \frac{c_p}{c_p - R}$
Outlet temperature	$T_{02} = T_{01} + \eta_{turb} T_{01} \left\{1 - \left(\frac{p_{02}}{p_{01}}\right)^{\frac{\gamma - 1}{\gamma}}\right\}$
Heat flows	$q_{in,turb} = \dot{m}_{turb} c_p T_{01}$ $q_{out,turb} = \dot{m}_{turb} c_p T_{02}$

Calculation	Equations
Drive shaft torque	$\tau_{turb} = \frac{\dot{W}_{turb}}{\omega}$

The equations use these variables.

p_{inlet}, p_{01}	Inlet control volume total pressure
T_{inlet}, T_{01}	Inlet control volume total temperature
h_{inlet}, h_{01}	Inlet control volume total specific enthalpy
p_{outlet}, p_{02}	Outlet control volume total pressure
T_{outlet}	Outlet control volume total temperature
h_{outlet}	Outlet control volume total specific enthalpy
$\dot{W}_{turb}$	Drive shaft power
T_{02}	Temperature exiting the turbine
h_{02}	Outlet total specific enthalpy
$\dot{m}_{turb}$	Turbine mass flow rate
$q_{in,\,turb}$	Turbine inlet heat flow rate
$q_{out,\,turb}$	Turbine outlet heat flow rate
η_{turb}	Turbine isentropic efficiency
T_{02s}	Isentropic outlet total temperature
h_{02s}	Isentropic outlet total specific enthalpy
R	Ideal gas constant
c_p	Specific heat at constant pressure
γ	Specific heat ratio
τ_{turb}	Drive shaft torque

Performance Lookup Tables

The block implements lookup tables based on these equations.

Calculation	Equation	
Corrected mass flow rate	$\dot{m}_{corr} = \dot{m}_{turb}\frac{\sqrt{T_{01}/T_{ref}}}{p_{01}/p_{ref}}$	
Corrected speed	$\omega_{corr} = \frac{\omega}{\sqrt{T_{01}/T_{ref}}}$	
Pressure expansion ratio	$p_r = \frac{p_{01}}{p_{02}}$	
Efficiency lookup table	Fixed geometry (3-D table)	$\eta_{turbfx,\,tbl} = f(\omega_{corr}, p_r)$
	Variable geometry (3-D table)	$\eta_{turbvr,\,tbl} = f(\omega_{corr}, p_r, L_{rack})$

Calculation	Equation	
Corrected mass flow lookup table	Fixed geometry (3-D table)	$\dot{m}_{corrfx,tbl} = f(\omega_{corr}, p_r)$
	Variable geometry (3-D table)	$\dot{m}_{corrvr,tbl} = f(\omega_{corr}, p_r, L_{rack})$

The equations use these variables.

p_{01}	Inlet control volume total pressure
p_r	Pressure expansion ratio
p_{02}	Outlet control volume total pressure
P_{ref}	Lookup table reference pressure
T_{01}	Inlet control volume total temperature
T_{ref}	Lookup table reference temperature
$\dot{m}_{turb}$	Turbine mass flow rate
ω	Drive shaft speed
ω_{corr}	Corrected drive shaft speed
L_{rack}	Variable geometry turbine rack position
$\eta_{turbfx,tbl}$	Efficiency 3-D lookup table for fixed geometry
$\dot{m}_{corrfx,tbl}$	Corrected mass flow rate 3-D lookup table for fixed geometry
$\eta_{turbvr,tbl}$	Efficiency 3-D lookup table for variable geometry
$\dot{m}_{corrvr,tbl}$	Corrected mass flow rate 3-D lookup table for variable geometry

Wastegate

To calculate the wastegate heat and mass flow rates, the Turbine block uses a Flow Restriction block. The Flow Restriction block uses the wastegate flow area.

$$A_{wg} = A_{wgpctcmd}\frac{A_{wgopen}}{100}$$

The equation uses these variables.

$A_{wgpctcmd}$	Wastegate valve area percent command
A_{wg}	Wastegate valve area
A_{wgopen}	Wastegate valve area when fully open

Combined Flow

To represent flow through the wastegate valve and turbine, the block uses these equations.

Calculation	Equations
Blocks not configured with a wastegate valve	$\dot{m}_{wg} = q_{wg} = 0$
Total mass flow rate	$\dot{m}_{total} = \dot{m}_{turb} + \dot{m}_{wg}$

Calculation	Equations
Total heat flow rate	$q_{inlet} = q_{in,turb} + q_{wg}$ $q_{outlet} = q_{out,turb} + q_{wg}$
Combined temperature exiting the wastegate valve and turbine	$T_{outflw} = \begin{cases} \frac{q_{outlet}}{\dot{m}_{total} c_p} & \dot{m}_{total} > \dot{m}_{thresh} \\ \frac{T_{02} + T_{outflw,wg}}{2} & else \end{cases}$

The block uses the internal signal `FlwDir` to track the direction of the flow.

The equations use these variables.

$\dot{m}_{total}$	Total mass flow rate through the wastegate valve and turbine
$\dot{m}_{turb}$	Turbine mass flow rate
$\dot{m}_{wg}$	Mass flow rate through the wastegate valve
q_{inlet}	Total inlet heat flow rate
q_{outlet}	Total outlet heat flow rate
$q_{in,turb}$	Turbine inlet heat flow rate
$q_{out,turb}$	Turbine outlet heat flow rate
q_{wg}	Wastegate valve heat flow rate
T_{02}	Temperature exiting the turbine
T_{outflw}	Total temperature exiting the block
$T_{outflw,wg}$	Temperature exiting the wastegate valve
$\dot{m}_{thresh}$	Mass flow rate threshold to prevent dividing by zero
c_p	Specific heat at constant pressure

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrDriveshft`	Power transmitted from the shaft	$-\dot{W}_{turb}$
		`PwrHeatFlwIn`	Heat flow rate at port A	q_{outlet}
		`PwrHeatFlwOut`	Heat flow rate at port B	q_{outlet}

Bus Signal			Description	Equations
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrLoss`	Power loss	$-q_{inlet}$ $-q_{outlet}$ $+\dot{W}_{turb}$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	*Not used*		

The equations use these variables.

$\dot{W}_{turb}$	Drive shaft power
q_{outlet}	Total outlet heat flow rate
q_{inlet}	Total inlet heat flow rate

Ports

Input

Ds — Drive shaft speed
two-way connector port

`ShaftSpd` — Signal containing the drive shaft angular speed, ω, in rad/s.

A — Inlet pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the inlet control volume:

- `InPrs` — Pressure, p_{inlet}, in Pa
- `InTemp` — Temperature, T_{inlet}, in K
- `InEnth` — Specific enthalpy, h_{inlet}, in J/kg

B — Outlet pressure, temperature, enthalpy, mass fractions
two-way connector port

Bus containing the outlet control volume:

- `OutPrs` — Pressure, p_{outlet}, in Pa
- `OutTemp` — Temperature, T_{outlet}, in K
- `OutEnth` — Specific enthalpy, h_{outlet}, in J/kg

RackPos — Rack position
scalar

Variable geometry turbine rack position, L_{rack}.

Dependencies

To create this port, select `Variable geometry` for the **Turbine type** parameter.

WgAreaPct — Wastegate area percent
scalar

Wastegate valve area percent, $A_{wgpctcmd}$.

Dependencies

To create this port, select **Include wastegate**.

Output

Info — Bus signal
bus

Bus signal containing these block calculations.

<table>
<tr><th colspan="3">Signal</th><th>Description</th><th>Units</th></tr>
<tr><td colspan="3">TurbOutletTemp</td><td>Temperature exiting the turbine</td><td>K</td></tr>
<tr><td colspan="3">DriveshftPwr</td><td>Drive shaft power</td><td>W</td></tr>
<tr><td colspan="3">DriveshftTrq</td><td>Drive shaft torque</td><td>N·m</td></tr>
<tr><td colspan="3">TurbMassFlw</td><td>Turbine mass flow rate</td><td>kg/s</td></tr>
<tr><td colspan="3">PrsRatio</td><td>Pressure ratio</td><td>N/A</td></tr>
<tr><td colspan="3">DriveshftCorrSpd</td><td>Corrected drive shaft speed</td><td>rad/s</td></tr>
<tr><td colspan="3">TurbEff</td><td>Turbine isentropic efficiency</td><td>N/A</td></tr>
<tr><td colspan="3">CorrMassFlw</td><td>Corrected mass flow rate</td><td>kg/s</td></tr>
<tr><td colspan="3">WgArea</td><td>Wastegate valve area</td><td>m^2</td></tr>
<tr><td colspan="3">WgMassFlw</td><td>Mass flow rate through the wastegate valve</td><td>kg/s</td></tr>
<tr><td colspan="3">WgOutletTemp</td><td>Temperature exiting the wastegate valve</td><td>K</td></tr>
<tr><td rowspan="5">PwrInfo</td><td rowspan="3">PwrTrnsfrd</td><td>PwrDriveshft</td><td>Power transmitted from the shaft</td><td>W</td></tr>
<tr><td>PwrHeatFlwIn</td><td>Heat flow rate at port A</td><td>W</td></tr>
<tr><td>PwrHeatFlwOut</td><td>Heat flow rate at port B</td><td>W</td></tr>
<tr><td>PwrNotTrnsfrd</td><td>PwrLoss</td><td>Power loss</td><td>W</td></tr>
<tr><td colspan="2">PwrStored</td><td colspan="2">Not used</td></tr>
</table>

Ds — Drive shaft torque
two-way connector port

`Trq` — Signal containing the drive shaft torque, τ_{turb}, in N·m.

A — Inlet mass flow rate, heat flow rate, temperature, mass fractions
two-way connector port

Bus containing:

- `MassFlwRate` — Total mass flow rate through wastegate valve and turbine, $-\dot{m}_{total}$, in kg/s
- `HeatFlwRate` — Total inlet heat flow rate, $-q_{inlet}$, in J/s
- `Temp` — Total inlet temperature, T_{inlet}, in K
- `MassFrac` — Mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide
  - `NOMassFrac` — Nitric oxide
  - `NO2MassFrac` — Nitrogen dioxide
  - `NOxMassFrac` — Nitric oxide and nitrogen dioxide
  - `PmMassFrac` — Particulate matter
  - `AirMassFrac` — Air
  - `BrndGasMassFrac` — Burned gas

B — Outlet mass flow rate, heat flow rate, temperature, mass fractions
two-way connector port

Bus containing:

- `MassFlwRate` — Turbine mass flow rate through wastegate valve and turbine, $\dot{m}_{turb}$, in kg/s
- `HeatFlwRate` — Total outlet heat flow rate, q_{outlet}, in J/s
- `Temp` — Total outlet temperature, T_{outflw}, in K
- `MassFrac` — Mass fractions, dimensionless.

  Specifically, a bus with these mass fractions:

  - `O2MassFrac` — Oxygen
  - `N2MassFrac` — Nitrogen
  - `UnbrndFuelMassFrac` — Unburned fuel
  - `CO2MassFrac` — Carbon dioxide
  - `H2OMassFrac` — Water
  - `COMassFrac` — Carbon monoxide

- NOMassFrac — Nitric oxide
- NO2MassFrac — Nitrogen dioxide
- NOxMassFrac — Nitric oxide and nitrogen dioxide
- PmMassFrac — Particulate matter
- AirMassFrac — Air
- BrndGasMassFrac — Burned gas

Parameters

Block Options

Turbine type — Select turbine type

Fixed geometry (default) | Variable geometry

Turbine type.

Dependencies

The table summarizes the parameter and port dependencies.

Value	Enables Parameters	Creates Ports
Fixed geometry	**Corrected mass flow rate table, mdot_corrfx_tbl** **Efficiency table, eta_turbfx_tbl** **Corrected speed breakpoints, w_corrfx_bpts1** **Pressure ratio breakpoints, Pr_fx_bpts2**	None
Variable geometry	**Corrected mass flow rate table, mdot_corrvr_tbl** **Efficiency table, eta_turbvr_tbl** **Corrected speed breakpoints, w_corrvr_bpts2** **Pressure ratio breakpoints, Pr_vr_bpts2** **Rack breakpoints, L_rack_bpts3**	RP

Include wastegate — Select

on (default) | off

Dependencies

Selecting the **Include wastegate** parameter enables:

- **Wastegate flow area, A_wgopen**
- **Pressure ratio linearize limit, Plim_wg**

Performance Tables

`Calibrate Performance Maps` — Calibrate tables with measured data
`selection`

If you have Model-Based Calibration Toolbox, click **Calibrate Performance Maps** to virtually calibrate the corrected mass flow rate and turbine efficiency lookup tables using measured data. The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import turbine data</td><td>Import this turbine data from a file. For more information, see “Using Data” (Model-Based Calibration Toolbox).
<table>
<tr><th>Turbine type</th><th>Data</th></tr>
<tr><td><code>Fixed geometry</code></td><td>

Speed, Spd, in rad/s
Corrected mass flow rate, MassFlwRate, in kg/s
Pressure ratio, PrsRatio, dimensionless
Efficiency, Eff, dimensionless

The speed, corrected mass flow rate, pressure ratio, and efficiency are in the 2nd-5th columns of the data file, respectively. The first and second rows of the data file provide the variable names and units. For example, use this format.
<table>
<tr><td>Name:</td><td>Spd</td><td>MassFlwRate</td><td>PrsRatio</td><td>Eff</td></tr>
<tr><td>Unit:</td><td>rad/s</td><td>kg/s</td><td></td><td></td></tr>
<tr><td>Data:</td><td><code>8373.3</code></td><td><code>0.02</code></td><td><code>1.21</code></td><td><code>0.44</code></td></tr>
<tr><td></td><td>...</td><td>...</td><td>...</td><td>...</td></tr>
</table>
</td></tr>
<tr><td><code>Variable geometry</code></td><td>

Speed, Spd, in rad/s
Corrected mass flow rate, MassFlwRate, kg/s
Rack position, RackPos, dimensionless
Pressure ratio, PrsRatio, dimensionless
Efficiency, Eff, dimensionless

Include data for several test points at each rack position operating point.

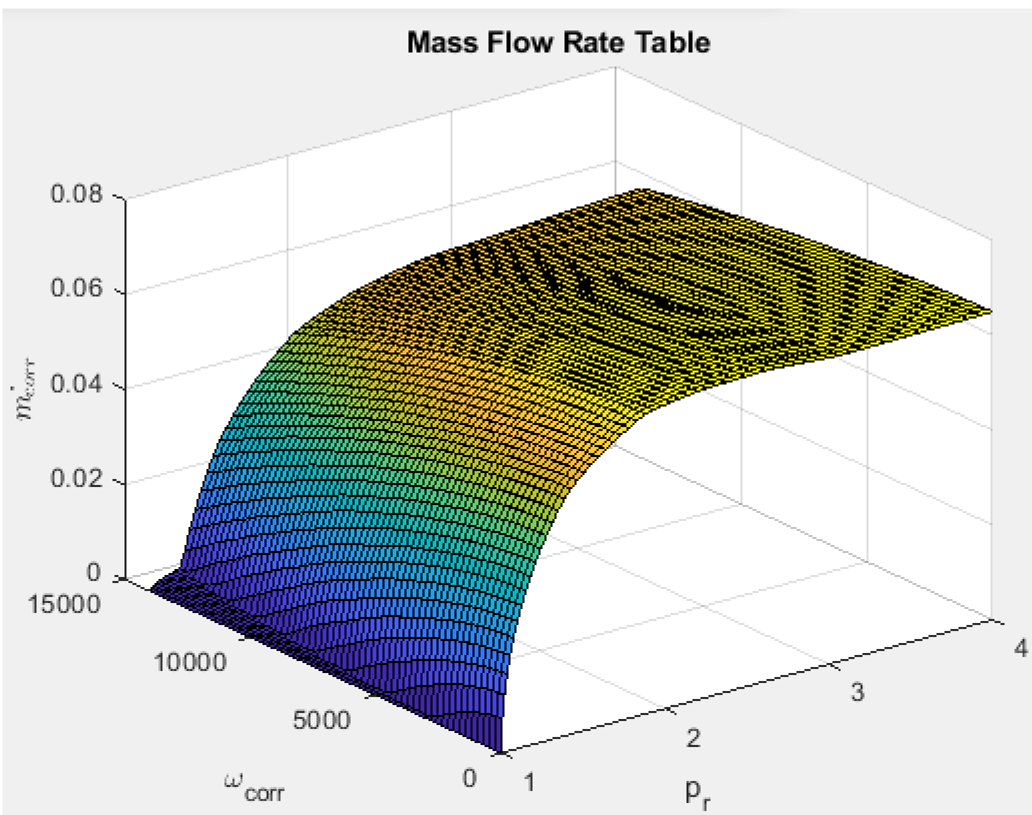
The speed, corrected mass flow rate, rack position, pressure ratio, and efficiency are in the 2nd-6th columns of the data file, respectively. The first and second rows of the data file provide the variable names and units. For example, use this format.
<table>
<tr><td>Name:</td><td>Spd</td><td>MassFlwRate</td><td>RackPos</td><td>PrsRatio</td><td>Eff</td></tr>
<tr><td>Unit:</td><td>rad/s</td><td>kg/s</td><td></td><td></td><td></td></tr>
<tr><td>Data:</td><td><code>8373.3</code></td><td><code>0.02</code></td><td><code>1</code></td><td><code>1.21</code></td><td><code>0.44</code></td></tr>
<tr><td></td><td>...</td><td>...</td><td></td><td>...</td><td>...</td></tr>
</table>
</td></tr>
</table>
Model-Based Calibration Toolbox limits the speed and pressure ratio breakpoint values to the maximum values in the file.</td></tr>
</table>

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td></td><td>To filter or edit the data, select Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
<tr><td>Generate response models</td><td>Model-Based Calibration Toolbox fits the imported data and generates response models.
<table>
<tr><th>Turbine type</th><th>Description</th></tr>
<tr><td><code>Fixed geometry</code></td><td>
<table>
<tr><th>Data</th><th>Response Model</th></tr>
<tr><td>Corrected mass flow rate</td><td>Square root turbine flow model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
<tr><td>Efficiency</td><td>Blade speed ratio (BSR) model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
</table>
</td></tr>
<tr><td><code>Variable geometry</code></td><td>Model-Based Calibration Toolbox uses a point-by-point test plan to fit the data. For each rack position, the block uses these response models to fit the corrected mass flow rate and efficiency data.
<table>
<tr><th>Data</th><th>Response Model</th></tr>
<tr><td>Corrected mass flow rate</td><td>Square root turbine flow model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
<tr><td>Efficiency</td><td>Blade speed ratio (BSR) model described in Modeling and Control of Engines and Drivelines[2]</td></tr>
</table>
</td></tr>
</table>
To assess or adjust the response model fit, select Edit in Application. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</td></tr>
<tr><td>Generate calibration</td><td>Model-Based Calibration Toolbox calibrates the response model and generates calibrated tables.
<table>
<tr><th>Turbine type</th><th>Description</th></tr>
<tr><td><code>Fixed geometry</code></td><td>Model-Based Calibration Toolbox uses the response models for the corrected mass flow rate and efficiency tables.</td></tr>
<tr><td><code>Variable geometry</code></td><td>Model-Based Calibration Toolbox fills the corrected mass flow rate and efficiency tables for each rack position. Model-Based Calibration Toolbox then combines the rack position-dependent tables into 3D lookup tables for corrected mass flow rate and efficiency.</td></tr>
</table>
To assess or adjust the calibration, select Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</td></tr>
</table>

Task	Description
Update block parameters	Update these corrected mass flow rate and efficiency parameters with the calibration. **Turbine type** / **Parameters** `Fixed geometry`: • **Corrected mass flow rate table, mdot_corrfx_tbl** • **Efficiency table, eta_turbfx_tbl** • **Corrected speed breakpoints, w_corrfx_bpts1** • **Pressure ratio breakpoints, Pr_fx_bpts2** `Variable geometry`: • **Corrected mass flow rate table, mdot_corrvr_tbl** • **Efficiency table, eta_turbvr_tbl** • **Corrected speed breakpoints, w_corrvr_bpts2** • **Pressure ratio breakpoints, Pr_vr_bpts2** • **Rack breakpoints, L_rack_bpts3**

`Corrected mass flow rate table, mdot_corrfx_tbl` — Lookup table
`array`

Corrected mass flow rate lookup table for fixed geometry, $\dot{m}_{corrfx,tbl}$, as a function of corrected driveshaft speed, ω_{corr}, and pressure ratio, p_r, in kg/s.

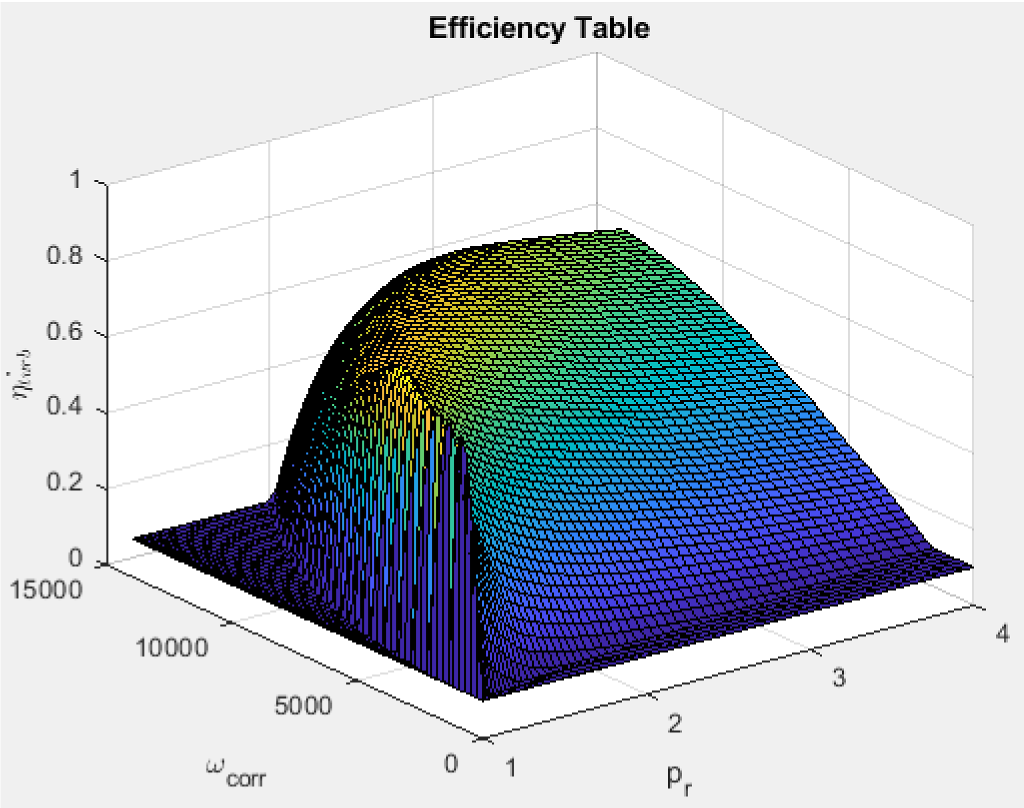


Dependencies

To enable this parameter, select `Fixed geometry` for the **Turbine type** parameter.

`Efficiency table, eta_turbfx_tb` — Lookup table
`array`

Efficiency lookup table for fixed geometry, $\eta_{turbfx,tbl}$, as a function of corrected driveshaft speed, ω_{corr}, and pressure ratio, p_r, dimensionless.



Dependencies

To enable this parameter, select `Fixed geometry` for the **Turbine type** parameter.

`Corrected speed breakpoints, w_corrfx_bpts1` — Fixed geometry
`[0 1552 3104 4657 6209 7761 9313 1.087e+04 1.242e+04 1.397e+04]` (default) | `vector`

Corrected drive shaft speed breakpoints for fixed geometry, $\omega_{corrfx,bpts1}$, in rad/s.

Dependencies

To enable this parameter, select `Fixed geometry` for the **Turbine type** parameter.

`Pressure ratio breakpoints, Pr_fx_bpts2` — Fixed geometry
`[1 1.333 1.667 2 2.333 2.667 3 3.333 3.667 4]` (default) | `vector`

Pressure ratio breakpoints for fixed geometry, $p_{rfx,bpts2}$.

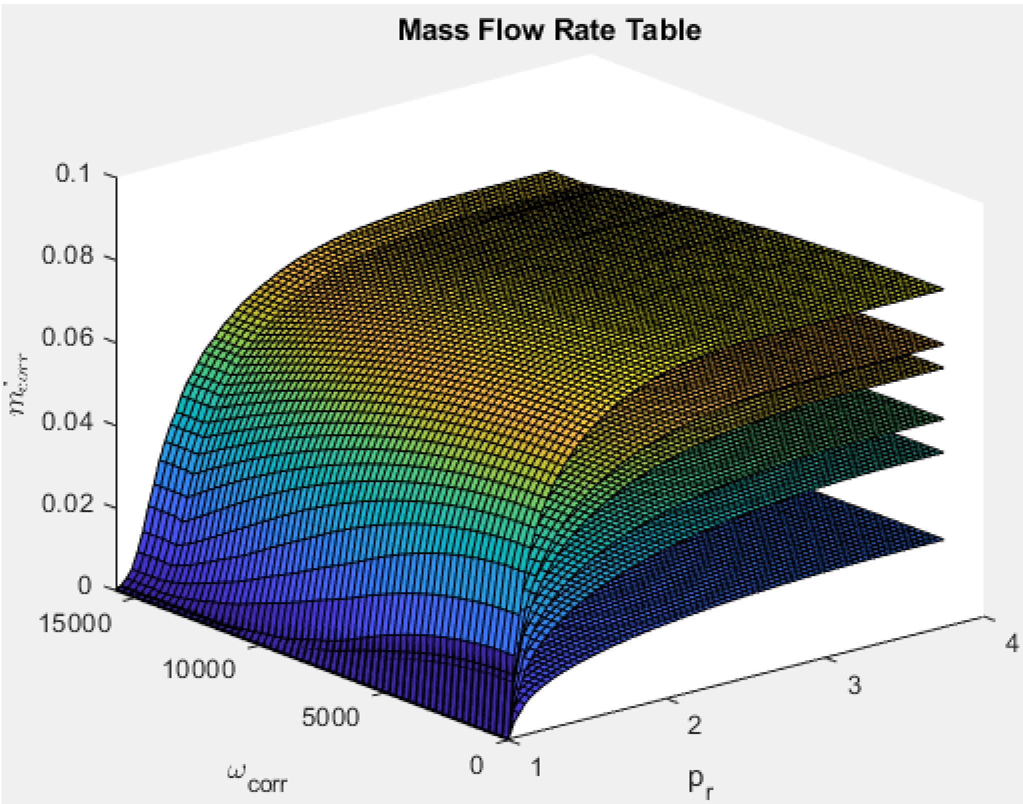
Dependencies

To enable this parameter, select `Fixed geometry` for the **Turbine type** parameter.

`Corrected mass flow rate table, mdot_corrvr_tbl` — Lookup table

`array`

Corrected mass flow rate lookup table for variable geometry, $\dot{m}_{corrvr,tbl}$, as a function of corrected driveshaft speed, ω_{corr}, and pressure ratio, p_r, in kg/s.



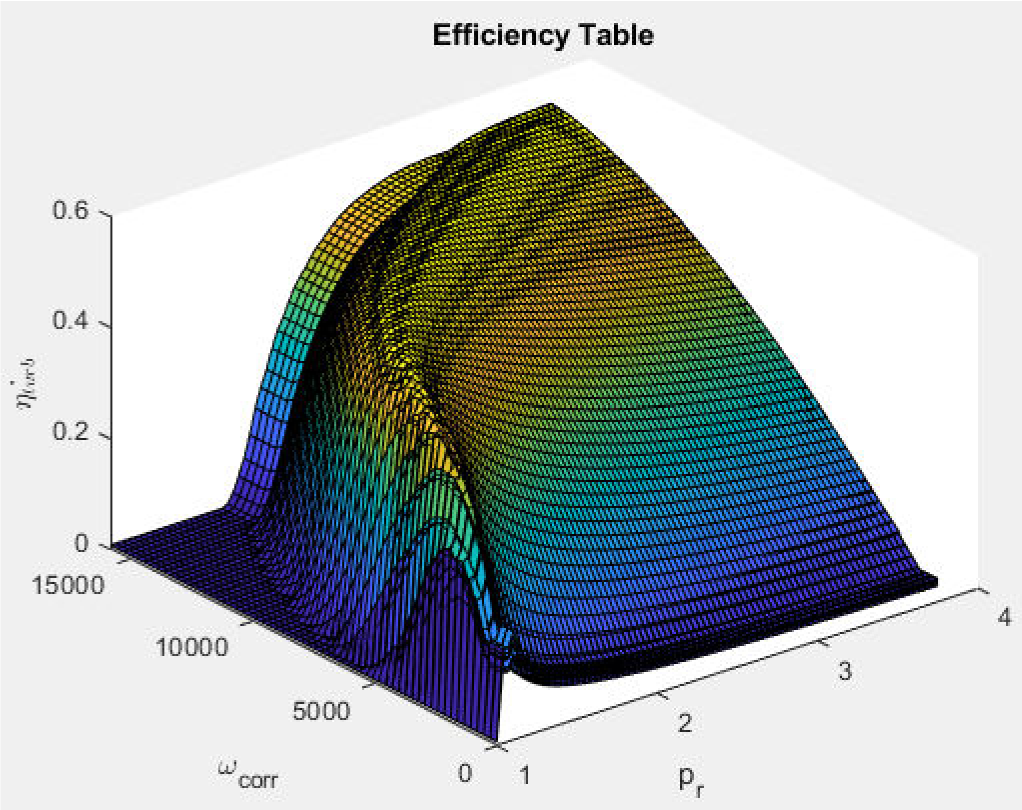
Dependencies

To enable this parameter, select `Variable geometry` for the **Turbine type** parameter.

`Efficiency table, eta_turbvr_tbl` — Lookup table

`array`

Efficiency lookup table for variable geometry, $\eta_{turbvr,tbl}$, as a function of corrected driveshaft speed, ω_{corr}, and pressure ratio, p_r, dimensionless.



Dependencies

To enable this parameter, select `Variable geometry` for the **Turbine type** parameter.

`Corrected speed breakpoints, w_corrvr_bpts2` — Variable geometry

`[0 1752 3504 5257 7009 8761 1.051e+04 1.227e+04 1.402e+04 1.577e+04]` (default) | `vector`

Corrected drive shaft speed breakpoints for variable geometry, $\omega_{corrvr, bpts1}$, in rad/s.

Dependencies

To enable this parameter, select `Variable geometry` for the **Turbine type** parameter.

`Pressure ratio breakpoints, Pr_vr_bpts2` — Variable geometry

`[1 1.306 1.611 1.917 2.222 2.528 2.833 3.139 3.444 3.75]` (default) | `vector`

Pressure ratio breakpoints for variable geometry.

Dependencies

To enable this parameter, select `Variable geometry` for the **Turbine type** parameter.

`Rack breakpoints, L_rack_bpts3` — Variable geometry

`[0 0.2 0.3 0.5 0.7 1]` (default) | `vector`

Rack position breakpoints for variable geometry, $L_{rack, bpts3}$.

Dependencies

To enable this parameter, select `Variable geometry` for the **Turbine type** parameter.

`Reference temperature, T_ref` — Temperature
`293.15` (default) | `scalar`

Performance map reference temperature, T_{ref}, in K.

`Reference pressure, P_ref` — Pressure
`101325` (default) | `scalar`

Performance map reference pressure, P_{ref}, in Pa.

Wastegate

`Wastegate flow area, A_wgopen` — Area
`0.0003` (default) | `scalar`

Area of fully opened wastegate valve, A_{wgopen}, in m^2.

Dependencies

To enable **Wastegate flow area, A_wgopen**, select the **Include wastegate** parameter.

`Pressure ratio linearize limit, Plim_wg` — Area, `m^2`
`0.95` (default) | `scalar`

Dependencies

Flow restriction linearization limit, $p_{lim,\,wg}$.

To enable **Pressure ratio linearize limit, Plim_wg**, select the **Include wastegate** parameter.

Properties

`Ideal gas constant, R` — Constant
`287` (default) | `scalar`

Ideal gas constant R, in J/(kg·K).

`Specific heat at constant pressure, cp` — Specific heat
`1005` (default) | `scalar`

Specific heat at constant pressure, c_p, in J/(kg·K).

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

[2] Eriksson, Lars and Lars Nielsen. *Modeling and Control of Engines and Drivelines*. Chichester, West Sussex, United Kingdom: John Wiley & Sons Ltd, 2014.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Compressor | Boost Drive Shaft

Topics

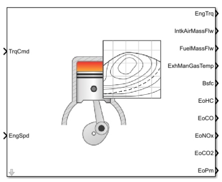
"Model-Based Calibration Toolbox"

Introduced in R2017a

Mapped Core Engine

Steady-state core engine model using lookup tables

Library: Powertrain Blockset / Propulsion / Combustion Engine Components / Core Engine



Description

The Mapped Core Engine block implements a steady-state core engine model using power, air mass flow, fuel flow, exhaust temperature, efficiency, and emission performance lookup tables. You can use the block for:

- Hardware-in-the-loop (HIL) engine control design.
- Vehicle-level fuel economy and performance simulations.

The block enables you to specify lookup tables for these engine characteristics. The lookup tables are functions of engine load, *L*, and engine speed *N*. If you select **Input engine temperature**, the tables are also a function of engine temperature, *T*.

- Power
- Air
- Fuel
- Temperature
- Efficiency
- Emissions
  - Hydrocarbon (HC)
  - Carbon monoxide (CO)
  - Nitric oxide and nitrogen dioxide (NOx)
  - Carbon dioxide (CO_2)
  - Particulate matter (PM) emissions

To bound the Mapped Core Engine block output, the block does not extrapolate the lookup table data.

Ports

Input

<*TrqCmd*> — Engine load
`TrqCmd` (default)

Engine load, *L*. Examples of engine load include:

- Commanded torque
- Commanded indicated mean effective pressure (IMEP) in the engine cylinder
- Normalized cylinder air mass
- Injected fuel mass

Dependencies

To specify an engine load port name, on the **Configuration** tab, enter a name in the **Load input port name** parameter field.

<*EngSpd*> — Engine speed

`EngSpd` (default)

Engine speed, *N*.

Dependencies

To specify an engine load port name, on the **Configuration** tab, enter a name in the **Speed input port name** parameter field.

<*EngTemp*> — Engine temperature

`EngTemp` (default)

Engine temperature, *T*.

Dependencies

To create the engine temperature input port name, select **Input engine temperature** parameter field.

To specify an engine load port name, on the **Configuration** tab, enter a name in the **Temperature input port name** parameter field.

Output

<*EngTrq*> — Power

`EngTrq` (default)

Engine power, T_{brake}.

Dependencies

- To create this port, on the **Configuration** tab, select **Power**.
- To specify the port name, on the **Power** tab, enter a name in the **Power output port name** parameter field.

<*IntkAirMassFlw*> — Air mass flow

`IntkAirMassFlw` (default)

Engine air mass flow, $\dot{m}_{intk}$.

Dependencies

- To create this port, on the **Configuration** tab, select **Air**.

- To specify the port name, on the **Air** tab, enter a name in the **Air output port name** parameter field.

<*FuelMassFlw*> — Fuel flow
`FuelMassFlw` (default)

Engine fuel flow, $\dot{m}_{fuel}$.

Dependencies

- To create this port, on the **Configuration** tab, select **Fuel**.
- To specify the port name, on the **Fuel** tab, enter a name in the **Fuel output port name** parameter field.

<*ExhManGasTemp*> — Exhaust temperature
`ExhManGasTemp` (default)

Engine exhaust temperature, T_{exh}.

Dependencies

- To create this port, on the **Configuration** tab, select **Temperature**.
- To specify the port name, on the **Temperature** tab, enter a name in the **Temperature output port name** parameter field.

<*Bsfc*> — Efficiency
`Bsfc` (default)

Brake-specific fuel consumption (BSFC), *Eff*.

Dependencies

- To create this port, on the **Configuration** tab, select **Efficiency**.
- To specify the port name, on the **Efficiency** tab, enter a name in the **Efficiency output port name** parameter field.

<*EoHC*> — Hydrocarbon emissions
`EoHC` (default)

Hydrocarbon emissions, *HC*.

Dependencies

- To create this port, on the **Configuration** tab, select **HC**.
- To specify the port name, on the **HC** tab, enter a name in the **HC output port name** parameter field.

<*EoCO*> — Carbon monoxide emissions
`EoCO` (default)

Carbon monoxide emissions, *CO*.

Dependencies

- To create this port, on the **Configuration** tab, select **CO**.

- To specify the port name, on the **CO** tab, enter a name in the **CO output port name** parameter field.

<EoNOx> — Nitric oxide and nitrogen dioxide emissions
`EoNOx` (default)

Nitric oxide and nitrogen dioxide emissions, *NOx*.

Dependencies

- To create this port, on the **Configuration** tab, select **NOx**.
- To specify the port name, on the **NOx** tab, enter a name in the **NOx output port name** parameter field.

<EoCO2> — Carbon dioxide emissions
`EoCO2` (default)

Carbon dioxide emissions, *CO2*.

Dependencies

- To create this port, on the **Configuration** tab, select **CO2**.
- To specify the port name, on the **CO2** tab, enter a name in the **CO2 output port name** parameter field.

<EoPm> — Particulate matter emissions
`EoPm` (default)

Particulate matter emissions, *PM*.

Dependencies

- To create this port, on the **Configuration** tab, select **PM**.
- To specify the port name, on the **PM** tab, enter a name in the **PM output port name** parameter field.

Parameters

Configuration

`Engine Type` — Type of engine image
`Compression-ignition (CI)` (default) | `Spark-ignition (SI)`

Type of mapped internal combustion engine image to use in the block.

`Load input port name` — Name
`TrqCmd` (default)

Engine load input port name.

`Breakpoints for load input` — Breakpoints
`vector`

Breakpoints for engine load input.

Speed input port name — Name
`EngSpd` (default)

Speed input port name.

Breakpoints for speed input — Breakpoints
`vector`

Breakpoints for engine speed input.

Temperature input port name — Name
`EngTemp` (default)

Temperature input port name.

Dependencies

To enable this parameter, select **Input engine temperature**.

Breakpoints for temperature input — Breakpoints
`[233.15 273.15 373.15]` (default) | `vector`

Breakpoints for engine temperature input.

Dependencies

To enable this parameter, select **Input engine temperature**.

Output Configuration — Create output ports
`on` (default)

Create the output ports.

Dependencies

The table summarizes the output ports that are created for each **Output** parameter selection.

Output Selection	Creates Port	Creates Tab
Power	*EngTrq*	**Power**
Air	*IntkAirMassFlw*	**Air**
Fuel	*FuelMassFlw*	**Fuel**
Temperature	*ExhManGasTemp*	**Temperature**
Efficiency	*Bsfc*	**Efficiency**
HC	*EoHC*	**HC**
CO	*EoCO*	**CO**
NOx	*EoNOx*	**NOx**
CO2	*EoCO2*	**CO2**
PM	*EoPm*	**PM**

Power

Power output port name — Power
`EngTrq` (default)

Power output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **Power**.

`Power table` — Power
`array`

Power table.

Dependencies

To create this parameter, on the **Configuration** tab, select **Power**.

Air

`Air output port name` — Air
`IntkAirMassFlw` (default)

Air mass flow output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **Air**.

`Air table` — Air
`array`

Air mass flow table.

Dependencies

To create this parameter, on the **Configuration** tab, select **Air**.

Fuel

`Fuel output port name` — Fuel
`FuelMassFlw` (default)

Fuel output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **Fuel**.

`Fuel table` — Fuel
`array`

Fuel table.

Dependencies

To create this parameter, on the **Configuration** tab, select **Fuel**.

Temperature

`Temperature output port name` — Temperature
`ExhManGasTemp` (default)

Temperature output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **Temperature**.

`Temperature table` — Temperature
`array`

Temperature table.

Dependencies

To create this parameter, on the **Configuration** tab, select **Temperature**.

Efficiency

`Efficiency output port name` — Efficiency
`Bsfc` (default)

Efficiency output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **Efficiency**.

`Efficiency table` — Efficiency
`array`

Efficiency table.

Dependencies

To create this parameter, on the **Configuration** tab, select **Efficiency**.

HC

`HC output port name` — Hydrocarbon
`EoHC` (default)

Hydrocarbon output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **HC**.

`HC table` — Hydrocarbon
`array`

Hydrocarbon table.

Dependencies

To create this parameter, on the **Configuration** tab, select **HC**.

CO

`CO output port name` — Carbon dioxide
`EoCO` (default)

Carbon monoxide output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **CO**.

`CO table` — Carbon dioxide
`array`

Carbon dioxide table.

Dependencies

To create this parameter, on the **Configuration** tab, select **CO**.

NOx

`NOx output port name` — Nitric oxide *NO* and nitrogen dioxide NO_2
`EoNOx` (default)

NOx output port name. NOx is nitric oxide *NO* and nitrogen dioxide NO_2.

Dependencies

To create this parameter, on the **Configuration** tab, select **NOx**.

`NOx table` — Nitric oxide *NO* and nitrogen dioxide NO_2
`array`

NOx emissions table. NOx is nitric oxide *NO* and nitrogen dioxide NO_2.

Dependencies

To create this parameter, on the **Configuration** tab, select **NOx**.

CO2

`CO2 output port name` — Carbon dioxide
`EoCO2` (default)

Carbon dioxide output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **CO2**.

`CO2 table` — Carbon dioxide
`array`

Carbon dioxide table.

Dependencies

To create this parameter, on the **Configuration** tab, select **CO2**.

PM

`PM output port name` — Particulate matter
`EoPm` (default)

Particulate matter output port name.

Dependencies

To create this parameter, on the **Configuration** tab, select **PM**.

`PM table` — Particulate matter
`array`

Particulate matter table.

Dependencies

To create this parameter, on the **Configuration** tab, select **PM**.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

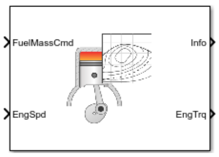
CI Core Engine | SI Core Engine

Introduced in R2017a

Mapped CI Engine

Compression-ignition engine model using lookup tables

Library: Powertrain Blockset / Propulsion / Combustion Engines
Vehicle Dynamics Blockset / Powertrain / Propulsion



Description

The Mapped CI Engine block implements a mapped compression-ignition (CI) engine model using power, air mass flow, fuel flow, exhaust temperature, efficiency, and emission performance lookup tables. You can use the block for:

- Hardware-in-the-loop (HIL) engine control design
- Vehicle-level fuel economy and performance simulations

The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of injected fuel mass, *F*, engine torque, *T*, engine speed, *N*, and engine temperature, $Temp_{Eng}$.

Input Command Setting	Input Engine Temperature Parameter Setting	Lookup Tables
`Fuel mass`	`off`	*f(F,N)*
	`on`	$f(F,N,Temp_{Eng})$
`Torque`	`off`	*f(T,N)*
	`on`	$f(T,N,Temp_{Eng})$

The block enables you to specify lookup tables for these engine characteristics:

- Power
- Air
- Fuel
- Temperature
- Efficiency
- Hydrocarbon (HC) emissions
- Carbon monoxide (CO) emissions
- Nitric oxide and nitrogen dioxide (NOx) emissions
- Carbon dioxide (CO_2) emissions
- Particulate matter (PM) emissions

To bound the Mapped CI Engine block output, the block does not extrapolate the lookup table data.

Virtual Calibration

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data. The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import firing data</td><td>Import this loss data from a file. For example, open <code><<i>matlabroot</i>>/toolbox/mbc/mbctraining/CiEngineData.xlsx</code>.

For more information, see “Using Data” (Model-Based Calibration Toolbox).

<table>
<tr><th>Input command</th><th>Required Data</th><th>Optional Data</th></tr>
<tr><td><code>Fuel mass</code></td><td>Engine speed, rpm
Commanded fuel mass per injection, mg
Engine torque, N·m</td><td rowspan="2">Air mass flow rate, kg/s
Brake specific fuel consumption, g/(kW·h)
CO2 mass flow rate, kg/s
CO mass flow rate, kg/s
Exhaust temperature, K
Fuel mass flow rate, kg/s
HC mass flow rate, kg/s
NOx mass flow rate, kg/s
Particulate matter mass flow rate, kg/s</td></tr>
<tr><td><code>Torque</code></td><td>Engine speed, rpm
Engine torque, N·m</td></tr>
</table>

Collect firing data at steady-state operating conditions when injectors deliver the fuel. Data should cover the engine speed and torque operating range. Model-Based Calibration Toolbox uses the firing data boundary as the maximum torque.

To filter or edit the data, select Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
<tr><td>Import non-firing data</td><td>Import this non-firing data from a file. For example, open <code><<i>matlabroot</i>>/toolbox/autoblks/autodemos/projectsrc/CIDynamometer/CalMappedEng/CiEngineData.xlsx</code>.
Engine speed, rpm
Engine torque, N·m
Collect non-firing (motoring) data at steady-state operating conditions when fuel is cut off. All non-firing torque points must be less than zero. Non-firing data is a function of engine speed only.</td></tr>
<tr><td>Generate response models</td><td>For both firing and non-firing data, the Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).

To assess or adjust the response model fit, select Edit in Application. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</td></tr>
</table>

Task	Description
Generate calibration	Model-Based Calibration Toolbox calibrates the firing and non-firing response models and generates calibrated tables. To assess or adjust the calibration, select **Edit in Application**. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).
Update block parameters	Update the block lookup table and breakpoint parameters with the calibration.

Cylinder Air Mass

The block calculates the normalized cylinder air mass using these equations.

$$M_{Nom} = \frac{P_{std}V_d}{N_{cyl}R_{air}T_{std}}$$

$$L = \frac{\left(\frac{60s}{min}\right)Cps \cdot \dot{m}_{air}}{\left(\frac{1000g}{Kg}\right)N_{cyl} \cdot N \cdot M_{Nom}}$$

The equations use these variables.

L	Normalized cylinder air mass
M_{Nom}	Nominal engine cylinder air mass at standard temperature and pressure, piston at bottom dead center (BDC) maximum volume, in kg
Cps	Crankshaft revolutions per power stroke, rev/stroke
P_{std}	Standard pressure
T_{std}	Standard temperature
R_{air}	Ideal gas constant for air and burned gas mixture
V_d	Displaced volume
N_{cyl}	Number of engine cylinders
N	Engine speed
$\dot{m}_{intk}$	Engine air mass flow, in g/s

Turbocharger Lag

To model turbocharger lag, select **Include turbocharger lag effect**. Turbocharger lag limits the maximum fuel mass per injection. To model the maximum fuel mass per injection, the block uses a first-order system with a time constant. At low torque, the engine does not require boost to provide sufficient air flow. When the requested fuel mass requires boost, the block uses a time constant to determine the maximum fuel mass per injection. The block uses these equations for the specified **Input command** setting.

Calculation	Input command Parameter Setting	
	`Fuel mass`	`Torque`
Dynamic torque	$\frac{dF_{max}}{dt} = \frac{1}{\tau_{eng}}(F_{cmd} - F_{max})$	$\frac{dT_{max}}{dt} = \frac{1}{\tau_{eng}}(T_{cmd} - T_{max})$
Fuel mass per injection or torque - with turbocharger lag	$F = \begin{cases} F_{cmd} & \text{when } F_{cmd} < F_{\max} \\ F_{max} & \text{when } F_{cmd} \geq F_{\max} \end{cases}$	$T_{target} = \begin{cases} T_{cmd} & \text{when } T_{cmd} < T_{\max} \\ T_{max} & \text{when } T_{cmd} \geq T_{\max} \end{cases}$
Fuel mass per injection or torque- without turbocharger lag	$F = F_{cmd} = F_{max}$	$T_{target} = T_{cmd} = T_{max}$
Boost time constant	$\tau_{bst} = \begin{cases} \tau_{bst,\,rising} & \text{when } F_{cmd} > F_{\max} \\ \tau_{bst,\,falling} & \text{when } F_{cmd} \leq F_{\max} \end{cases}$	$\tau_{bst} = \begin{cases} \tau_{bst,\,rising} & \text{when } T_{cmd} > T_{\max} \\ \tau_{bst,\,falling} & \text{when } T_{cmd} \leq T_{\max} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{nat} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \geq f_{bst}(N) \end{cases}$	

The equations use these variables.

T_{brake}	Brake torque
F	Fuel mass per injection
F_{cmd}, F_{max}	Commanded and maximum fuel mass per injection, respectively
T_{target}, T_{cmd}, T_{max}	Target, commanded, and maximum torque, respectively
τ_{bst}	Boost time constant
$\tau_{bst,rising}$, $\tau_{bst,falling}$	Boost rising and falling time constant, respectively
τ_{eng}	Final time constant
τ_{nat}	Time constant below the boost torque speed line
$f_{bst}(N)$	Boost torque/speed line
N	Engine speed

Fuel Flow

To calculate the fuel economy for high-fidelity models, the block uses the volumetric fuel flow.

$$Q_{fuel} = \frac{\dot{m}_{fuel}}{\left(\frac{1000kg}{m^3}\right)Sg_{fuel}}$$

The equation uses these variables.

$\dot{m}_{fuel}$	Fuel mass flow
Sg_{fuel}	Specific gravity of fuel

Q_{fuel}	Volumetric fuel flow

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrCrkshft`	Crankshaft power	$-\tau_{eng}\omega$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFuel`	Fuel input power	$\dot{m}_{fuel}LHV$
		`PwrLoss`	Power loss	$\tau_{eng}\omega - \dot{m}_{fuel}LHV$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease		*Not used*	

The equations use these variables.

LHV	Fuel lower heating value
ω	Engine speed, rad/s
$\dot{m}_{fuel}$	Fuel mass flow
τ_{eng}	Fuel mass per injection time constant

Ports

Input

`FuelMassCmd` — Injected fuel mass command
`scalar`

Injected fuel mass command, F, in mg/inj.

Dependencies

To enable this port, for **Input command**, select `Fuel mass`.

`TrqCmd` — Torque command
`scalar`

Torque command, T, in N·m.

Dependencies

To enable this port, for **Input command**, select `Torque`.

EngSpd — Engine speed
scalar

Engine speed, N, in rpm.

EngTemp — Engine temperature
scalar

Engine temperature, $Temp_{Eng}$, in K.

Dependencies

To enable this port, select **Input engine temperature**.

Output

Info — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
IntkGasMassFlw	Engine air mass flow output	kg/s
NrmlzdAirChrg	Normalized engine cylinder air mass	N/A
Afr	Air-fuel ratio (AFR)	N/A
FuelMassFlw	Engine fuel flow output	kg/s
FuelVolFlw	Volumetric fuel flow	m^3/s
ExhManGasTemp	Engine exhaust gas temperature	K
EngTrq	Engine torque output	N·m
EngSpd	Engine speed	rpm
CrkAng	Engine crankshaft absolute angle $\int_0^{(360)Cps} EngSpd\frac{180}{30}d\theta$ where Cps is crankshaft revolutions per power stroke.	degrees crank angle
Bsfc	Engine brake-specific fuel consumption (BSFC)	g/kWh
EoHC	Engine out hydrocarbon emission mass flow	kg/s
EoCO	Engine out carbon monoxide emission mass flow rate	kg/s
EoNOx	Engine out nitric oxide and nitrogen dioxide emissions mass flow	kg/s
EoCO2	Engine out carbon dioxide emission mass flow	kg/s

Signal			Description	Units
EoPM			Engine out particulate matter emission mass flow	kg/s
PwrInfo	PwrTrnsfrd	PwrCrkshft	Crankshaft power	W
	PwrNotTrnsfrd	PwrFuel	Fuel input power	W
		PwrLoss	Power loss	W
	PwrStored		*Not used*	

EngTrq — Power
scalar

Engine power, T_{brake}, in N·m.

Parameters

Block Options

Input command — Table functions
Fuel mass (default) | Torque

The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of injected fuel mass, *F*, engine torque, *T*, engine speed, *N*, and engine temperature, $Temp_{Eng}$.

Input Command Setting	Input Engine Temperature Parameter Setting	Lookup Tables
Fuel mass	off	$f(F,N)$
	on	$f(F,N,Temp_{Eng})$
Torque	off	$f(T,N)$
	on	$f(T,N,Temp_{Eng})$

Dependencies

- Selecting `Fuel mass` enables **Breakpoints for commanded fuel mass input, f_tbrake_f_bpt**.
- Selecting `Torque` enables **Breakpoints for commanded torque input, f_tbrake_t_bpt**.
- Selecting **Input engine temperature** enables **Breakpoints for temperature input, f_tbrake_engtmp_bpt**.

Include turbocharger lag effect — Increase time constant
off (default)

To model turbocharger lag, select **Include turbocharger lag effect**. Turbocharger lag limits the maximum fuel mass per injection. To model the maximum fuel mass per injection, the block uses a first-order system with a time constant. At low torque, the engine does not require boost to provide sufficient air flow. When the requested fuel mass requires boost, the block uses a time constant to determine the maximum fuel mass per injection. The block uses these equations for the specified **Input command** setting.

Calculation	Input command Parameter Setting	
	`Fuel mass`	`Torque`
Dynamic torque	$\frac{dF_{max}}{dt} = \frac{1}{\tau_{eng}}(F_{cmd} - F_{max})$	$\frac{dT_{max}}{dt} = \frac{1}{\tau_{eng}}(T_{cmd} - T_{max})$
Fuel mass per injection or torque - with turbocharger lag	$F = \begin{cases} F_{cmd} & \text{when } F_{cmd} < F_{\max} \\ F_{max} & \text{when } F_{cmd} \geq F_{\max} \end{cases}$	$T_{target} = \begin{cases} T_{cmd} & \text{when } T_{cmd} < T_{\max} \\ T_{max} & \text{when } T_{cmd} \geq T_{\max} \end{cases}$
Fuel mass per injection or torque- without turbocharger lag	$F = F_{cmd} = F_{max}$	$T_{target} = T_{cmd} = T_{max}$
Boost time constant	$\tau_{bst} = \begin{cases} \tau_{bst,\, rising} & \text{when } F_{cmd} > F_{\max} \\ \tau_{bst,\, falling} & \text{when } F_{cmd} \leq F_{\max} \end{cases}$	$\tau_{bst} = \begin{cases} \tau_{bst,\, rising} & \text{when } T_{cmd} > T_{\max} \\ \tau_{bst,\, falling} & \text{when } T_{cmd} \leq T_{\max} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{nat} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \geq f_{bst}(N) \end{cases}$	

The equations use these variables.

T_{brake}	Brake torque
F	Fuel mass per injection
F_{cmd}, F_{max}	Commanded and maximum fuel mass per injection, respectively
T_{target}, T_{cmd}, T_{max}	Target, commanded, and maximum torque, respectively
τ_{bst}	Boost time constant
$\tau_{bst,rising}$, $\tau_{bst,falling}$	Boost rising and falling time constant, respectively
τ_{eng}	Final time constant
τ_{nat}	Time constant below the boost torque speed line
$f_{bst}(N)$	Boost torque/speed line
N	Engine speed

Dependencies

Selecting **Include turbocharger lag effect** enables these parameters:

- **Boost torque line, f_tbrake_bst**
- **Time constant below boost line, tau_nat**
- **Rising maximum fuel mass boost time constant, tau_bst_rising**
- **Falling maximum fuel mass boost time constant, tau_bst_falling**

`Input engine temperature` — Create input port

`off` (default) | `on`

Select this to create the `EngTemp` input port.

The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of injected fuel mass, *F*, engine torque, *T*, engine speed, *N*, and engine temperature, $Temp_{Eng}$.

Input Command Setting	Input Engine Temperature Parameter Setting	Lookup Tables
`Fuel mass`	`off`	*f(F,N)*
	`on`	$f(F,N,Temp_{Eng})$
`Torque`	`off`	*f(T,N)*
	`on`	$f(T,N,Temp_{Eng})$

Configuration

`Calibrate Maps` — Calibrate tables with measured data
selection

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data. The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import firing data</td><td>Import this loss data from a file. For example, open <matlabroot>/toolbox/mbc/mbctraining/CiEngineData.xlsx.

For more information, see “Using Data” (Model-Based Calibration Toolbox).

<table>
<tr><th>Input command</th><th>Required Data</th><th>Optional Data</th></tr>
<tr><td>Fuel mass</td><td>• Engine speed, rpm
• Commanded fuel mass per injection, mg
• Engine torque, N·m</td><td rowspan="2">• Air mass flow rate, kg/s
• Brake specific fuel consumption, g/(kW·h)
• CO2 mass flow rate, kg/s
• CO mass flow rate, kg/s
• Exhaust temperature, K
• Fuel mass flow rate, kg/s
• HC mass flow rate, kg/s
• NOx mass flow rate, kg/s
• Particulate matter mass flow rate, kg/s</td></tr>
<tr><td>Torque</td><td>• Engine speed, rpm
• Engine torque, N·m</td></tr>
</table>

Collect firing data at steady-state operating conditions when injectors deliver the fuel. Data should cover the engine speed and torque operating range. Model-Based Calibration Toolbox uses the firing data boundary as the maximum torque.

To filter or edit the data, select **Edit in Application**. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
</table>

Task	Description
Import non-firing data	Import this non-firing data from a file. For example, open `<matlabroot>/toolbox/autoblks/autodemos/projectsrc/CIDynamometer/CalMappedEng/CiEngineData.xlsx`. • Engine speed, rpm • Engine torque, N·m Collect non-firing (motoring) data at steady-state operating conditions when fuel is cut off. All non-firing torque points must be less than zero. Non-firing data is a function of engine speed only.
Generate response models	For both firing and non-firing data, the Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs). To assess or adjust the response model fit, select **Edit in Application**. The Model-Based Calibration Toolbox Model Browser opens. For more information, see "Model Assessment" (Model-Based Calibration Toolbox).
Generate calibration	Model-Based Calibration Toolbox calibrates the firing and non-firing response models and generates calibrated tables. To assess or adjust the calibration, select **Edit in Application**. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see "Calibration Lookup Tables" (Model-Based Calibration Toolbox).
Update block parameters	Update the block lookup table and breakpoint parameters with the calibration.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Breakpoints for commanded fuel mass input, f_tbrake_f_bpt` — Breakpoints

1-by-M vector

Breakpoints, in mg/inj.

Dependencies

Setting **Input command** to `Fuel mass` enables this parameter.

`Breakpoints for commanded torque input, f_tbrake_t_bpt` — Breakpoints

1-by-M vector

Breakpoints, in N·m.

Dependencies

Setting **Input command** to `Torque` enables this parameter.

`Breakpoints for engine speed input, f_tbrake_n_bpt` — Breakpoints

1-by-N vector

Breakpoints, in rpm.

Breakpoints for temperature input, f_tbrake_engtmp_bpt — Breakpoints
[233.15 273.15 373.15] (default) | 1-by-L vector

Breakpoints, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

Number of cylinders, NCyl — Number
4 (default) | scalar

Number of cylinders.

Crank revolutions per power stroke, Cps — Crank revolutions
2 (default) | scalar

Crank revolutions per power stroke.

Total displaced volume, Vd — Volume
0.0015 (default) | scalar

Volume displaced by engine, in m^3.

Fuel lower heating value, Lhv — Heating value
45e6 (default) | scalar

Fuel lower heating value, *LHV*, in J/kg.

Fuel specific gravity, Sg — Specific gravity
0.832 (default) | scalar

Specific gravity of fuel, Sg_{fuel}, dimensionless.

Ideal gas constant air, Rair — Constant
287 (default) | scalar

Ideal gas constant of air and residual gas entering the engine intake port, in J/(kg·K).

Air standard pressure, Pstd — Pressure
101325 (default) | scalar

Standard air pressure, in Pa.

Air standard temperature, Tstd — Temperature
293.15 (default) | scalar

Standard air temperature, in K.

Boost torque line, f_tbrake_bst — Boost lag
[90,95,95,95,96,100,104,104,104,100,95,85,75,67,60,55] (default) | 1-by-M vector

Boost torque line, $f_{bst}(N)$, in N·m.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

Time constant below boost line — Time constant below
0.1 (default) | scalar

Time constant below boost line, τ_{nat}, in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

Rising maximum fuel mass boost time constant, tau_bst_rising — Rising time constant
1.0 (default) | scalar

Rising maximum fuel mass boost time constant, $\tau_{bst,rising}$, in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

Falling maximum fuel mass boost time constant, tau_bst_falling — Falling time constant
0.7 (default) | scalar

Falling maximum fuel mass boost time constant, $\tau_{bst,falling}$, in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

Turbocharger time constant blend fuel mass fraction, f_blend_frac — Time constant
0.01 (default) | scalar

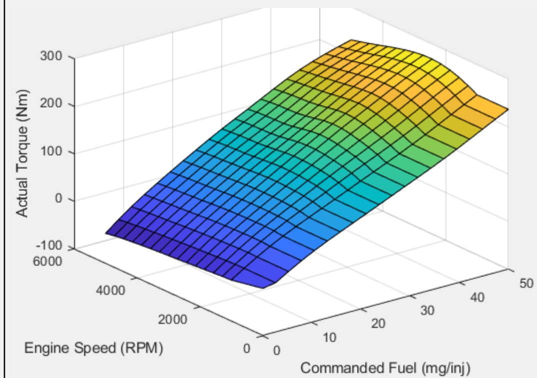
Turbocharger time constant blend fuel mass fraction, in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

Power

Brake torque map, f_tbrake — 2D lookup table
M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The engine brake torque lookup table is a function of commanded fuel mass and engine speed, $T_{brake} = f(F, N)$, where: • T_{brake} is engine torque, in N·m. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
`Torque`	The engine brake torque lookup table is a function of target torque and engine speed, $T_{brake} = f(T_{target}, N)$, where: • T_{brake} is engine torque, in N·m. • T_{target} is target torque, in N·m. • N is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot brake torque map` — Plot table

button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Brake torque map, f_tbrake_3d` — 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The engine brake torque lookup table is a function of commanded fuel mass and engine speed, $T_{brake} = f(F, N, Temp_{Eng})$, where: • T_{brake} is engine torque, in N·m. • F is commanded fuel mass, in mg per injection. • $Temp_{Eng}$ is engine temperature, in K.

Input Command Setting	Description
`Torque`	The engine brake torque lookup table is a function of target torque and engine speed, $T_{brake} = f(T_{target}, N, Temp_{Eng})$, where: • T_{brake} is engine torque, in N·m. • T_{target} is target torque, in N·m. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

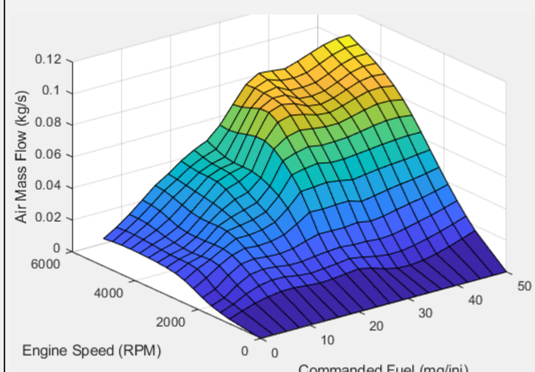
Air

`Air mass flow map, f_air` — 2D lookup table

M-by-N matrix

<table>
<tr><th>Input Command Setting</th><th>Description</th></tr>
<tr><td><code>Fuel mass</code></td><td>The air mass flow lookup table is a function of commanded fuel mass and engine speed, $\dot{m}_{intk} = f(F_{max}, N)$, where:

- $\dot{m}_{intk}$ is engine air mass flow, in kg/s.
- F_{max} is commanded fuel mass, in mg per injection.
- N is engine speed, in rpm.



</td></tr>
<tr><td><code>Torque</code></td><td>The air mass flow lookup table is a function of maximum torque and engine speed, $\dot{m}_{intk} = f(T_{max}, N)$, where:

- $\dot{m}_{intk}$ is engine air mass flow, in kg/s.
- T_{max} is maximum torque, in N·m.
- N is engine speed, in rpm.
</td></tr>
</table>

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot air mass map` — Plot table

button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Air mass flow map, f_air_3d` — 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The air mass flow lookup table is a function of commanded fuel mass and engine speed, $\dot{m}_{intk} = f(F_{max}, N, Temp_{Eng})$, where: • $\dot{m}_{intk}$ is engine air mass flow, in kg/s. • F_{max} is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
`Torque`	The air mass flow lookup table is a function of maximum torque and engine speed, $\dot{m}_{intk} = f(T_{max}, N, Temp_{Eng})$, where: • $\dot{m}_{intk}$ is engine air mass flow, in kg/s. • T_{max} is maximum torque, in N·m. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

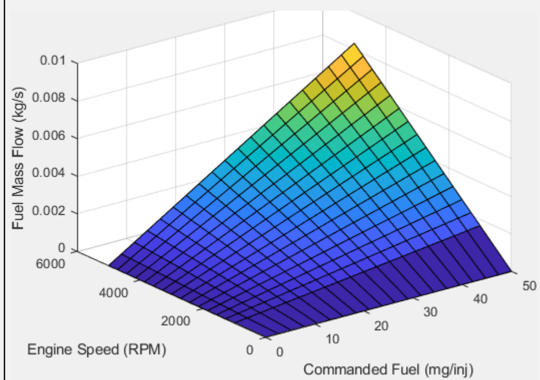
Dependencies

To enable this parameter, select **Input engine temperature**.

Fuel

`Fuel flow map, f_fuel` — 2D lookup table

M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The engine fuel flow lookup table is a function of commanded fuel mass and engine speed, *MassFlow*= *f*(*F*, *N*), where: • *MassFlow* is engine fuel mass flow, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. 
`Torque`	The engine fuel flow lookup table is a function of target torque and engine speed, *MassFlow* = *f*(T_{target}, *N*), where: • *MassFlow* is engine fuel mass flow, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot fuel flow map` — Plot table

button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Fuel flow map, f_fuel_3d` — 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The engine fuel flow lookup table is a function of commanded fuel mass, engine speed, and engine temperature, $MassFlow= ƒ(F, N, Temp_{Eng})$, where: • *MassFlow* is engine fuel mass flow, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
`Torque`	The engine fuel flow lookup table is a function of target torque and engine speed, and engine temperature, $MassFlow = ƒ(T_{target}, N, Temp_{Eng})$, where: • *MassFlow* is engine fuel mass flow, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

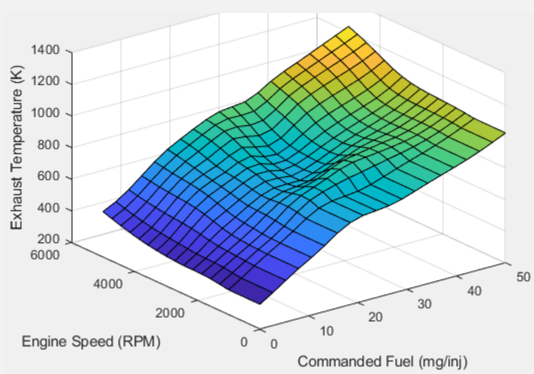
Dependencies

To enable this parameter, select **Input engine temperature**.

Temperature

`Exhaust temperature map, f_texh` — 2D lookup table

M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The engine exhaust temperature table is a function of commanded fuel mass and engine speed, $T_{exh}= ƒ(F, N)$, where: • $T_{exh}$is exhaust temperature, in K. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. 

Input Command Setting	Description
`Torque`	The engine exhaust temperature table is a function of target torque and engine speed, $T_{exh} = f(T_{target}, N)$, where: • T_{exh} is exhaust temperature, in K. • T_{target} is target torque, in N·m. • N is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot exhaust temperature map` — Plot table

button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Exhaust temperature map, f_texh_3d` — 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The engine exhaust temperature table is a function of commanded fuel mass and engine speed, $T_{exh} = f(F, N, Temp_{Eng})$, where: • T_{exh} is exhaust temperature, in K. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
`Torque`	The engine exhaust temperature table is a function of target torque and engine speed, $T_{exh} = f(T_{target}, N, Temp_{Eng})$, where: • T_{exh} is exhaust temperature, in K. • T_{target} is target torque, in N·m. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

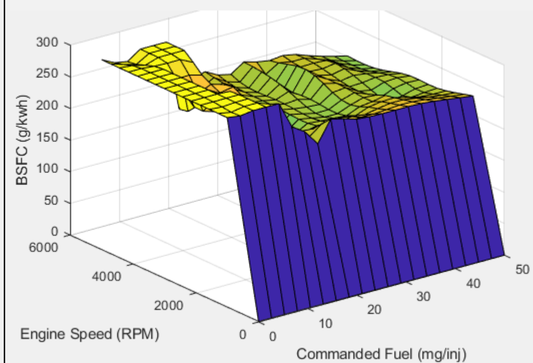
Dependencies

To enable this parameter, select **Input engine temperature**.

Efficiency

`BSFC map, f_eff` — 2D lookup table

M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The brake-specific fuel consumption (BSFC) efficiency is a function of commanded fuel mass and engine speed, $BSFC = f(F, N)$, where: • $BSFC$ is BSFC, in g/kWh. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. 
`Torque`	The brake-specific fuel consumption (BSFC) efficiency is a function of target torque and engine speed, $BSFC = f(T_{target}, N)$, where: • $BSFC$ is BSFC, in g/kWh. • T_{target} is target torque, in N·m. • N is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot BSFC map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`BSFC map, f_eff_3d` — 3D lookup table
M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The brake-specific fuel consumption (BSFC) efficiency is a function of commanded fuel mass and engine speed, $BSFC = f(F, N, Temp_{Eng})$, where: • $BSFC$ is BSFC, in g/kWh. • F is commanded fuel mass, in mg per injection. • N is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

Input Command Setting	Description
`Torque`	The brake-specific fuel consumption (BSFC) efficiency is a function of target torque and engine speed, $BSFC = f(T_{target}, N, Temp_{Eng})$, where: • *BSFC* is BSFC, in g/kWh. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

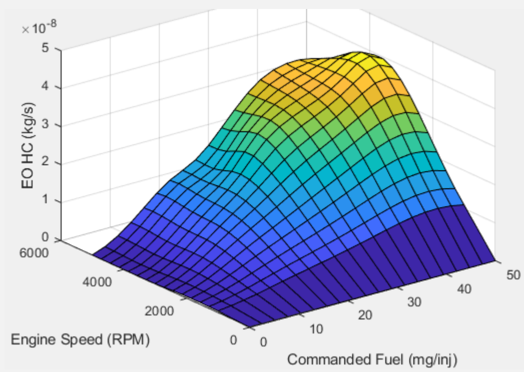
Dependencies

To enable this parameter, select **Input engine temperature**.

HC

`EO HC map, f_hc` — 2D lookup table

M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The engine-out hydrocarbon emissions are a function of commanded fuel mass and engine speed, $EO\ HC= f(F, N)$, where: • *EO HC* is engine-out hydrocarbon emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. 
`Torque`	The engine-out hydrocarbon emissions are a function of target torque and engine speed, $EO\ HC = f(T_{target}, N)$, where: • *EO HC* is engine-out hydrocarbon emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot EO HC map` — Plot table

button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO HC map, f_hc_3d` — 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The engine-out hydrocarbon emissions are a function of commanded fuel mass and engine speed, $EO\ HC = f(F, N, Temp_{Eng})$, where: • *EO HC* is engine-out hydrocarbon emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
`Torque`	The engine-out hydrocarbon emissions are a function of target torque and engine speed, $EO\ HC = f(T_{target}, N, Temp_{Eng})$, where: • *EO HC* is engine-out hydrocarbon emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

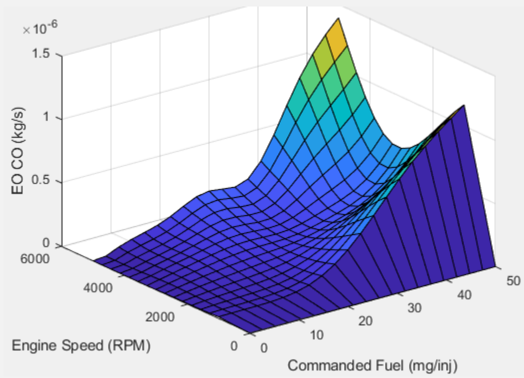
Dependencies

To enable this parameter, select **Input engine temperature**.

CO

`EO CO map, f_co` — 2D lookup table

M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The engine-out carbon monoxide emissions are a function of commanded fuel mass and engine speed, *EO CO*= ƒ(*F*, *N*), where: • *EO CO* is engine-out carbon monoxide emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. 
`Torque`	The engine-out carbon monoxide emissions are a function of target torque and engine speed, *EO CO* = ƒ(T_{target}, *N*), where: • *EO CO* is engine-out carbon monoxide emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot EO CO map` — Plot table

button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO CO map, f_co_3d` — 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The engine-out carbon monoxide emissions are a function of commanded fuel mass and engine speed, $EO\ CO = f(F, N, Temp_{Eng})$, where: • *EO CO* is engine-out carbon monoxide emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
`Torque`	The engine-out carbon monoxide emissions are a function of target torque and engine speed, $EO\ CO = f(T_{target}, N, Temp_{Eng})$, where: • *EO CO* is engine-out carbon monoxide emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

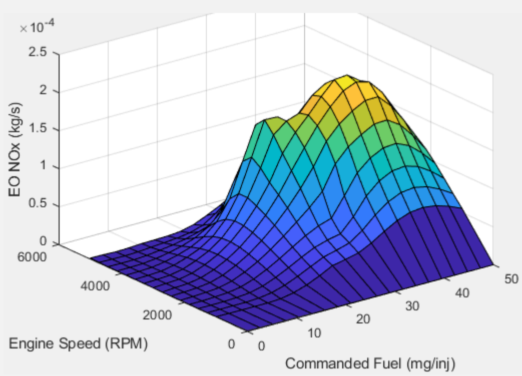
Dependencies

To enable this parameter, select **Input engine temperature**.

NOx

`EO NOx map, f_nox` — 2D lookup table

M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded fuel mass and engine speed, $EO\ NOx = f(F, N)$, where: • *EO NOx* is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. 

Input Command Setting	Description
`Torque`	The engine-out nitric oxide and nitrogen dioxide emissions are a function of target torque and engine speed, $EO\ NOx = f(T_{target}, N)$, where: • *EO NOx* is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot EO NOx map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO NOx map, f_nox_3d` — 3D lookup table
`M`-by-`N`-by-`L` array

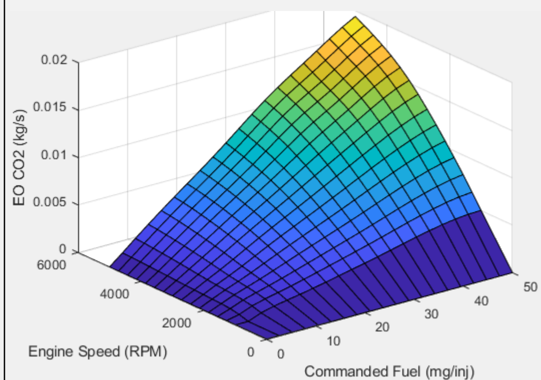
Input Command Setting	Description
`Fuel mass`	The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded fuel mass, engine speed, and engine temperature, $EO\ NOx = f(F, N, Temp_{Eng})$, where: • *EO NOx* is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
`Torque`	The engine-out nitric oxide and nitrogen dioxide emissions are a function of target torque, engine speed, and engine temperature, $EO\ NOx = f(T_{target}, N, Temp_{Eng})$, where: • *EO NOx* is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

CO2

`EO CO2 map, f_co2` — 2D lookup table
M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The engine-out carbon dioxide emissions are a function of commanded fuel mass and engine speed, *EO CO2*= ƒ(*F*, *N*), where: • *EO CO2* is engine-out carbon dioxide emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. 
`Torque`	The engine-out carbon dioxide emissions are a function of target torque and engine speed, *EO CO2* = ƒ(T_{target}, *N*), where: • *EO CO2* is engine-out carbon dioxide emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot CO2 map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO CO2 map, f_co2_3d` — 3D lookup table
M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The engine-out carbon dioxide emissions are a function of commanded fuel mass, engine speed, and engine temperature, $EO\ CO2 = f(F, N, Temp_{Eng})$, where: • *EO CO2* is engine-out carbon dioxide emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
`Torque`	The engine-out carbon dioxide emissions are a function of target torque, engine speed, and engine temperature, $EO\ CO2 = f(T_{target}, N, Temp_{Eng})$, where: • *EO CO2* is engine-out carbon dioxide emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

PM

`EO PM map, f_pm` — 2D lookup table
M-by-N matrix

Input Command Setting	Description
`Fuel mass`	The engine-out PM emissions are a function of commanded fuel mass and engine speed, where: • *EO PM* is engine-out PM emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm.
`Torque`	The engine-out PM emissions are a function of target torque and engine speed, $EO\ PM = f(T_{target}, N)$, where: • *EO PM* is engine-out PM emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot EO PM map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO PM map, f_pm_3d` — 3D lookup table

M-by-N-by-L array

Input Command Setting	Description
`Fuel mass`	The engine-out PM emissions are a function of commanded fuel mass, engine speed, and engine temperature, where: • *EO PM* is engine-out PM emissions, in kg/s. • *F* is commanded fuel mass, in mg per injection. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.
`Torque`	The engine-out PM emissions are a function of target torque, engine speed, and engine temperature, $EO\ PM = f(T_{target}, N, T)$, where: • *EO PM* is engine-out PM emissions, in kg/s. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm. • $Temp_{Eng}$ is engine temperature, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

CI Core Engine | Mapped Motor | Mapped SI Engine

Topics

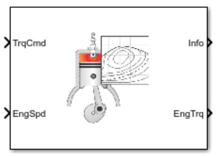
"Generate Mapped CI Engine from a Spreadsheet"
"Engine Calibration Maps"
"Model-Based Calibration Toolbox"

Introduced in R2017a

Mapped SI Engine

Spark-ignition engine model using lookup tables

Library: Powertrain Blockset / Propulsion / Combustion Engines
Vehicle Dynamics Blockset / Powertrain / Propulsion



Description

The Mapped SI Engine block implements a mapped spark-ignition (SI) engine model using power, air mass flow, fuel flow, exhaust temperature, efficiency, and emission performance lookup tables. You can use the block for:

- Hardware-in-the-loop (HIL) engine control design
- Vehicle-level fuel economy and performance simulations

The block enables you to specify lookup tables for these engine characteristics. The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of commanded torque, T_{cmd}, brake torque, T_{brake}, and engine speed, N. If you select **Input engine temperature**, the tables are also a function of engine temperature, $Temp_{Eng}$.

Table	Input Engine Temperature Parameter Setting	
	`off`	`on`
Power	$f(T_{cmd},N)$	$f(T_{cmd},N,Temp_{Eng})$
Air	$f(T_{brake},N)$	$f(T_{brake},N,Temp_{Eng})$
Fuel		
Temperature		
Efficiency		
HC		
CO		
NOx		
CO2		
PM		

To bound the Mapped SI Engine block output, the block does not extrapolate the lookup table data.

Virtual Calibration

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data. The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import firing data</td><td>Import this loss data from a file. For example, open <code><matlabroot>/toolbox/mbc/mbctraining/SiEngineData.xlsx</code>.

For more information, see “Using Data” (Model-Based Calibration Toolbox).

<table>
<tr><th>Required Data</th><th>Optional Data</th></tr>
<tr><td>• Engine speed, rpm
• Engine torque, N·m</td><td>• Air mass flow rate, kg/s
• Brake specific fuel consumption, g/(kW·h)
• CO2 mass flow rate, kg/s
• CO mass flow rate, kg/s
• Exhaust temperature, K
• Fuel mass flow rate, kg/s
• HC mass flow rate, kg/s
• NOx mass flow rate, kg/s
• Particulate matter mass flow rate, kg/s</td></tr>
</table>

Collect firing data at steady-state operating conditions when injectors deliver the fuel. Data should cover the engine speed and torque operating range. Model-Based Calibration Toolbox uses the firing data boundary as the maximum torque.

To filter or edit the data, select Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
<tr><td>Import non-firing data</td><td>Import this non-firing data from a file. For example, open <code><matlabroot>/toolbox/autoblks/autodemos/projectsrc/SIDynamometer/CalMappedEng/SiEngineData.xlsx</code>.

• Engine speed, rpm
• Engine torque, N·m

Collect non-firing (motoring) data at steady-state operating conditions when fuel is cut off. All non-firing torque points must be less than zero. Non-firing data is a function of engine speed only.</td></tr>
<tr><td>Generate response models</td><td>For both firing and non-firing data, the Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).

To assess or adjust the response model fit, select Edit in Application. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</td></tr>
<tr><td>Generate calibration</td><td>Model-Based Calibration Toolbox calibrates the firing and non-firing response models and generates calibrated tables.

To assess or adjust the calibration, select Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</td></tr>
</table>

Task	Description
Update block parameters	Update the block lookup table and breakpoint parameters with the calibration.

Cylinder Air Mass

The block calculates the normalized cylinder air mass using these equations.

$$M_{Nom} = \frac{P_{std}V_d}{N_{cyl}R_{air}T_{std}}$$

$$L = \frac{\left(\frac{60s}{min}\right)Cps \cdot \dot{m}_{air}}{\left(\frac{1000g}{Kg}\right)N_{cyl} \cdot N \cdot M_{Nom}}$$

The equations use these variables.

L	Normalized cylinder air mass
M_{Nom}	Nominal engine cylinder air mass at standard temperature and pressure, piston at bottom dead center (BDC) maximum volume, in kg
Cps	Crankshaft revolutions per power stroke, rev/stroke
P_{std}	Standard pressure
T_{std}	Standard temperature
R_{air}	Ideal gas constant for air and burned gas mixture
V_d	Displaced volume
N_{cyl}	Number of engine cylinders
N	Engine speed
$\dot{m}_{intk}$	Engine air mass flow, in g/s

Turbocharger Lag

To model turbocharger lag, select **Include turbocharger lag effect**. During throttle control, the time constant models the manifold filling and emptying dynamics. When the torque request requires a turbocharger boost, the block uses a larger time constant to represent the turbocharger lag. The block uses these equations.

Dynamic torque	$\frac{dT_{brake}}{dt} = \frac{1}{\tau_{eng}}(T_{stdy} - T_{brake})$
Boost time constant	$\tau_{bst} = \begin{cases} \tau_{bst,\,rising} & \text{when } T_{stdy} > T_{brake} \\ \tau_{bst,\,falling} & \text{when } T_{stdy} \le T_{brake} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{thr} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \ge f_{bst}(N) \end{cases}$

The equations use these variables.

T_{brake}	Brake torque

T_{stdy}	Steady-state target torque
τ_{bst}	Boost time constant
$\tau_{bst,rising}$, $\tau_{bst,falling}$	Boost rising and falling time constant, respectively
τ_{eng}	Final time constant
τ_{thr}	Time constant during throttle control
$f_{bst}(N)$	Boost torque speed line
N	Engine speed

Fuel Flow

To calculate the fuel economy for high-fidelity models, the block uses the volumetric fuel flow.

$$Q_{fuel} = \frac{\dot{m}_{fuel}}{\left(\frac{1000kg}{m^3}\right)Sg_{fuel}}$$

The equation uses these variables.

$\dot{m}_{fuel}$	Fuel mass flow
Sg_{fuel}	Specific gravity of fuel
Q_{fuel}	Volumetric fuel flow

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrCrkshft`	Crankshaft power	$-\tau_{eng}\omega$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrFuel`	Fuel input power	$\dot{m}_{fuel}LHV$
		`PwrLoss`	Power loss	$\tau_{eng}\omega - \dot{m}_{fuel}LHV$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease		*Not used*	

The equations use these variables.

LHV	Fuel lower heating value

ω	Engine speed, rad/s
$\dot{m}_{fuel}$	Fuel mass flow
τ_{eng}	Fuel mass per injection time constant

Ports

Input

`TrqCmd` — Commanded torque
`scalar`

Torque, T_{cmd}, in N·m.

`EngSpd` — Engine speed
`scalar`

Engine speed, N, in rpm.

`EngTemp` — Engine temperature
`scalar`

Engine temperature, $Temp_{Eng}$, in K.

Dependencies

To enable this port, select **Input engine temperature**.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
`IntkGassMassFlw`	Engine air mass flow output	kg/s
`NrmlzdAirChrg`	Normalized engine cylinder air mass	N/A
`Afr`	Air-fuel ratio (AFR)	N/A
`FuelMassFlw`	Engine fuel flow output	kg/s
`FuelVolFlw`	Volumetric fuel flow	m^3/s
`ExhManGasTemp`	Engine exhaust gas temperature	K
`EngTrq`	Engine torque output	N·m
`EngSpd`	Engine speed	rpm

Signal			Description	Units
`CrkAng`			Engine crankshaft absolute angle $\int_{0}^{(360)Cps} EngSpd\frac{180}{30}d\theta$ where *Cps* is crankshaft revolutions per power stroke.	degrees crank angle
`Bsfc`			Engine brake-specific fuel consumption (BSFC)	g/kWh
`EoHC`			Engine out hydrocarbon emission mass flow	kg/s
`EoCO`			Engine out carbon monoxide emission mass flow rate	kg/s
`EoNOx`			Engine out nitric oxide and nitrogen dioxide emissions mass flow	kg/s
`EoCO2`			Engine out carbon dioxide emission mass flow	kg/s
`EoPM`			Engine out particulate matter emission mass flow	kg/s
`PwrInfo`	`PwrTrnsfrd`	`PwrCrkshft`	Crankshaft power	W
	`PwrNotTrnsfrd`	`PwrFuel`	Fuel input power	W
		`PwrLoss`	Power loss	W
	`PwrStored`		*Not used*	

`EngTrq` — Engine brake torque
`scalar`

Engine brake torque, T_{brake}, in N·m.

Parameters

Block Options

`Include turbocharger lag effect` — Increase time constant
`off` (default)

To model turbocharger lag, select **Include turbocharger lag effect**. During throttle control, the time constant models the manifold filling and emptying dynamics. When the torque request requires a turbocharger boost, the block uses a larger time constant to represent the turbocharger lag. The block uses these equations.

Dynamic torque	$\frac{dT_{brake}}{dt} = \frac{1}{\tau_{eng}}(T_{stdy} - T_{brake})$

Boost time constant	$\tau_{bst} = \begin{cases} \tau_{bst,\,rising} & \text{when } T_{stdy} > T_{brake} \\ \tau_{bst,\,falling} & \text{when } T_{stdy} \le T_{brake} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{thr} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \ge f_{bst}(N) \end{cases}$

The equations use these variables.

T_{brake}	Brake torque
T_{stdy}	Steady-state target torque
τ_{bst}	Boost time constant
$\tau_{bst,rising}$, $\tau_{bst,falling}$	Boost rising and falling time constant, respectively
τ_{eng}	Final time constant
τ_{thr}	Time constant during throttle control
$f_{bst}(N)$	Boost torque speed line
N	Engine speed

Dependencies

Selecting **Include turbocharger lag effect** enables these parameters:

- **Boost torque line, f_tbrake_bst**
- **Time constant below boost line, tau_thr**
- **Rising torque boost time constant, tau_bst_rising**
- **Falling torque boost time constant, tau_bst_falling**

`Input engine temperature` — Create input port

`off` (default) | `on`

Select this to create the `EngTemp` input port.

The block enables you to specify lookup tables for these engine characteristics. The lookup tables, developed with the Model-Based Calibration Toolbox, are functions of commanded torque, T_{cmd}, brake torque, T_{brake}, and engine speed, N. If you select **Input engine temperature**, the tables are also a function of engine temperature, $Temp_{Eng}$.

Table	Input Engine Temperature Parameter Setting	
	`off`	`on`
Power	$f(T_{cmd},N)$	$f(T_{cmd},N,Temp_{Eng})$
Air	$f(T_{brake},N)$	$f(T_{brake},N,Temp_{Eng})$
Fuel		
Temperature		
Efficiency		
HC		
CO		

Table	Input Engine Temperature Parameter Setting	
	`off`	`on`
NOx		
CO2		
PM		

Configuration

`Calibrate Maps` — Calibrate tables with measured data

`selection`

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data. The dialog box steps through these tasks.

Task	Description
Import firing data	Import this loss data from a file. For example, open `<matlabroot>/toolbox/mbc/mbctraining/SiEngineData.xlsx`. For more information, see "Using Data" (Model-Based Calibration Toolbox). **Required Data:** • Engine speed, rpm • Engine torque, N·m **Optional Data:** • Air mass flow rate, kg/s • Brake specific fuel consumption, g/(kW·h) • CO2 mass flow rate, kg/s • CO mass flow rate, kg/s • Exhaust temperature, K • Fuel mass flow rate, kg/s • HC mass flow rate, kg/s • NOx mass flow rate, kg/s • Particulate matter mass flow rate, kg/s Collect firing data at steady-state operating conditions when injectors deliver the fuel. Data should cover the engine speed and torque operating range. Model-Based Calibration Toolbox uses the firing data boundary as the maximum torque. To filter or edit the data, select **Edit in Application**. The Model-Based Calibration Toolbox Data Editor opens.

Task	Description
Import non-firing data	Import this non-firing data from a file. For example, open `<matlabroot>/toolbox/autoblks/autodemos/projectsrc/SIDynamometer/CalMappedEng/SiEngineData.xlsx`. • Engine speed, rpm • Engine torque, N·m Collect non-firing (motoring) data at steady-state operating conditions when fuel is cut off. All non-firing torque points must be less than zero. Non-firing data is a function of engine speed only.
Generate response models	For both firing and non-firing data, the Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs). To assess or adjust the response model fit, select **Edit in Application**. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).
Generate calibration	Model-Based Calibration Toolbox calibrates the firing and non-firing response models and generates calibrated tables. To assess or adjust the calibration, select **Edit in Application**. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).
Update block parameters	Update the block lookup table and breakpoint parameters with the calibration.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Breakpoints for commanded torque, f_tbrake_t_bpt` — Breakpoints
1-by-M vector

Breakpoints, in N·m.

`Breakpoints for engine speed input, f_tbrake_n_bpt` — Breakpoints
1-by-N vector

Breakpoints, in rpm.

`Breakpoints for temperature input, f_tbrake_engtmp_bpt` — Breakpoints
`[233.15 273.15 373.15]` (default) | 1-by-L vector

Breakpoints, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

`Number of cylinders, NCyl` — Number
4 (default) | `scalar`

Number of cylinders.

`Crank revolutions per power stroke, Cps` — Crank revolutions
`2` (default) | `scalar`

Crank revolutions per power stroke.

`Total displaced volume, Vd` — Volume
`0.0015` (default) | `scalar`

Volume displaced by engine, in m^3.

`Fuel lower heating value, Lhv` — Heating value
`45e6` (default) | `scalar`

Fuel lower heating value, *LHV*, in J/kg.

`Fuel specific gravity, Sg` — Specific gravity
`0.745` (default) | `scalar`

Specific gravity of fuel, Sg_{fuel}, dimensionless.

`Ideal gas constant air, Rair` — Constant
`287` (default) | `scalar`

Ideal gas constant of air and residual gas entering the engine intake port, in J/(kg*K).

`Air standard pressure, Pstd` — Pressure
`101325` (default) | `scalar`

Standard air pressure, in Pa.

`Air standard temperature, Tstd` — Temperature
`293.15` (default) | `scalar`

Standard air temperature, in K.

`Boost torque line, f_tbrake_bst` — Boost lag
`1`-by-`M` vector

Boost torque line, $f_{bst}(N)$, in N·m.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

`Time constant below boost line` — Time constant below
`0.2` (default) | `scalar`

Time constant below boost line, τ_{thr}, in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

`Rising torque boost time constant, tau_bst_rising` — Rising time constant
`1.5` (default) | `scalar`

Rising torque boost time constant, $\tau_{bst,rising}$, in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

`Falling torque boost time constant, tau_bst_falling` — Falling time constant

`1` (default) | `scalar`

Falling torque boost time constant, $\tau_{bst,falling}$, in s.

Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

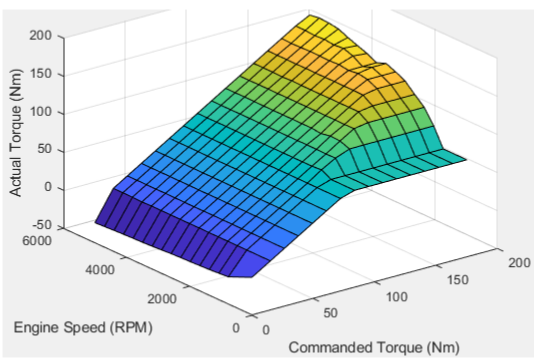
Power

`Brake torque map, f_tbrake` — 2D lookup table

M-by-N matrix

The engine torque lookup table is a function of commanded engine torque and engine speed, $T = f(T_{cmd}, N)$, where:

- T is engine torque, in N·m.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



`Plot brake torque map` — Plot table

button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Brake torque map, f_tbrake_3d` — 3D lookup table

M-by-N-by-L array

The engine torque lookup table is a function of commanded engine torque, engine speed, and engine temperature, $T = f(T_{cmd}, N, Temp_{Eng})$, where:

- T is engine torque, in N·m.
- T_{cmd} is commanded engine torque, in N·m.

- N is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

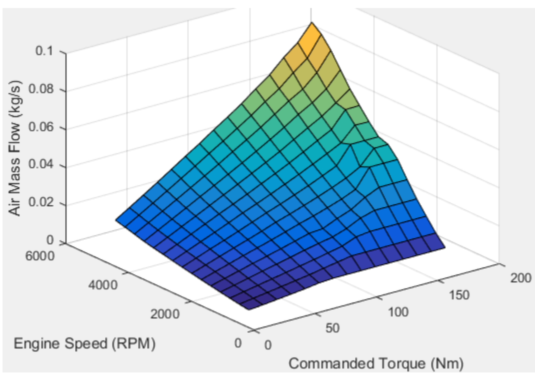
To enable this parameter, select **Input engine temperature**.

Air

`Air mass flow map, f_air` — 2D lookup table
M-by-N matrix

The engine air mass flow lookup table is a function of commanded engine torque and engine speed, $\dot{m}_{intk} = f(T_{cmd}, N)$, where:

- $\dot{m}_{intk}$ is engine air mass flow, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot air mass map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Air mass flow map, f_air_3d` — 3D lookup table
M-by-N-by-L array

The engine air mass flow lookup table is a function of commanded engine torque, engine speed, and engine temperature, $\dot{m}_{intk} = f(T_{cmd}, N, Temp_{Eng})$, where:

- $\dot{m}_{intk}$ is engine air mass flow, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.

- N is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

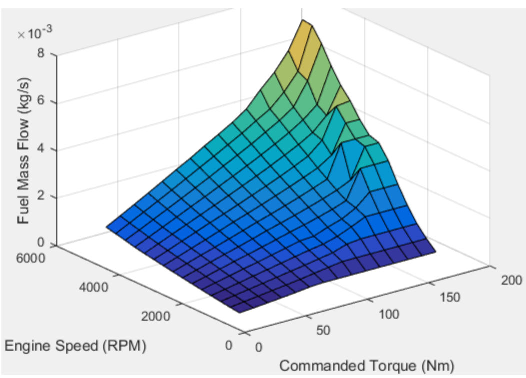
To enable this parameter, select **Input engine temperature**.

Fuel

`Fuel flow map, f_fuel` — 2D lookup table
M-by-N matrix

The engine fuel mass flow lookup table is a function of commanded engine torque and engine speed, $MassFlow = f(T_{cmd}, N)$, where:

- $MassFlow$ is engine fuel mass flow, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot fuel flow map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Fuel flow map, f_fuel_3d` — 3D lookup table
M-by-N-by-L array

The engine fuel mass flow lookup table is a function of commanded engine torque, engine speed, and engine temperature, $MassFlow = f(T_{cmd}, N, Temp_{Eng})$, where:

- $MassFlow$ is engine fuel mass flow, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.

- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

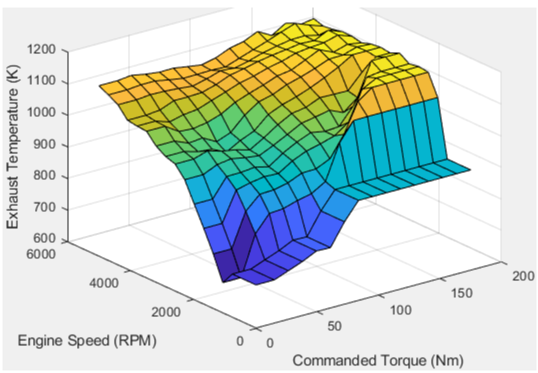
Temperature

`Exhaust temperature map, f_texh` — 2D lookup table

M-by-N matrix

The engine exhaust temperature lookup table is a function of commanded engine torque and engine speed, $T_{exh} = f(T_{cmd}, N)$, where:

- T_{exh} is exhaust temperature, in K.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot exhaust temperature map` — Plot table

button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Exhaust temperature map, f_texh_3d` — 3D lookup table

array

The engine exhaust temperature lookup table is a function of commanded engine torque, engine speed, and engine temperature, $T_{exh} = f(T_{cmd}, N, Temp_{Eng})$, where:

- T_{exh} is exhaust temperature, in K.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

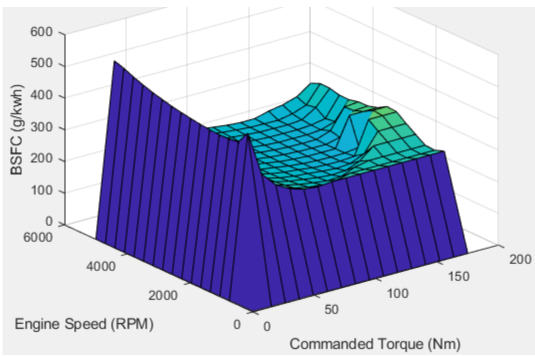
To enable this parameter, select **Input engine temperature**.

Efficiency

BSFC map, f_eff — 2D lookup table
M-by-N-by-L array

The brake-specific fuel consumption (BSFC) efficiency is a function of commanded engine torque and engine speed, $BSFC = f(T_{cmd}, N)$, where:

- *BSFC* is BSFC, in g/kWh.
- T_{cmd} is commanded engine torque, in N·m.
- *N* is engine speed, in rpm.



Dependencies

To enable this parameter, clear **Input engine temperature**.

Plot BSFC map — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

BSFC map, f_eff_3d — 3D lookup table
M-by-N-by-L array

The brake-specific fuel consumption (BSFC) efficiency is a function of commanded engine torque, engine speed, and engine temperature, $BSFC = f(T_{cmd}, N, Temp_{Eng})$, where:

- *BSFC* is BSFC, in g/kWh.
- T_{cmd} is commanded engine torque, in N·m.
- *N* is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

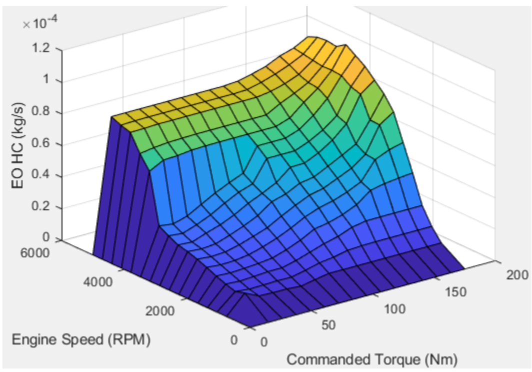
To enable this parameter, select **Input engine temperature**.

HC

`EO HC map, f_hc` — 2D lookup table
M-by-N matrix

The engine-out hydrocarbon emissions are a function of commanded engine torque and engine speed, $EO\ HC = f(T_{cmd}, N)$, where:

- *EO HC* is engine-out hydrocarbon emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- *N* is engine speed, in rpm.



Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot EO HC map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO HC map, f_hc_3d` — 3D lookup table
M-by-N-by-L array

The engine-out hydrocarbon emissions are a function of commanded engine torque, engine speed, and engine temperature, $EO\ HC = f(T_{cmd}, N, Temp_{Eng})$, where:

- *EO HC* is engine-out hydrocarbon emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- *N* is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

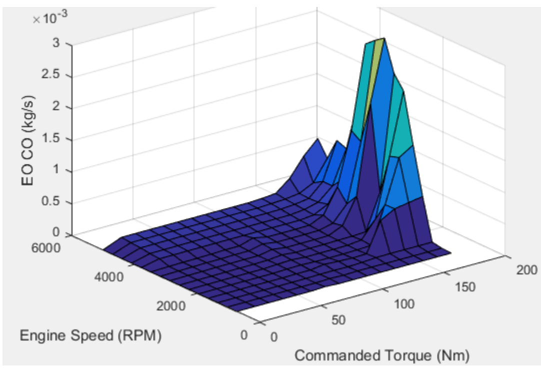
To enable this parameter, select **Input engine temperature**.

CO

`EO CO map, f_co` — 2D lookup table
M-by-N matrix

The engine-out carbon monoxide emissions are a function of commanded engine torque and engine speed, $EO\ CO = f(T_{cmd}, N)$, where:

- $EO\ CO$ is engine-out carbon monoxide emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot EO CO map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO HC map, f_hc_3d` — 3D lookup table
M-by-N-by-L array

The engine-out hydrocarbon emissions are a function of commanded engine torque, engine speed, and engine temperature, $EO\ HC = f(T_{cmd}, N, Temp_{Eng})$, where:

- $EO\ HC$ is engine-out hydrocarbon emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

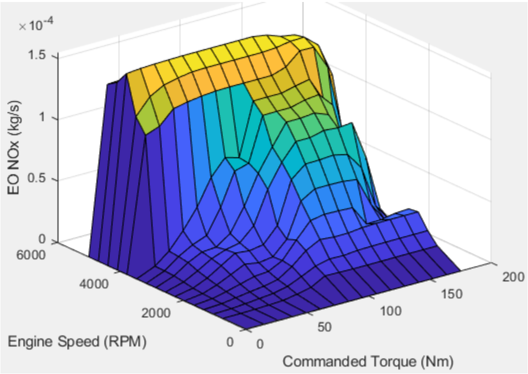
To enable this parameter, select **Input engine temperature**.

NOx

`EO NOx map, f_nox` — 2D lookup table
M-by-N matrix

The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded engine torque and engine speed, $EO\ NOx = f(T_{cmd}, N)$, where:

- $EO\ NOx$ is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot EO NOx map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO NOx map, f_nox_3d` — 3D lookup table
M-by-N-by-L array

The engine-out nitric oxide and nitrogen dioxide emissions are a function of commanded engine torque, engine speed, and engine temperature, $EO\ NOx = f(T_{cmd}, N, Temp_{Eng})$, where:

- $EO\ NOx$ is engine-out nitric oxide and nitrogen dioxide emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

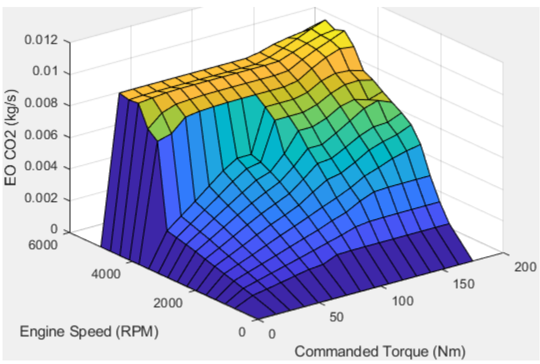
To enable this parameter, select **Input engine temperature**.

CO2

`EO CO2 map, f_co2` — 2D lookup table
M-by-N matrix

The engine-out carbon dioxide emissions are a function of commanded engine torque and engine speed, $EO\ CO2 = f(T_{cmd}, N)$, where:

- $EO\ CO2$ is engine-out carbon dioxide emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot CO2 map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO CO2 map, f_co2_3d` — 3D lookup table
M-by-N-by-L array

The engine-out carbon dioxide emissions are a function of commanded engine torque, engine speed, and engine temperature, $EO\ CO2 = f(T_{cmd}, N, Temp_{Eng})$, where:

- $EO\ CO2$ is engine-out carbon dioxide emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- N is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

PM

`EO PM map, f_pm` — 2D lookup table
M-by-N matrix

The engine-out particulate matter emissions are a function of commanded engine torque and engine speed, where:

- *EO PM* is engine-out PM emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- *N* is engine speed, in rpm.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`Plot EO PM map` — Plot table
button

Click to plot table.

Dependencies

To enable this parameter, clear **Input engine temperature**.

`EO PM map, f_pm_3d` — 3D lookup table
M-by-N-by-L array

The engine-out particulate matter emissions are a function of commanded engine torque, engine speed, and engine temperature, where:

- *EO PM* is engine-out PM emissions, in kg/s.
- T_{cmd} is commanded engine torque, in N·m.
- *N* is engine speed, in rpm.
- $Temp_{Eng}$ is engine temperature, in K.

Dependencies

To enable this parameter, select **Input engine temperature**.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

SI Core Engine | Mapped Motor | Mapped CI Engine

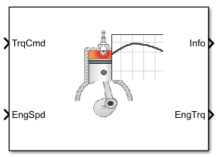
Topics
"Generate Mapped SI Engine from a Spreadsheet"
"Engine Calibration Maps"
"Model-Based Calibration Toolbox"

Introduced in R2017a

Simple Engine

Simplified engine model using lookup tables

Library: Powertrain Blockset / Propulsion / Combustion Engines
Vehicle Dynamics Blockset / Powertrain / Propulsion



Description

The Simple Engine block implements a simplified engine model using a maximum torque vs engine speed table, two scalar fuel mass properties, and one scalar engine efficiency parameter to estimate engine torque and fuel flow. You can use the block for:

- Hardware-in-the-loop (HIL) engine control design
- Vehicle-level fuel economy and performance simulations

Ports

Input

`TrqCmd` — Commanded torque
`scalar`

Torque, in N·m.

`EngSpd` — Engine speed
`scalar`

Engine speed, in rpm.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
`IntkGasMassFlw` (zeroed out intentionally)	Engine air mass flow output	kg/s
`NrmlzdAirChrg` (zeroed out intentionally)	Normalized engine cylinder air mass	N/A
`Afr` (zeroed out intentionally)	Air-fuel ratio (AFR)	N/A
`FuelMassFlw`	Engine fuel flow output	kg/s
`FuelVolFlw`	Volumetric fuel flow	m^3/s
`ExhManGasTemp` (zeroed out intentionally)	Engine exhaust gas temperature	K

<table>
<tr><th colspan="3">Signal</th><th>Description</th><th>Units</th></tr>
<tr><td colspan="3"><code>EngTrq</code></td><td>Engine torque output</td><td>N·m</td></tr>
<tr><td colspan="3"><code>EngSpd</code></td><td>Engine speed</td><td>rpm</td></tr>
<tr><td colspan="3"><code>CrkAng</code> (zeroed out intentionally)</td><td>Engine crankshaft absolute angle
$$\int_0^{(360)Cps} EngSpd\frac{180}{30}d\theta$$
where Cps is crankshaft revolutions per power stroke.</td><td>degrees crank angle</td></tr>
<tr><td colspan="3"><code>Bsfc</code></td><td>Engine brake-specific fuel consumption (BSFC)</td><td>g/kWh</td></tr>
<tr><td colspan="3"><code>EoHC</code> (zeroed out intentionally)</td><td>Engine out hydrocarbon emission mass flow</td><td>kg/s</td></tr>
<tr><td colspan="3"><code>EoCO</code> (zeroed out intentionally)</td><td>Engine out carbon monoxide emission mass flow rate</td><td>kg/s</td></tr>
<tr><td colspan="3"><code>EoNOx</code> (zeroed out intentionally)</td><td>Engine out nitric oxide and nitrogen dioxide emissions mass flow</td><td>kg/s</td></tr>
<tr><td colspan="3"><code>EoCO2</code> (zeroed out intentionally)</td><td>Engine out carbon dioxide emission mass flow</td><td>kg/s</td></tr>
<tr><td colspan="3"><code>EoPM</code> (zeroed out intentionally)</td><td>Engine out particulate matter emission mass flow</td><td>kg/s</td></tr>
<tr><td rowspan="4"><code>PwrInfo</code></td><td><code>PwrTrnsfrd</code></td><td><code>PwrCrkshft</code></td><td>Crankshaft power</td><td>W</td></tr>
<tr><td rowspan="2"><code>PwrNotTrnsfrd</code></td><td><code>PwrFuel</code></td><td>Fuel input power</td><td>W</td></tr>
<tr><td><code>PwrLoss</code></td><td>Power loss</td><td>W</td></tr>
<tr><td colspan="2"><code>PwrStored</code></td><td colspan="2">Not used</td></tr>
</table>

EngTrq — Engine brake torque
`scalar`

Engine brake torque, in N·m.

Parameters

Engine maximum torque, f_tqmax — Breakpoints
`[75.679776480773256 75.679776480773256 97.173658538143172 116.84042599160529 152.21029882684542 175 174.99889520597083 174.99996520122858 175 175 175 175 175 175 175 175]` (default)

Breakpoints, in N·m.

Breakpoints for engine speed input, f_tqmax_n_bpt — Breakpoints
`[0 750 1053.57142857143 1357.14285714286 1660.71428571429 1964.28571428571 2267.85714285714 2571.42857142857 2875 3178.57142857143 3482.14285714286 3785.71428571429 4089.28571428571 4392.85714285714 4696.42857142857 5000]` (default)

Breakpoints, in rpm.

Fuel lower heating value, Lhv — Heating value
4.6E+7 (default)

Fuel lower heating value, in J/kg.

Fuel specific gravity, Sg — Specific gravity
0.745 (default)

Specific gravity of fuel, dimensionless.

Average brake specific fuel consumption, BsfcAvg — Average brake specific fuel consumption
350 (default)

Average brake specific fuel consumption, in g/kwh.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

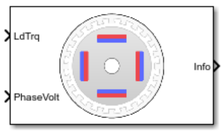
Introduced in R2021b

Electric Motor, Converters, Inverter Blocks

Interior PMSM

Three-phase interior permanent magnet synchronous motor with sinusoidal back electromotive force

Library: Powertrain Blockset / Propulsion / Electric Motors and Inverters
Motor Control Blockset / Electrical Systems / Motors



Description

The Interior PMSM block implements a three-phase interior permanent magnet synchronous motor (PMSM) with sinusoidal back electromotive force. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

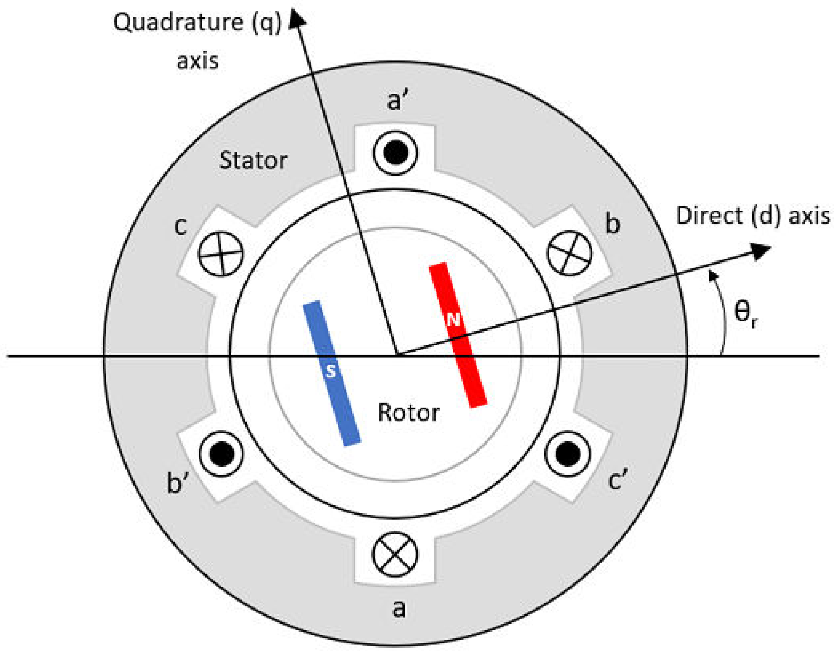
By default, the block sets the **Simulation type** parameter to `Continuous` to use a continuous sample time during simulation. If you want to generate code for fixed-step double- and single-precision targets, considering setting the parameter to `Discrete`. Then specify a **Sample Time, Ts** parameter.

On the **Parameters** tab, if you select `Back-emf`, the block implements this equation to calculate the permanent flux linkage constant.

$$\lambda_{pm} = \frac{1}{\sqrt{3}} \cdot \frac{K_e}{1000P} \cdot \frac{60}{2\pi}$$

Motor Construction

This figure shows the motor construction with a single pole pair on the motor.



The motor magnetic field due to the permanent magnets creates a sinusoidal rate of change of flux with motor angle.

For the axes convention, the a-phase and permanent magnet fluxes are aligned when motor angle θ_r is zero.

Three-Phase Sinusoidal Model Electrical System

The block implements these equations, expressed in the motor flux reference frame (dq frame). All quantities in the motor reference frame are referred to the stator.

$$\omega_e = P\omega_m$$

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}P\omega_m i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}P\omega_m i_d - \frac{\lambda_{pm}P\omega_m}{L_q}$$

$$T_e = 1.5P[\lambda_{pm}i_q + (L_d - L_q)i_d i_q]$$

The L_q and L_d inductances represent the relation between the phase inductance and the motor position due to the saliency of the motor.

The equations use these variables.

L_q, L_d	q- and d-axis inductances (H)
R	Resistance of the stator windings (ohm)
i_q, i_d	q- and d-axis currents (A)
v_q, v_d	q- and d-axis voltages (V)

ω_m	Angular mechanical velocity of the motor (rad/s)
ω_e	Angular electrical velocity of the motor (rad/s)
λ_{pm}	Permanent flux linkage constant (Wb)
K_e	Back electromotive force (EMF) (Vpk_LL/krpm, where Vpk_LL is the peak voltage line-to-line measurement)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)
Θ_e	Electrical angle (rad)

Mechanical System

The motor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}\left(T_e - T_f - F\omega_m - T_m\right)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm^2)
F	Combined viscous friction of motor and load (N·m/(rad/s))
θ_m	Motor mechanical angular position (rad)
T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrMtr`	Mechanical power	P_{mot}	$P_{mot} = -\omega_m T_e$
		`PwrBus`	Electrical power	P_{bus}	$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input	`PwrElecLoss`	Resistive power loss	P_{elec}	$P_{elec} = -\frac{3}{2}(R_s i_{sd}^2 + R_s i_{sq}^2)$

Bus Signal			Description	Variable	Equations
	• Negative signals indicate a loss	`PwrMechLoss`	Mechanical power loss	P_{mech}	When **Port Configuration** is set to `Torque`: $P_{mech} = \quad -\left(\omega_m^2 F + \quad \lvert\omega_m\rvert T_f\right)$ When **Port Configuration** is set to `Speed`: $P_{mech} = \quad 0$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrMtrStored`	Stored motor power	P_{str}	$P_{str} = \quad P_{bus} + \quad P_{mot} + \quad P_{elec} \quad + \quad P_{mech}$

The equations use these variables.

R_s	Stator resistance (ohm)
i_a, i_b, i_c	Stator phase a, b, and c current (A)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
v_{an}, v_{bn}, v_{cn}	Stator phase a, b, and c voltage (V)
ω_m	Angular mechanical velocity of the rotor (rad/s)
F	Combined motor and load viscous damping (N·m/(rad/s))
T_e	Electromagnetic torque (Nm)
T_f	Combined motor and load friction torque (Nm)

Amplitude invariant dq transformation

The block uses these equations to implement amplitude invariant dq transformation to ensure that the dq and three phase amplitudes are equal.

$$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(\Theta_{da}) & \cos(\Theta_{da} - \frac{2\pi}{3}) & \cos(\Theta_{da} + \frac{2\pi}{3}) \\ -\sin(\Theta_{da}) & -\sin(\Theta_{da} - \frac{2\pi}{3}) & -\sin(\Theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \cos(\Theta_{da}) & -\sin(\Theta_{da}) \\ \cos(\Theta_{da} - \frac{2\pi}{3}) & -\sin(\Theta_{da} - \frac{2\pi}{3}) \\ \cos(\Theta_{da} + \frac{2\pi}{3}) & -\sin(\Theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix}$$

The equations use these variables.

Θ_{da}	dq stator electrical angle with respect to the rotor a-axis (rad)
v_{sq}, v_{sd}	Stator q- and d-axis voltages (V)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
v_a, v_b, v_c	Stator voltage phases a, b, c (V)
i_a, i_b, i_c	Stator currents phases a, b, c (A)

Ports

Input

`LdTrq` — Load torque on motor
`scalar`

Load torque on the motor shaft, T_m, in N·m.

Dependencies

To create this port, select `Torque` for the **Port Configuration** parameter.

Spd — Motor shaft speed
`scalar`

Angular velocity of the motor, ω_m, in rad/s.

Dependencies

To create this port, select `Speed` for the **Port Configuration** parameter.

`PhaseVolt` — Stator terminal voltages
1-by-3 array

Stator terminal voltages, V_a, V_b, and V_c, in V.

Dependencies

To create this port, select `Speed` or `Torque` for the **Port Configuration** parameter.

Output

`Info` — Bus signal
bus

The bus signal contains these block calculations.

Signal	Description	Variable	Units
`IaStator`	Stator phase current A	i_a	A
`IbStator`	Stator phase current B	i_b	A
`IcStator`	Stator phase current C	i_c	A
`IdSync`	Direct axis current	i_d	A
`IqSync`	Quadrature axis current	i_q	A
`VdSync`	Direct axis voltage	v_d	V

Signal			Description	Variable	Units
VqSync			Quadrature axis voltage	v_q	V
MtrSpd			Angular mechanical velocity of the motor	ω_m	rad/s
MtrPos			Motor mechanical angular position	θ_m	rad
MtrTrq			Electromagnetic torque	T_e	N·m
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	P_{mot}	W
		PwrBus	Electrical power	P_{bus}	W
	PwrNotTrnsfrd	PwrElecLoss	Resistive power loss	P_{elec}	W
		PwrMechLoss	Mechanical power loss	P_{mech}	W
	PwrStored	PwrMtrStored	Stored motor power	P_{str}	W

PhaseCurr — Phase a, b, c current
1-by-3 array

Phase a, b, c current, i_a, i_b, and i_c, in A.

MtrTrq — Motor torque
scalar

Motor torque, T_{mtr}, in N·m.

Dependencies

To create this port, select Speed for the **Mechanical input configuration** parameter.

MtrSpd — Motor speed
scalar

Angular speed of the motor, ω_{mtr}, in rad/s.

Dependencies

To create this port, select Torque for the **Mechanical input configuration** parameter.

Parameters

Block Options

Mechanical input configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
Torque	LdTrq	MtrSpd

Port Configuration	Creates Input Port	Creates Output Port
Speed	Spd	MtrTrq

Simulation type — Select simulation type
Continuous (default) | Discrete

By default, the block uses a continuous sample time during simulation. If you want to generate code for single-precision targets, considering setting the parameter to Discrete.

Dependencies

Setting **Simulation type** to Discrete creates the **Sample Time, Ts** parameter.

Sample Time (Ts) — Sample time for discrete integration
scalar

Integration sample time for discrete simulation, in s.

Dependencies

Setting **Simulation type** to Discrete creates the **Sample Time, Ts** parameter.

Parameters

Number of pole pairs (P) — Pole pairs
scalar

Motor pole pairs, P.

Stator phase resistance per phase (Rs) — Resistance
scalar

Stator phase resistance per phase, R_s, in ohm.

Stator d-axis and q-axis inductance (Ldq) — Inductance
vector

Stator d-axis and q-axis inductance, L_d, L_q, in H.

Permanent flux linkage constant (lambda_pm) — Flux
scalar

Permanent flux linkage constant, λ_{pm}, in Wb.

Back-emf constant (Ke) — Back electromotive force
scalar

Back electromotive force, EMF, K_e, in Vpk_LL/krpm. Vpk_LL is the peak voltage line-to-line measurement.

To calculate the permanent flux linkage constant, the block implements this equation.

$$\lambda_{pm} = \frac{1}{\sqrt{3}} \cdot \frac{K_e}{1000P} \cdot \frac{60}{2\pi}$$

`Physical inertia, viscous damping, and static friction (mechanical)` — Inertia, damping, friction
`vector`

Mechanical properties of the motor:

- Inertia, J, in kg.m^2
- Viscous damping, F, in N·m/(rad/s)
- Static friction, T_f, in N·m

Dependencies

To enable this parameter, select the `Torque` configuration parameter.

Initial Values

`Initial d-axis and q-axis current (idq0)` — Current
`vector`

Initial q- and d-axis currents, i_q, i_d, in A.

`Initial mechanical position (theta_init)` — Angle
`scalar`

Initial motor angular position, θ_{m0}, in rad.

`Initial mechanical speed (omega_init)` — Speed
`scalar`

Initial angular velocity of the motor, ω_{m0}, in rad/s.

Dependencies

To enable this parameter, select the `Torque` configuration parameter.

References

[1] Kundur, P. *Power System Stability and Control*. New York, NY: McGraw Hill, 1993.

[2] Anderson, P. M. *Analysis of Faulted Power Systems*. Hoboken, NJ: Wiley-IEEE Press, 1995.

Extended Capabilities

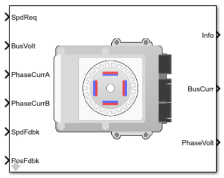
C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
Interior PM Controller | Flux-Based PMSM | Induction Motor | Mapped Motor | Surface Mount PMSM

Introduced in R2017a

Interior PM Controller

Torque-based, field-oriented controller for an internal permanent magnet synchronous motor
Library: Powertrain Blockset / Propulsion / Electric Motor Controllers

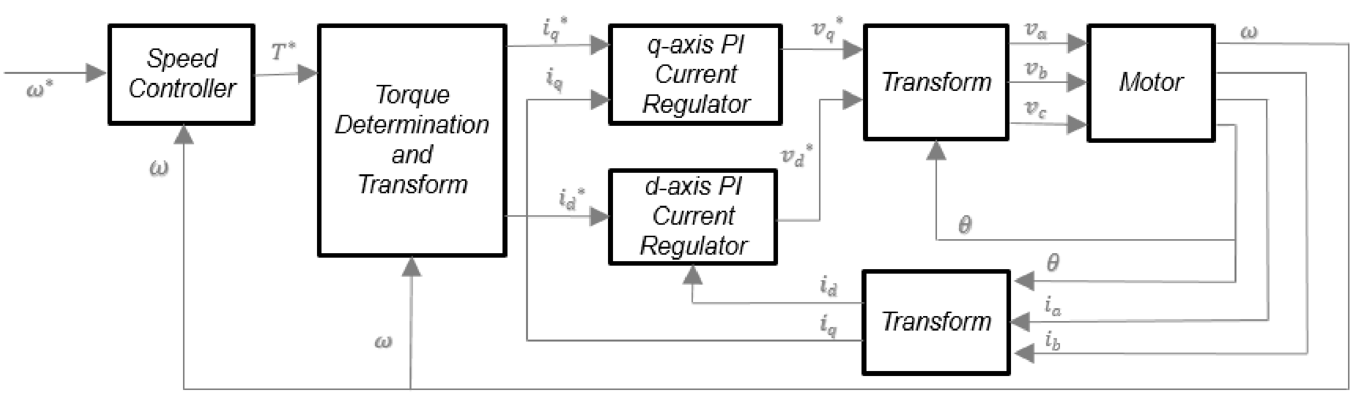


Description

The Interior PM Controller block implements a torque-based, field-oriented controller for an internal permanent magnet synchronous motor (PMSM) with an optional outer-loop speed controller. The internal torque control implements strategies for achieving maximum torque per ampere (MTPA) and weakening the magnetic flux. You can specify either the speed or torque control type.

The Interior PM Controller implements equations for speed control, torque determination, regulators, transforms, and motors.

The figure illustrates the information flow in the block.



The block implements equations that use these variables.

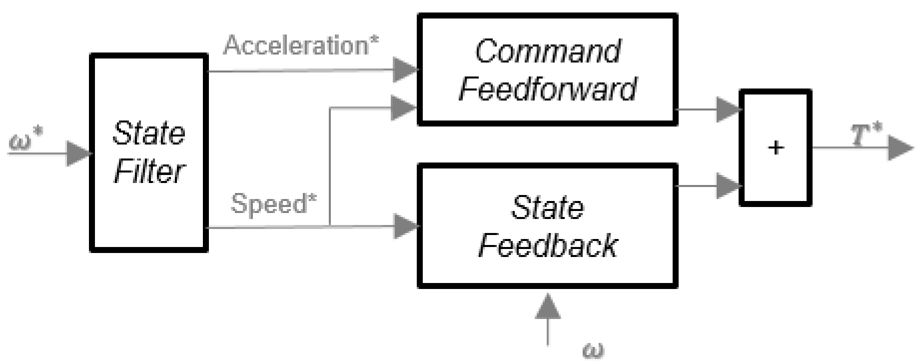
ω	Rotor speed
ω*	Rotor speed command
T*	Torque command
i_d	d-axis current
i^*_d	d-axis current command
i_q	q-axis current
i^*_q	q-axis current command

v_d,	d-axis voltage
v^*_d	d-axis voltage command
v_q	q-axis voltage
v^*_q	q-axis voltage command
v_a, v_b, v_c	Stator phase a, b, c voltages
i_a, i_b, i_c	Stator phase a, b, c currents

Speed Controller

To implement the speed controller, select the **Control Type** parameter `Speed Control`. If you select the **Control Type** parameter `Torque Control`, the block does not implement the speed controller.

The speed controller determines the torque command by implementing a state filter, and calculating the feedforward and feedback commands. If you do not implement the speed controller, input a torque command to the Interior PM Controller block.



State Filter

The state filter is a low-pass filter that generates the acceleration command based on the speed command. On the **Speed Controller** tab:

- To make the speed-command lag time negligible, specify a **Bandwidth of the state filter** parameter.
- To calculate a **Speed regulation time constant, Ksf** gain based on the state filter bandwidth, select **Calculate Speed Regulator Gains**.

The discrete form of characteristic equation is given by:

$$z + K_{sf}T_{sm} - 1$$

The filter calculates the gain using this equation.

$$K_{sf} = \frac{1 - \exp\left(-T_{sm}2\pi EV_{sf}\right)}{T_{sm}}$$

The equations use these variables.

EV_{sf}	Bandwidth of the speed command filter
T_{sm}	Motion controller sample time
K_{sf}	Speed regulator time constant

State Feedback

To generate the state feedback torque, the block uses the filtered speed error signal from the state filter. The feedback torque calculation also requires gains for speed regulator.

On the **Speed Controller** tab, select **Calculate Speed Regulator Gains** to calculate:

- **Proportional gain, ba**
- **Angular gain, Ksa**
- **Rotational gain, Kisa**

For the gain calculations, the block uses the inertia from the **Physical inertia, viscous damping, static friction** parameter value on the **Motor Parameters** tab.

The gains for the state feedback are calculated using these equations.

Calculation	Equations
Discrete forms of characteristic equation	$z^3 + \frac{\left(-3J_p + T_s b_a + T_s^2 K_{sa} + T_s^3 K_{isa}\right)}{J_p} z^2 + \frac{\left(3J_p - 2T_s b_a - T_s^2 K_{sa}\right)}{J_p} z + \frac{-J_p + T_s b_a}{J_p}$ $(z - p_1)(z - p_2)(z - p_3) = z^3 + (p_1 + p_2 + p_3)z^2 + (p_1 p_2 + p_2 p_3 + p_1 3)z^2 - p_1 p_2 p_3$
Speed regulator proportional gain	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$
Speed regulator integral gain	$K_{sa} = \frac{J_p(p_1 p_2 + p_2 p_3 + p_3 p_1) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$
Speed regulator double integral gain	$K_{isa} = \frac{-J_p(p_1 + p_2 + p_3) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$

The equations use these variables.

P	Motor pole pairs
b_a	Speed regulator proportional gain
K_{sa}	Speed regulator integral gain
K_{isa}	Speed regulator double integral gain
J_p	Motor inertia
T_{sm}	Motion controller sample time

Command Feedforward

To generate the state feedforward torque, the block uses the filtered speed and acceleration from the state filter. Also, the feedforward torque calculation uses the inertia, viscous damping, and static friction. To achieve zero tracking error, the torque command is the sum of the feedforward and feedback torque commands.

Selecting **Calculate Speed Regulator Gains** on the **Speed Controller** tab updates the inertia, viscous damping, and static friction with the **Physical inertia, viscous damping, static friction** parameter values on the **Motor Parameters** tab.

The feedforward torque command uses this equation.

$$T_{cmd\_ff} = J_p\dot{\omega}_m + F_v\omega_m + F_s\frac{\omega_m}{|\omega_m|}$$

where:

J_p	Motor inertia
T_{cmd_ff}	Torque command feedforward
F_s	Static friction torque constant
F_v	Viscous friction torque constant
F_s	Static friction torque constant
ω_m	Rotor speed

Torque Determination

The block uses a maximum torque per ampere (MTPA) trajectory to calculate the base speed and the current commands. The available bus voltage determines the base speed. The direct (d) and quadrature (q) permanent magnet (PM) determines the induced voltage.

Calculation	Equations
Electrical base speed transition into field weakening	$\omega_{base} = \frac{v_{max}}{\sqrt{(L_q i_q)^2 + (L_d i_d + \lambda_{pm})^2}}$
d-axis voltage	$v_d = -\omega_e L_q i_{q_{max}}$
q-axis voltage	$v_q = \omega_e(L_d i_{d\_max} + \lambda_{pm})$
Maximum phase current	$i_{max}2 = i_{d\_\mathrm{max}}^2 + i_{q\_\mathrm{max}}^2$
Maximum line to neutral voltage	$v_{max} = \frac{v_{bus}}{\sqrt{3}}$
d-axis phase current MTPA table	$I_m = \frac{2T_{max}}{3P\lambda_{pm}}$ $i_{d\_mtpa} = \frac{\lambda_{pm}}{4(L_q - L_d)} - \sqrt{\frac{\lambda_{pm}^2}{16(L_q - L_d)^2} + \frac{I_m^2}{2}}$
q-axis phase current MTPA table	$i_{q\_mtpa} = \sqrt{I_m^2 - (i_{mtpa})^2}$
Torque MTPA breakpoints	$T_{mtpa} = \frac{3}{2}P(\lambda_{pm} i_q + (L_d - L_q) i_d i_q)$

Calculation	Equations
Field weakening, using the speed-based voltage limits	$\left(L_q i_q\right)^2 + \left(L_d i_d + \lambda_{pm}\right)^2 \le \frac{v_{max}^2}{\omega_e^2}$ $i_q = \sqrt{i_{max}^2 - i_d^2}$ $\left(L_d^2 - L_q^2\right) i_d^2 + 2\lambda_{pm} L_d i_d + \lambda_{pm} + L_q^2 i_{max}^2 - \frac{v_{max}^2}{\omega_e^2} = 0$ $i_{dfw} = \frac{-\lambda_{pm} L_d + \sqrt{\left(\lambda_{pm} L_d\right)^2 - \left(L_d^2 - L_q^2\right)\left(\lambda_{pm}^2 + L_q^2 i_{max}^2 - \frac{v_{max}^2}{\omega_e^2}\right)}}{\left(L_d^2 - L_q^2\right)}$ $T_{fw} = \frac{3}{2} P\left(\lambda_{pm} i_{qfw} + \left(L_d - L_q\right) i_{dfw} i_{qfw}\right)$

Current command	`If` $\lvert\omega_e\rvert \le \omega_{base}$
	    $i_{dref} = i_{d_{mtpa}}(T_{ref})$
	    $i_{qref} = i_{q_{mtpa}}(T_{ref})$
	`Else`
	    $i_{dfw} = \max\left(i_{dfw}, -i_{max}\right)$
	    $i_{qfw} = \sqrt{i_{max}^2 - i_d^2}$
	    `If` $T_{fw} < T_{ref}$
	        $i_{dref} = i_{dfw}$
	        $i_{qref} = i_{qfw}$
	    `Else`
	        $i_{dref} = i_{dfw}$
	        $i_{qref} = \frac{T_{ref}}{\frac{3}{2} P\left(\lambda_{pm} + \left(L_d - L_q\right) i_{dfw}\right)}$
	    `End`
	`End`

The equations use these variables.

i_{max}	Maximum phase current
i_d	d-axis current
i_q	q-axis current
i_{d_max}	Maximum d-axis phase current
i_{q_max}	Maximum q-axis phase current
i_{d_mtpa}	d-axis phase current MTPA table
i_{q_mtpa}	q-axis phase current MTPA table
I_m	Estimated maximum current
i_{dfw}	d-axis field weakening current
i_{qfw}	q-axis field weakening current

ω_e	Rotor electrical speed
λ_{pm}	Permanent magnet flux linkage
v_d	d-axis voltage
v_q	q-axis voltage
v_{max}	Maximum line to neutral voltage
v_{bus}	DC bus voltage
L_d	d-axis winding inductance
L_q	q-axis winding inductance
P	Motor pole pairs
T_{fw}	Field weakening torque
T_{mtpa}	Torque MTPA breakpoints

Current Regulators

The block regulates the current with an anti-windup feature. Classic proportional-integrator (PI) current regulators do not consider the d-axis and q-axis coupling or the back-electromagnetic force (EMF) coupling. As a result, transient performance deteriorates. To account for the coupling, the block implements the complex vector current regulator (CVCR) in the scalar format of the rotor reference frame. The CVCR decouples:

- d-axis and q-axis current cross-coupling
- Back-EMF cross-coupling

The current frequency response is a first-order system, with a bandwidth of $EV_{current}$.

The block implements these equations.

Calculation	Equations
Motor voltage, in the rotor reference frame	$L_d\frac{di_d}{dt} = v_d - R_s i_d + p\omega_m L_q i_q$ $L_q\frac{di_q}{dt} = v_q - R_s i_q - p\omega_m L_d i_d - p\omega_m \lambda_{pm}$
Current regulator gains	$\omega_b = 2\pi EV_{current}$ $K_{p\_d} = L_d\omega_b$ $K_{p\_q} = L_q\omega_b$ $K_i = R_s\omega_b$
Transfer functions	$\frac{i_d}{i_{dref}} = \frac{\omega_b}{s + \omega_b}$ $\frac{i_q}{i_{qref}} = \frac{\omega_b}{s + \omega_b}$

The equations use these variables.

$EV_{current}$	Current regulator bandwidth
i_d	d-axis current

i_q	q-axis current
K_{p_d}	Current regulator d-axis gain
K_{p_q}	Current regulator q-axis gain
L_d	d-axis winding inductance
L_q	q-axis winding inductance
R_s	Stator phase winding resistance
ω_m	Rotor speed
v_d	d-axis voltage
v_q	q-axis voltage
λ_{pm}	Permanent magnet flux linkage
P	Motor pole pairs

Transforms

To calculate the voltages and currents in balanced three-phase (a, b) quantities, quadrature two-phase (α, β) quantities, and rotating (d, q) reference frames, the block uses the Clarke and Park Transforms.

In the transform equations.

$$\omega_e = P\omega_m$$

$$\frac{d\theta_e}{dt} = \omega_e$$

Transform	Description	Equations
Clarke	Converts balanced three-phase quantities (a, b) into balanced two-phase quadrature quantities (α, β).	$x_\alpha = \frac{2}{3}x_a - \frac{1}{3}x_b - \frac{1}{3}x_c$ $x_\beta = \frac{\sqrt{3}}{2}x_b - \frac{\sqrt{3}}{2}x_c$
Park	Converts balanced two-phase orthogonal stationary quantities (α, β) into an orthogonal rotating reference frame (d, q).	$x_d = x_\alpha\cos\theta_e + x_\beta\sin\theta_e$ $x_q = -x_\alpha\sin\theta_e + x_\beta\cos\theta_e$
Inverse Clarke	Converts balanced two-phase quadrature quantities (α, β) into balanced three-phase quantities (a, b).	$x_a = x_a$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$
Inverse Park	Converts an orthogonal rotating reference frame (d, q) into balanced two-phase orthogonal stationary quantities (α, β).	$x_\alpha = x_d\cos\theta_e - x_q\sin\theta_e$ $x_\beta = x_d\sin\theta_e + x_q\cos\theta_e$

The transforms use these variables.

ω_m	Rotor speed
P	Motor pole pairs

ω_e	Rotor electrical speed
Θ_e	Rotor electrical angle
x	Phase current or voltage

Motor

The block uses the phase currents and phase voltages to estimate the DC bus current. Positive current indicates battery discharge. Negative current indicates battery charge. The block uses these equations.

Load power	$Ld_{Pwr} = v_a \quad i_a + \quad v_b \quad i_b + \quad v_c \quad i_c$
Source power	$Src_{Pwr} = \quad Ld_{Pwr} + Pwr_{Loss}$
DC bus current	$i_{bus} = \quad \frac{Src_{Pwr}}{v_{bus}}$
Estimated rotor torque	$MtrTrq_{est} = 1.5P[\lambda i_q + (L_d - L_q)i_d i_q]$
Power loss for single efficiency source to load	$Pwr_{Loss} = \frac{100 - Eff}{Eff} \cdot Ld_{Pwr}$
Power loss for single efficiency load to source	$Pwr_{Loss} = \frac{100 - Eff}{100} \cdot \lvert Ld_{Pwr} \rvert$
Power loss for tabulated efficiency	$Pwr_{Loss} = \quad f(\omega_m, MtrTrq_{est})$

The equations use these variables.

v_a, v_b, v_c	Stator phase a, b, c voltages
v_{bus}	Estimated DC bus voltage
i_a, i_b, i_c	Stator phase a, b, c currents
i_{bus}	Estimated DC bus current
Eff	Overall inverter efficiency
ω_m	Rotor mechanical speed
L_q	q-axis winding inductance
L_d	d-axis winding inductance
i_q	q-axis current
i_d	d-axis current
λ	Permanent magnet flux linkage
P	Motor pole pairs

Electrical Losses

To specify the electrical losses, on the **Electrical Losses** tab, for **Parameterize losses by**, select one of these options.

Setting	Block Implementation
`Single efficiency measurement`	Electrical loss calculated using a constant value for inverter efficiency.

Setting	Block Implementation
`Tabulated loss data`	Electrical loss calculated as a function of motor speeds and load torques.
`Tabulated efficiency data`	Electrical loss calculated using inverter efficiency that is a function of motor speeds and load torques. • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

Ports

Input

SpdReq — Rotor speed command
`scalar`

Rotor speed command, ω^*_m, in rad/s.

Dependencies

To create this port, select `Speed Control` for the **Control Type** parameter.

`TrqCmd` — Torque command
`scalar`

Torque command, T^*, in N·m.

Dependencies

To create this port, select `Torque Control` for the **Control Type** parameter.

`BusVolt` — DC bus voltage
`scalar`

DC bus voltage, v_{bus}, in V.

`PhaseCurrA` — Current
`scalar`

Stator current phase a, i_a, in A.

`PhaseCurrB` — Current
`scalar`

Stator current phase b, i_b, in A.

`SpdFdbk` — Rotor speed
`scalar`

Rotor speed, ω_m, in rad/s.

`PosFdbk` — Rotor electrical angle
`scalar`

Rotor electrical angle, Θ_m, in rad.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
`SrcPwr`	Source power	W
`LdPwr`	Load power	W
`PwrLoss`	Power loss	W
`MtrTrqEst`	Estimated motor torque	N·m

`BusCurr` — Bus current
`scalar`

Estimated DC bus current, i_{bus}, in A.

`PhaseVolt` — Stator terminal voltages
`array`

Stator terminal voltages, V_a, V_b, and V_c, in V.

Parameters

Block Options

`Control Type` — Select control
`Speed Control` (default) | `Torque Control`

If you select `Torque Control`, the block does not implement the speed controller.

This table summarizes the port configurations.

Port Configuration	Creates Ports
`Speed Control`	`SpdReq`

Port Configuration	Creates Ports
`Torque Control`	`TrqCmd`

Motor Parameters

`Stator resistance, Rs` — Resistance
`0.02` (default) | `scalar`

Stator phase winding resistance, R_s, in ohm.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Stator resistance, Rs	**D and Q axis integral gain, Ki**	**Current Controller**

`D-axis inductance, Ld` — Inductance
`1.7e-3` (default) | `scalar`

D-axis winding inductance, L_d, in H.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
D-axis inductance, Ld	**Torque Breakpoints, T_mtpa** **D-axis table data, id_mtpa** **Q-axis table data, iq_mtpa** **D, q, and max current limits, idq_limits**	**Id and Iq Calculation**

`Q-axis inductance, Lq` — Inductance
`3.2e-3` (default) | `scalar`

Q-axis winding inductance, L_q, in H.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Q-axis inductance, Lq	**Torque Breakpoints, T_mtpa** **D-axis table data, id_mtpa** **Q-axis table data, iq_mtpa** **D, Q, and max current limits, idq_limits**	**Id and Iq Calculation**

`Permanent magnet flux, lambda_pm` — Flux
`0.2205` (default) | `scalar`

Permanent magnet flux, λ_{pm}, in Wb.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Permanent magnet flux, lambda_pm	**Torque Breakpoints, T_mtpa** **D-axis table data, id_mtpa** **Q-axis table data, iq_mtpa** **D, Q, and max current limits, idq_limits**	**Id and Iq Calculation**

`Number of pole pairs, PolePairs` — Poles
`4` (default) | `scalar`

Motor pole pairs, *P*.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Number of pole pairs, PolePairs	**Torque Breakpoints, T_mtpa** **D-axis table data, id_mtpa** **Q-axis table data, iq_mtpa** **D, Q, and max current limits, idq_limits**	**Id and Iq Calculation**

`Physical inertia, viscous damping, static friction, Mechanical` — Inertia, damping, friction
`[0.0027, 4.924e-4, 0]` (default) | `vector`

Mechanical properties of the motor:

- Motor inertia, F_v, in kgm^2
- Viscous friction torque constant, F_v, in N·m/(rad/s)
- Static friction torque constant, F_s, in N·m

Dependencies

To enable this parameter, set the **Control Type** parameter to `Speed Control`.

For the gain calculations, the block uses the inertia from the **Physical inertia, viscous damping, static friction** parameter value that is on the **Motor Parameters** tab.

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Physical inertia, viscous damping, static friction, Mechanical	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa** **Inertia compensation, Jcomp** **Viscous damping compensation, Fv** **Static friction, Fs**	**Speed Controller**

Id and Iq Calculation

`Motor constraint` — Motor constraint
`Maximum Torque` (default) | `Maximum Current`

Motor constraint for MTPA control.

`Maximum current, I_max` — Current
`44` (default) | `scalar`

Maximum current, in A.

Dependencies

To enable this parameter, set **Motor constraint** to `Maximum Current`.

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	**Tab**
Maximum torque, T_max	**Torque Breakpoints, T_mtpa** **D-axis table data, id_mtpa** **Q-axis table data, iq_mtpa** **D, Q, and max current limits, idq_limits**	**Id and Iq Calculation**

`Maximum torque, T_max` — Torque

`60` (default) | `scalar`

Maximum torque, in N·m.

Dependencies

To enable this parameter, set **Motor constraint** to `Maximum Torque`.

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	**Tab**
Maximum torque, T_max	**Torque Breakpoints, T_mtpa** **D-axis table data, id_mtpa** **Q-axis table data, iq_mtpa** **D, Q, and max current limits, idq_limits**	**Id and Iq Calculation**

`MTPA table breakpoints, bp` — Number of breakpoints

`10` (default) | `scalar`

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	**Tab**
MTPA table breakpoints, pb	**Torque Breakpoints, T_mtpa** **D-axis table data, id_mtpa** **Q-axis table data, iq_mtpa** **D, Q, and max current limits, idq_limits**	**Id and Iq Calculation**

`Calculate MTPA Table Data` — Derive parameters

button

Click to derive parameters.

Dependencies

On the **Id and Iq Calculation** tab, when you select **Calculate MPTA Table data**, the block calculates derived parameters. The table summarizes the derived parameter dependencies on other block parameters.

Derived Parameter on Id and Iq Calculation tab		Depends On	
		Parameter	Tab
Torque Breakpoints, T_mtpa	$T_{mtpa} = \frac{3}{2}P\left(\lambda_{pm}i_q + \left(L_d - L_q\right)i_d i_q\right)$	**Maximum torque, T_max** **MTPA table breakpoints, pb**	**Id and Iq Calculation**
D-axis table data, id_mtpa	$I_m = \frac{2T_{max}}{3P\lambda_{pm}}$ $i_{d\_mtpa} = \frac{\lambda_{pm}}{4\left(L_q - L_d\right)} - \sqrt{\frac{\lambda_{pm}^2}{16\left(L_q - L_d\right)^2} + \frac{I_m^2}{2}}$	**Permanent magnet flux, lambda_pm** **D-axis inductance, Ld** **Q-axis inductance, Lq** **Number of pole pairs, PolePairs**	**Motor Parameters**
Q-axis table data, iq_mtpa	$i_{q\_mtpa} = \sqrt{I_m^2 - \left(i_{mtpa}\right)^2}$		
D, Q, and max current limits, idq_limits			

The equations use these variables.

i_{max}	Maximum phase current
i_d	d-axis current
i_q	q-axis current
i_{d_max}	Maximum d-axis phase current
i_{q_max}	Maximum q-axis phase current
i_{d_mtpa}	d-axis phase current MTPA table
i_{q_mtpa}	q-axis phase current MTPA table
λ_{pm}	Permanent magnet flux linkage
L_d	d-axis winding inductance
L_q	q-axis winding inductance
P	Motor pole pairs
T_{mtpa}	Torque MTPA breakpoints
I_m	Estimated maximum current

Torque Breakpoints, T_mtpa — Derived

`[0 6.41323967543524 12.8472271930531 19.3221671098192 25.8572437875407 32.4702594835269 39.177408529382 45.9931820911486 52.930379967864 60.0001984561834]` (default) | `vector`

Derived torque breakpoints, in N·m.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	**Tab**
Torque Breakpoints, T_mtpa	**Maximum torque, T_max** **MTPA table breakpoints, pb**	**Id and Iq Calculation**
	Permanent magnet flux, lambda_pm **D-axis inductance, Ld** **Q-axis inductance, Lq** **Number of pole pairs, PolePairs**	**Motor Parameters**

`D-axis table data, id_mtpa` — Derived
`[0 -0.159333276810563 -0.633258709677809 -1.41005695027301 -2.47173666500257 -3.79592548539108 -5.35786489234899 -7.13217478652462 -9.09420364751938 -11.2209236729158]` (default) | `vector`

Derived d-axis table data, in A.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	**Tab**
D-axis table data, id_mtpa	**Maximum torque, T_max** **MTPA table breakpoints, pb**	**Id and Iq Calculation**
	Permanent magnet flux, lambda_pm **D-axis inductance, Ld** **Q-axis inductance, Lq** **Number of pole pairs, PolePairs**	**Motor Parameters**

`Q-axis table data, iq_mtpa` — Derived
`[0 4.84224935172196 9.66902512748937 14.4660510262181 19.2212063070062 23.9250934510846 28.5711892538614 33.1556572971289 37.6769488702032 42.1353166357157]` (default) | `vector`

Derived q-axis table data, in A.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
D-axis table data, id_mtpa	**Maximum torque, T_max** **MTPA table breakpoints, pb**	**Id and Iq Calculation**
	Permanent magnet flux, lambda_pm **D-axis inductance, Ld** **Q-axis inductance, Lq** **Number of pole pairs, PolePairs**	**Motor Parameters**

`D, Q, and max current limits, idq_limits` — Derived

`[-11.2210468862948 42.1352838229553 43.6038305205566]` (default) | `array`

Derived d, q, and maximum current limits, in A.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
D, Q, and max current limits, idq_limits	**Maximum torque, T_max** **MTPA table breakpoints, pb**	**Id and Iq Calculation**
	Permanent magnet flux, lambda_pm **D-axis inductance, Ld** **Q-axis inductance, Lq** **Number of pole pairs, PolePairs**	**Motor Parameters**

Current Controller

`Bandwidth of the current regulator, EV_current` — Bandwidth

`200` (default) | `scalar`

Derived current regulator bandwidth, in Hz.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the current regulator, EV_current	**D-axis proportional gain, Kp_d** **Q-axis proportional gain, Kp_q** **D and Q axis proportional gain, Ki**	**Current Controller**

`Sample time for the torque control, Tst` — Time

`5e-5` (default) | `scalar`

Derived torque control sample time, in s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Sample time for the torque control, Tst	**Speed regulation time constant, Ksf**	**Speed Controller**

`Calculate Current Regulator Gains` — Derive parameters

button

Click to derive parameters.

Dependencies

On the **Current Controller** tab, when you select **Calculate Current Regulator Gains**, the block calculates derived parameters. The table summarizes the derived parameter dependencies on other block parameters.

Derived Parameter on Current Controller tab	Dependency	
	Parameter	Tab
D-axis proportional gain, Kp_d **Q-axis proportional gain, Kp_q** **D and Q axis integral gain, Ki**	**Bandwidth of the current regulator, EV_current**	**Current Controller**
	Stator resistance, Rs	**Motor Parameters**

`D-axis proportional gain, Kp_d` — Derived

`2.1363` (default) | `scalar`

Derived d-axis proportional gain, in V/A.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
D-axis proportional gain, Kp_d	**Bandwidth of the current regulator, EV_current**	**Current Controller**

`Q-axis proportional gain, Kp_q` — Derived
`4.0212` (default) | `scalar`

Derived q-axis proportional gain, in V/A.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Q-axis proportional gain, Kp_q	**Bandwidth of the current regulator, EV_current**	**Current Controller**

`D and Q axis integral gain, Ki` — Derived
`25.1327` (default) | `scalar`

Derived d- and q- axis integral gains, in V/A·s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
D and Q axis integral gain, Ki	**Stator resistance, Rs**	**Motor Parameters**

Speed Controller

`Bandwidth of the motion controller, EV_motion` — Bandwidth
`[20, 4, 0.8]` (default) | `vector`

Motion controller bandwidth, in Hz. Set the first element of the vector to the desired cutoff frequency. Set the second and third elements of the vector to the higher-order cut off frequencies. You can set the value of the next element to `1/5` the value of the previous element. For example, if the desired cutoff frequency is `20` Hz, specify `[20 4 0.8]`.

Dependencies

The parameter is enabled when the **Control Type** parameter is set to `Speed Control`.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the motion controller, EV_motion	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa**	**Speed Controller**

`Bandwidth of the state filter, EV_sf` — Bandwidth

`200` (default) | `scalar`

State filter bandwidth, in Hz.

Dependencies

The parameter is enabled when the **Control Type** parameter is set to `Speed Control`.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the state filter, EV_sf	**Speed regulation time constant, Ksf**	**Speed Controller**

`Calculate Speed Regulator Gains` — Derive parameters

button

Click to derive parameters.

Dependencies

On the **Speed Controller** tab, when you select **Calculate Speed Regulator Gains**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Speed Controller tab		Depends On	
		Parameter	Tab
Proportional gain, ba	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$	**Bandwidth of the motion controller, EV_motion** **Bandwidth of the state filter, EV_sf**	**Speed Controller**
Angular gain, Ksa	$K_{sa} = \frac{J_p(p_1 p_2 + p_2 p_3 + p_3 p_1) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$	**Sample time for the torque control, Tst**	**Current Controller**
Rotational gain, Kisa	$K_{isa} = \frac{-J_p(p_1 + p_2 + p_3) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

Derived Parameter on Speed Controller tab		Depends On	
		Parameter	Tab
Speed regulation time constant, Ksf	$K_{sf} = \frac{1 - \exp(-T_{sm} 2\pi EV_{sf})}{T_{sm}}$		
Inertia compensation, Jcomp	$J_{comp} = J_p$	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
Viscous damping compensation, Fv	F_v		
Static friction, Fs	F_s		

The equations use these variables.

P	Motor pole pairs
b_a	Speed regulator proportional gain
K_{sa}	Speed regulator integral gain
K_{isa}	Speed regulator double integral gain
K_{sf}	Speed regulator time constant
J_p	Motor inertia
EV_{sf}	State filter bandwidth
EV_{motion}	Motion controller bandwidth

`Proportional gain, ba` — Derived

`3.7477` (default) | `scalar`

Derived proportional gain, in N·m/(rad/s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Proportional gain, ba	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
	Bandwidth of the motion controller, EV_motion	**Speed Controller**

`Angular gain, Ksa` — Derived

`94.0877` (default) | `scalar`

Derived angular gain, in N·m/rad.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Angular gain, Ksa	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
	Bandwidth of the motion controller, EV_motion	**Speed Controller**

`Rotational gain, Kisa` — Derived
`381.7822` (default) | `scalar`

Derived rotational gain, in N·m/(rad*s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Rotational gain, Kisa	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
	Bandwidth of the motion controller, EV_motion	**Speed Controller**

`Speed regulation time constant, Ksf` — Derived
`1217.9727` (default) | `scalar`

Derived speed regulation time constant, in 1/s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Speed regulation time constant, Ksf	**Sample time for the torque control, Tst**	**Current Controller**
	Bandwidth of the state filter, EV_sf	**Speed Controller**

`Inertia compensation, Jcomp` — Derived
`0.025` (default) | `scalar`

Derived inertia compensation, in kg·m^2.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Inertia compensation, Jcomp	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

`Viscous damping compensation, Fv` — Derived

`0` (default) | `scalar`

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Viscous damping compensation, Fv	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

`Static friction, Fs` — Derived

`0` (default) | `scalar`

Derived static friction, in N·m/(rad/s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Static friction, Fs	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

Electrical Losses

`Parameterize losses by` — Select type

`Single efficiency measurement` (default) | `Tabulated loss data` | `Tabulated efficiency data`

Setting	Block Implementation
`Single efficiency measurement`	Electrical loss calculated using a constant value for inverter efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of motor speeds and load torques.

Setting	Block Implementation
`Tabulated efficiency data`	Electrical loss calculated using inverter efficiency that is a function of motor speeds and load torques. • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

`Overall inverter efficiency, eff` — Constant
`98` (default) | `scalar`

Overall inverter efficiency, *Eff*, in %.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Vector of speeds (w) for tabulated loss, w_loss_bp` — Breakpoints
`[0 200 400 600 800 1000]` (default) | 1-by-M vector

Speed breakpoints for lookup table when calculating losses, in rad/s.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Vector of torques (T) for tabulated loss, T_loss_bp` — Breakpoints
`[0 25 50 75 100]` (default) | 1-by-N vector

Torque breakpoints for lookup table when calculating losses, in N·m.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Corresponding losses, losses_table` — Table
`[100 100 100 100 100;100 150 200 250 300;100 200 300 400 500;100 250 400 550 700;100 300 500 700 900;100 350 600 850 1100]` (default) | M-by-N array

Array of values for electrical losses as a function of `M` speeds and `N` torques, in W. Each value specifies the losses for a specific combination of speed and torque. The matrix size must match the dimensions defined by the speed and torque vectors.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Vector of speeds (w) for tabulated efficiency, w_eff_bp` — Breakpoints
`[200 400 600 800 1000]` (default) | 1-by-`M` vector

Speed breakpoints for lookup table when calculating efficiency, in rad/s.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

`Vector of torques (T) for tabulated efficiency, T_eff_bp` — Breakpoints
`[25 50 75 100]` (default) | 1-by-`N` vector

Torque breakpoints for lookup table when calculating efficiency, in N·m.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

`Corresponding efficiency, efficiency_table` — Table
`[96.2 98.1 98.7 99;98.1 99 99.4 99.5;98.7 99.4 99.6 99.7;99 99.5 99.7 99.8;99.2 99.6 99.7 99.8]` (default) | `M`-by-`N` array

Array of efficiency as a function of `M` speeds and `N` torque, in %. Each value specifies the efficiency for a specific combination of speed and torque. The matrix size must match the dimensions defined by the speed and torque vectors.

The block ignores efficiency values for zero speed or zero torque. Losses are zero when either torque or speed is zero. The block uses linear interpolation.

To get the desired level of accuracy for lower power conditions, you can provide tabulated data for low speeds and low torques.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

References

[1] Lorenz, Robert D., Thomas Lipo, and Donald W. Novotny. “Motion control with induction motors.” *Proceedings of the IEEE*, Vol. 82, Issue 8, August 1994, pp. 1215–1240.

[2] Morimoto, Shigeo, Masayuka Sanada, and Yoji Takeda. “Wide-speed operation of interior permanent magnet synchronous motors with high-performance current regulator.” *IEEE Transactions on Industry Applications*, Vol. 30, Issue 4, July/August 1994, pp. 920–926.

[3] Li, Muyang. “Flux-Weakening Control for Permanent-Magnet Synchronous Motors Based on Z-Source Inverters.” Master’s Thesis, Marquette University, e-Publications@Marquette, Fall 2014.

[4] Briz, Fernando, Michael W. Degner, and Robert D. Lorenz. "Analysis and design of current regulators using complex vectors." *IEEE Transactions on Industry Applications*, Vol. 36, Issue 3, May/June 2000, pp. 817–825.

[5] Briz, Fernando, et al. "Current and flux regulation in field-weakening operation [of induction motors]."*IEEE Transactions on Industry Applications*, Vol. 37, Issue 1, Jan/Feb 2001, pp. 42–50.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

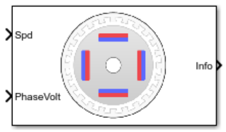
Interior PMSM | Flux-Based PM Controller | IM Controller | Surface Mount PM Controller

Introduced in R2017a

Flux-Based PMSM

Flux-based permanent magnet synchronous motor

Library: Powertrain Blockset / Propulsion / Electric Motors and Inverters



Description

The Flux-Based PMSM block implements a flux-based three-phase permanent magnet synchronous motor (PMSM) with a tabular-based electromotive force. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

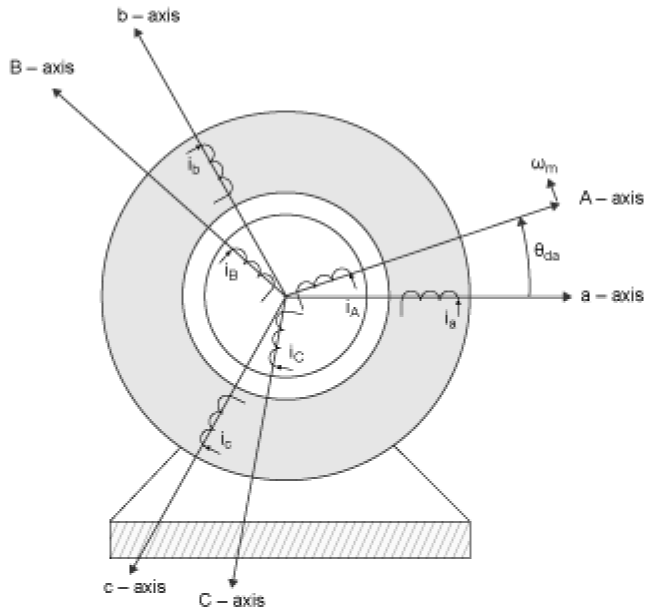
Flux-based motor models take into account magnetic saturation and iron losses. To calculate the magnetic saturation and iron loss, the Flux-Based PMSM block uses the inverse of the flux linkages. To obtain the block parameters, you can use finite-element analysis (FEA) or measure phase voltages using a dynamometer.

By default, the block sets the **Simulation Type** parameter to `Continuous` to use a continuous sample time during simulation. If you want to generate code for fixed-step double- and single-precision targets, considering setting the parameter to `Discrete`. Then specify a **Sample Time, Ts** parameter.

To enable power loss calculations suitable for code generation targets that limit memory, select **Enable memory optimized 2D LUT**.

Three-Phase Sinusoidal Model Electrical System

The block implements equations that are expressed in a stationary rotor reference (dq) frame. The *d*-axis aligns with the *a*-axis. All quantities in the rotor reference frame are referred to the stator.



The block uses these equations.

Calculation	Equation
q- and *d*-axis voltage	$v_d = \frac{d\psi_d}{dt} + R_s i_d - \omega_e \psi_q$ $v_q = \frac{d\psi_q}{dt} + R_s i_q + \omega_e \psi_d$
q- and *d*-axis current	$i_d = f(\psi_d, \psi_q)$ $i_q = g(\psi_d, \psi_q)$
Electromechanical torque	$T_e = 1.5P[\psi_d i_q - \psi_q i_d]$

The equations use these variables.

ω_m	Rotor mechanical speed
ω_e	Rotor electrical speed
Θ_{da}	dq stator electrical angle with respect to the rotor a-axis
R_s, R_r	Resistance of the stator and rotor windings, respectively
i_q, i_d	*q*- and *d*-axis current, respectively
v_q, v_d	*q*- and *d*-axis voltage, respectively
Ψ_q, Ψ_d	*q*- and *d*-axis magnet flux, respectively
P	Number of pole pairs
T_e	Electromagnetic torque

Transforms

To calculate the voltages and currents in balanced three-phase (a, b) quantities, quadrature two-phase (α, β) quantities, and rotating (d, q) reference frames, the block uses the Clarke and Park Transforms.

In the transform equations.

$$\omega_e = P\omega_m$$

$$\frac{d\theta_e}{dt} = \omega_e$$

Transform	Description	Equations
Clarke	Converts balanced three-phase quantities (a, b) into balanced two-phase quadrature quantities (α, β).	$x_\alpha = \frac{2}{3}x_a - \frac{1}{3}x_b - \frac{1}{3}x_c$ $x_\beta = \frac{\sqrt{3}}{2}x_b - \frac{\sqrt{3}}{2}x_c$
Park	Converts balanced two-phase orthogonal stationary quantities (α, β) into an orthogonal rotating reference frame (d, q).	$x_d = x_\alpha \cos\theta_e + x_\beta \sin\theta_e$ $x_q = -x_\alpha \sin\theta_e + x_\beta \cos\theta_e$
Inverse Clarke	Converts balanced two-phase quadrature quantities (α, β) into balanced three-phase quantities (a, b).	$x_a = x_a$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$
Inverse Park	Converts an orthogonal rotating reference frame (d, q) into balanced two-phase orthogonal stationary quantities (α, β).	$x_\alpha = x_d \cos\theta_e - x_q \sin\theta_e$ $x_\beta = x_d \sin\theta_e + x_q \cos\theta_e$

The transforms use these variables.

ω_m	Rotor mechanical speed
P	Motor pole pairs
ω_e	Rotor electrical speed
Θ_e	Rotor electrical angle
x	Phase current or voltage

Mechanical System

The rotor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}\left(T_e - T_f - F\omega_m - T_m\right)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of rotor and load
F	Combined viscous friction of rotor and load
θ_m	Rotor mechanical angular position
T_m	Rotor shaft torque
T_e	Electromagnetic torque
T_f	Combined rotor and load friction torque
ω_m	Rotor mechanical speed

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrMtr`	Mechanical power	P_{mot}	$P_{mot} = -\omega_m T_e$
		`PwrBus`	Electrical power	P_{bus}	$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrElecLoss`	Resistive power loss	P_{elec}	$P_{elec} = -\frac{3}{2}(R_s i_{sd}^2 + R_s i_{sq}^2)$
		`PwrMechLoss`	Mechanical power loss	P_{mech}	When **Port Configuration** is set to `Torque`: $P_{mech} = -\left(\omega_m^2 F + \lvert\omega_m\rvert T_f\right)$ When **Port Configuration** is set to `Speed`: $P_{mech} = 0$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrMtrStored`	Stored motor power	P_{str}	$P_{str} = P_{bus} + P_{mot} + P_{elec} + P_{mech}$

The equations use these variables.

R_s	Stator resistance

i_a, i_b, i_c	Stator phase a, b, and c current
i_{sq}, i_{sd}	Stator q- and d-axis currents
v_{an}, v_{bn}, v_{cn}	Stator phase a, b, and c voltage
ω_m	Angular mechanical velocity of the rotor
F	Combined motor and load viscous damping
T_e	Electromagnetic torque
T_f	Combined motor and load friction torque

Lookup Table Memory Optimization

The data for the **Corresponding d-axis current, id** and **Corresponding q-axis current, iq** lookup tables are functions of the *d*- and *q*-axis flux.

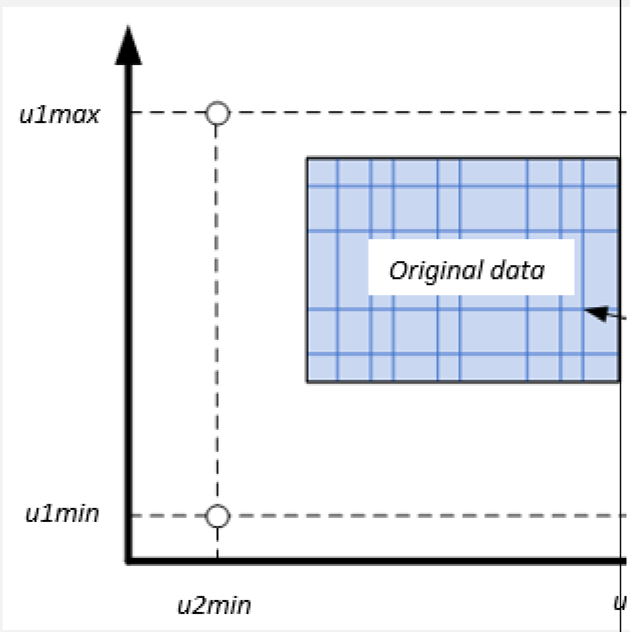
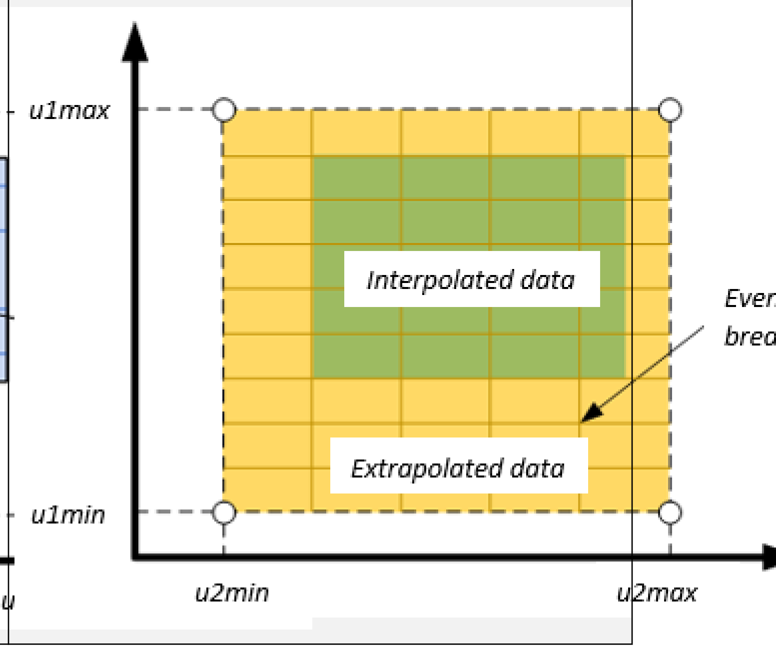
To enable current calculations suitable for code generation targets that limit memory, select **Enable memory optimized 2D LUT**. The block uses linear interpolation to optimize the current lookup table values for code generation. This table summarizes the optimization implementation.

Use Case	Implementation
d- and *q*-axis flux aligns with the lookup table breakpoint values.	Memory-optimized current is current lookup table value at intersection of flux values.
d- and *q*-axis flux does not align with the lookup table breakpoint values, but is within range.	Memory-optimized current is linear interpolation between corresponding flux values.
d- and *q*-axis flux does not align with the lookup table breakpoint values, and is out of range.	Cannot compute an memory-optimized current. Block uses extrapolated data.

Extrapolation

The lookup tables optimized for code generation do not support extrapolation for data that is out of range. However, you can include pre-calculated extrapolation values in the power loss lookup table by selecting **Specify Extrapolation**.

The block uses the endpoint parameters to resize the table data.

User Input	Extrapolation
	

Ports

Input

LdTrq — Rotor shaft torque
scalar

Rotor shaft input torque, T_m, in N·m.

Dependencies

To create this port, select `Torque` for the **Port Configuration** parameter.

Spd — Rotor shaft speed
scalar

Angular velocity of the rotor, ω_m, in rad/s.

Dependencies

To create this port, select `Speed` for the **Port Configuration** parameter.

PhaseVolt — Stator terminal voltages
1-by-3 array

Stator terminal voltages, V_a, V_b, and V_c, in V.

Dependencies

To create this port, select `Speed` or `Torque` for the **Port Configuration** parameter.

Output

`Info` — Bus signal
bus

The bus signal contains these block calculations.

Signal			Description	Variable	Units
`IaStator`			Stator phase current A	i_a	A
`IbStator`			Stator phase current B	i_b	A
`IcStator`			Stator phase current C	i_c	A
`IdSync`			Direct axis current	i_d	A
`IqSync`			Quadrature axis current	i_q	A
`VdSync`			Direct axis voltage	v_d	V
`VqSync`			Quadrature axis voltage	v_q	V
`MtrSpd`			Angular mechanical velocity of the rotor	ω_m	rad/s
`MtrPos`			Rotor mechanical angular position	θ_m	rad
`MtrTrq`			Electromagnetic torque	T_e	N·m
`PwrInfo`	`PwrTrnsfrd`	`PwrMtr`	Mechanical power	P_{mot}	W
		`PwrBus`	Electrical power	P_{bus}	W
	`PwrNotTrnsfrd`	`PwrElecLoss`	Resistive power loss	P_{elec}	W
		`PwrMechLoss`	Mechanical power loss	P_{mech}	W
	`PwrStored`	`PwrMtrStored`	Stored motor power	P_{str}	W

`PhaseCurr` — Phase a, b, c current
1-by-3 array

Phase a, b, c current, i_a, i_b, and i_c, in A.

`MtrTrq` — Motor torque
`scalar`

Motor torque, T_{mtr}, in N·m.

Dependencies

To create this port, select `Speed` for the **Port configuration** parameter.

`MtrSpd` — Motor speed
`scalar`

Angular speed of the motor, ω_{mtr}, in rad/s.

Dependencies

To create this port, select `Torque` for the **Port configuration** parameter.

Parameters

Block Options

`Simulation type` — Select simulation type
`Continuous` (default) | `Discrete`

By default, the block uses a continuous sample time during simulation. If you want to generate code for single-precision targets, considering setting the parameter to `Discrete`.

Dependencies

Setting **Simulation Type** to `Discrete` creates the **Sample Time, Ts** parameter.

`Sample time, Ts` — Sample time for discrete integration
`0.001` (default) | `scalar`

Integration sample time for discrete simulation, in s.

Dependencies

Setting **Simulation Type** to `Discrete` creates the **Sample Time, Ts** parameter.

`Port Configuration` — Select port configuration
`Torque` (default) | `Speed`

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
`Torque`	`LdTrq`	`MtrSpd`
`Speed`	`Spd`	`MtrTrq`

`Enable memory optimized 2D LUT` — Selection
`off` (default) | `on`

Enable generation of optimized lookup tables, suitable code generation targets that limit memory.

`Vector of d-axis flux, flux_d` — Flux breakpoints
1-by-M vector

d-axis flux, Ψ_d, breakpoints, in Wb.

`Resample storage size for flux_d, n1` — Flux bit size
2 (default) | 4 | 8 | 16 | 32 | 64 | 128 | 256

Flux breakpoint storage size, *n1*, dimensionless. The block resamples the **Corresponding d-axis current, id** and **Corresponding q-axis current, iq** data based on the storage size.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT**.

`Vector of q-axis flux, flux_q` — Flux breakpoints
1-by-N vector

q-axis flux, Ψ_q, breakpoints, in Wb.

`Resample storage size for flux_q, n2` — Flux bit size
2 (default) | 4 | 8 | 16 | 32 | 64 | 128 | 256

Flux breakpoint storage size, *n2*, dimensionless. The block resamples the **Corresponding d-axis current, id** and **Corresponding q-axis current, iq** data based on the storage size.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT**.

`Corresponding d-axis current, id` — 2D lookup table
`M`-by-`N` array

Array of values for *d*-axis current, i_d, as a function of `M` *d*-fluxes, Ψ_d, and `N` *q*-fluxes, Ψ_q, in A. Each value specifies the current for a specific combination of *d*- and *q*-axis flux. The array size must match the dimensions defined by the flux vectors.

If you set **Enable memory optimized 2D LUT**, the block converts the data to single precision.

`Corresponding q-axis current, iq` — 2D lookup table
`M`-by-`N` array

Array of values for *q*-axis current, i_d, as a function of `M` *d*-fluxes, Ψ_d, and `N` *q*-fluxes, Ψ_q, in A. Each value specifies the current for a specific combination of *d*- and *q*-axis flux. The array size must match the dimensions defined by the flux vectors.

If you set **Enable memory optimized 2D LUT**, the block converts the data to single precision.

`flux_d max endpoint, u1max` — Flux breakpoint
`0.22457` (default) | `scalar`

Flux breakpoint maximum extrapolation endpoint, *u1max*, in Wb.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT** and **Specify Extrapolation**.

`flux_d min endpoint, u1min` — Flux breakpoint
`-0.22607` (default) | `scalar`

Flux breakpoint minimum extrapolation endpoint, *u1min*, in Wb.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT** and **Specify Extrapolation**.

`flux_q max endpoint, u2max` — Flux breakpoint
`0.42959` (default) | `scalar`

Flux breakpoint maximum extrapolation endpoint, *u2max*, in Wb.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT** and **Specify Extrapolation**.

`flux_q min endpoint, u2min` — Flux breakpoint
`-0.4296` (default) | `scalar`

Flux breakpoint minimum extrapolation endpoint, *u2min*, in Wb.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT** and **Specify Extrapolation**.

`Stator phase resistance, Rs` — Resistance
`0.02` (default) | `scalar`

Stator phase resistance, R_s, in ohm.

`Number of pole pairs, P` — Pole pairs
`4` (default) | `scalar`

Motor pole pairs, *P*.

`Initial flux, fluxdq0` — Flux
`[0 0]` (default) | `vector`

Initial *d*- and *q*-axis flux, Ψ_{q0} and Ψ_{d0}, in Wb.

`Initial mechanical position, theta_init` — Angle
`0` (default) | `scalar`

Initial rotor angular position, θ_{m0}, in rad.

`Initial mechanical speed, omega_init` — Speed
`0` (default) | `scalar`

Initial angular velocity of the rotor, ω_{m0}, in rad/s.

Dependencies

To enable this parameter, select the `Torque` configuration parameter.

`Physical inertia, viscous damping, and static friction, mechanical` — Inertia, damping, friction
`[0.0027, 4.924e-4, 0]` (default) | `vector`

Mechanical properties of the rotor:

- Inertia, *J*, in kgm^2
- Viscous damping, *F*, in N·m/(rad/s)
- Static friction, T_f, in N·m

Dependencies

To enable this parameter, select the `Torque` configuration parameter.

References

[1] Hu, Dakai, Yazan Alsmadi, and Longya Xu. “High fidelity nonlinear IPM modeling based on measured stator winding flux linkage.” *IEEE Transactions on Industry Applications*, Vol. 51, No. 4, July/August 2015.

[2] Chen, Xiao, Jiabin Wang, Bhaskar Sen, Panagiotis Lasari, Tianfu Sun. "A High-Fidelity and Computationally Efficient Model for Interior Permanent-Magnet Machines Considering the Magnetic Saturation, Spatial Harmonics, and Iron Loss Effect." *IEEE Transactions on Industrial Electronics*, Vol. 62, No. 7, July 2015.

[3] Ottosson, J., M. Alakula. "A compact field weakening controller implementation." *International Symposium on Power Electronics, Electrical Drives, Automation and Motion*, July, 2006.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
Flux-Based PM Controller | Induction Motor | Interior PMSM | Mapped Motor | Surface Mount PMSM

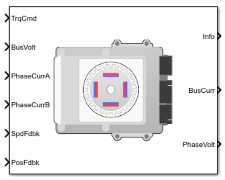
Topics
"Generate Parameters for Flux-Based Blocks"

Introduced in R2017b

Flux-Based PM Controller

Controller for a flux-based permanent magnet synchronous motor

Library: Powertrain Blockset / Propulsion / Electric Motor Controllers

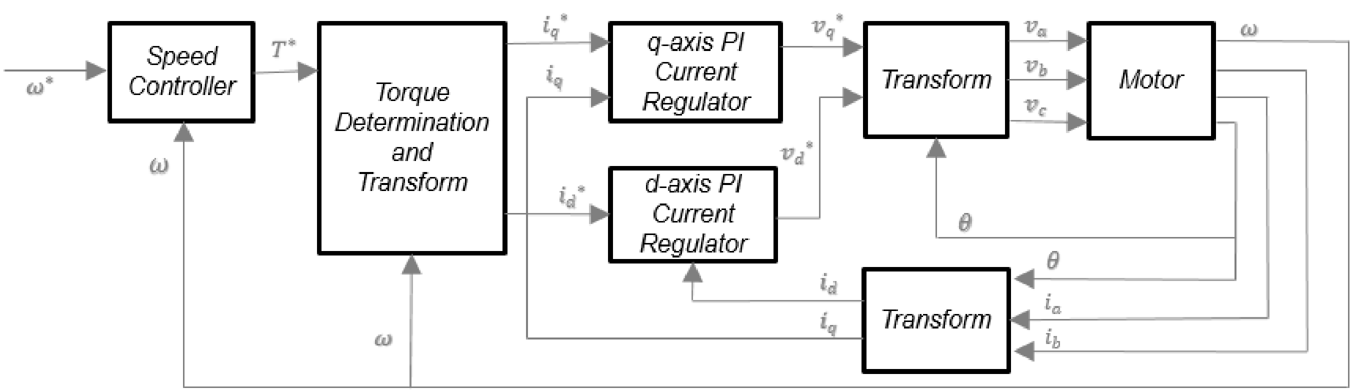


Description

The Flux Based PM Controller block implements a flux-based, field-oriented controller for an interior permanent magnet synchronous motor (PMSM) with an optional outer-loop speed controller. The internal torque control implements strategies for achieving maximum torque per ampere (MTPA) and weakening the magnetic flux. You can specify either the speed or torque control type.

The Flux Based PM Controller implements equations for speed control, torque determination, regulators, transforms, and motors.

The figure illustrates the information flow in the block.



The block implements equations using these variables.

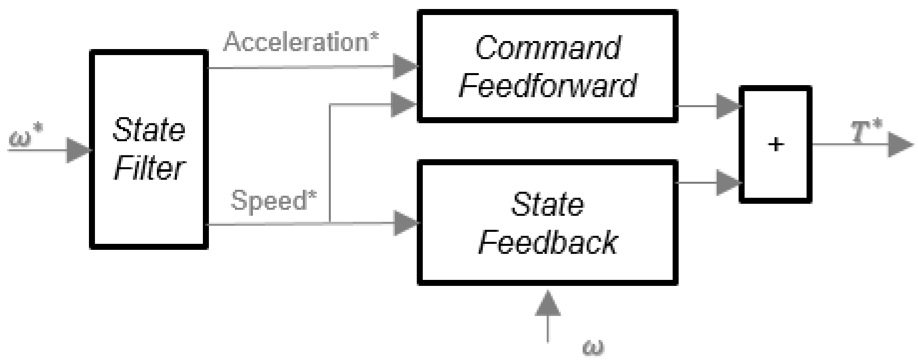
ω	Rotor speed
ω*	Rotor speed command
T*	Torque command
i_d	d-axis current
i^*_d	d-axis current command
i_q	q-axis current
i^*_q	q-axis current command

v_d,	*d*-axis voltage
v^*_d	*d*-axis voltage command
v_q	*q*-axis voltage
v^*_q	*q*-axis voltage command
v_a, v_b, v_c	Stator phase a, b, c voltages
i_a, i_b, i_c	Stator phase a, b, c currents

Speed Controller

To implement the speed controller, select the **Control Type** parameter `Speed Control`. If you select the **Control Type** parameter `Torque Control`, the block does not implement the speed controller.

The speed controller determines the torque command by implementing a state filter, and calculating the feedforward and feedback commands. If you do not implement the speed controller, input a torque command to the Flux Based PM Controller block.



State Filter

The state filter is a low-pass filter that generates the acceleration command based on the speed command. The discrete form of characteristic equation is given by:

$$z + K_{sf}T_{sm} - 1$$

The filter calculates the gain using this equation.

$$K_{sf} = \frac{1 - \exp\left(-T_{sm}2\pi EV_{sf}\right)}{T_{sm}}$$

The equations use these variables.

EV_{sf}	Bandwidth of the speed command filter
T_{sm}	Motion controller sample time
K_{sf}	Speed regulator time constant

State Feedback

To generate the state feedback torque, the block uses the filtered speed error signal from the state filter. To filter the speed, the block uses a proportional integral (PI) controller.

$$T_{cmd} = Kp_{\omega}(\omega_m^* - \omega_m) + Ki_{\omega}\frac{zT_{sm}}{z-1}(\omega_m^* - \omega_m)$$

The equations use these variables.

ω_m	Rotor speed
$\omega{*}_m$	Rotor speed command
T_{cmd}	Torque command
Kp_{ω}	Speed regulator proportional gain
Ki_{ω}	Speed regulator integral gain
T_{sm}	Speed regulator sample rate

Command Feedforward

To generate the state feedforward torque, the block uses the filtered speed and acceleration from the state filter. Also, the feedforward torque calculation uses the inertia, viscous damping, and static friction. To achieve zero tracking error, the torque command is the sum of the feedforward and feedback torque commands.

The feedforward torque command uses this equation.

$$T_{cmd\_ff} = \quad J_p\dot{\omega}_m + F_v\omega_m + F_s\frac{\omega_m}{|\omega_m|}$$

where:

J_p	Rotor inertia
T_{cmd_ff}	Torque command feedforward
F_s	Static friction torque constant
F_v	Viscous friction torque constant
F_s	Static friction torque constant
ω_m	Rotor speed

Current Command

The block uses lookup tables to determine the *d*-axis and *q*-axis current commands. The lookup tables are functions of mechanical speed and torque. To determine the lookup tables, you can use an external finite element analysis (FEA) models or dynamometer test results.

$$i_{dref} = f(|\omega_m|, |T_{ref}|)$$

$$i_{qref} = sign(T_{ref}) * f(|\omega_m|, |T_{ref}|)$$

The equations use these variables.

ω_m	Rotor speed
T_{ref}	Torque command
i_{dref}, i_{qref}	*d*- and *q*-axis reference current, respectively

Voltage Command

The block uses these equations to calculate the voltage in the motor reference frame.

$$v_d = \frac{d\psi_d}{dt} + R_s i_d - \omega_e \psi_q$$

$$v_q = \frac{d\psi_q}{dt} + R_s i_q + \omega_e \psi_d$$

$$\frac{d\psi_d}{dt} + R_s i_d = Kp_d(i_d^* - i_d) + Ki_d \frac{zT_{st}}{z-1}(i_d^* - i_d)$$

$$\frac{d\psi_q}{dt} + R_s i_q = Kp_q(i_q^* - i_q) + Ki_q \frac{zT_{st}}{z-1}(i_q^* - i_q)$$

$$v_d = Kp_i(i_d^* - i_d) + Ki_d \frac{zT_{st}}{z-1}(i_d^* - i_d) + \omega_e \psi_q$$

$$v_q = Kp_i(i_q^* - i_q) + Ki_q \frac{zT_{st}}{z-1}(i_q^* - i_q) - \omega_e \psi_d$$

$$\psi_q = f(i_d, i_q)$$

$$\psi_d = f(i_d, i_q)$$

The equations use these variables.

ω_m	Rotor mechanical speed
ω_e	Rotor electrical speed
R_s, R_r	Resistance of the stator and rotor windings, respectively
i_q, i_d	*q*- and *d*-axis current, respectively
v_q, v_d	*q*- and *d*-axis voltage, respectively
Ψ_q, Ψ_d	*q*- and *d*-axis magnet flux, respectively
T_{st}	Current regulator sample rate
Ki_d , Ki_q	*d*- and *q*- axis integral gain, respectively
Kp_d , Kp_q	*d*- and *q*- axis proportional gain, respectively

Transforms

To calculate the voltages and currents in balanced three-phase (*a*, *b*) quantities, quadrature two-phase (*α*, *β*) quantities, and rotating (*d*, *q*) reference frames, the block uses the Clarke and Park Transforms.

In the transform equations.

$$\omega_e = P\omega_m$$

$$\frac{d\theta_e}{dt} = \omega_e$$

Transform	Description	Equations
Clarke	Converts balanced three-phase quantities (a, b) into balanced two-phase quadrature quantities (α, β).	$x_\alpha = \frac{2}{3}x_a - \frac{1}{3}x_b - \frac{1}{3}x_c$ $x_\beta = \frac{\sqrt{3}}{2}x_b - \frac{\sqrt{3}}{2}x_c$
Park	Converts balanced two-phase orthogonal stationary quantities (α, β) into an orthogonal rotating reference frame (d, q).	$x_d = x_\alpha \cos\theta_e + x_\beta \sin\theta_e$ $x_q = -x_\alpha \sin\theta_e + x_\beta \cos\theta_e$
Inverse Clarke	Converts balanced two-phase quadrature quantities (α, β) into balanced three-phase quantities (a, b).	$x_a = x_a$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$
Inverse Park	Converts an orthogonal rotating reference frame (d, q) into balanced two-phase orthogonal stationary quantities (α, β).	$x_\alpha = x_d \cos\theta_e - x_q \sin\theta_e$ $x_\beta = x_d \sin\theta_e + x_q \cos\theta_e$

The transforms use these variables.

ω_m	Rotor speed
P	Rotor pole pairs
ω_e	Rotor electrical speed
Θ_e	Rotor electrical angle
x	Phase current or voltage

Motor

The block uses the phase currents and phase voltages to estimate the DC bus current. Positive current indicates battery discharge. Negative current indicates battery charge.

The block uses these equations.

Load power	$Ld_{Pwr} = v_a \ i_a + v_b \ i_b + v_c \ i_c$
Source power	$Src_{Pwr} = Ld_{Pwr} + Pwr_{Loss}$
DC bus current	$i_{bus} = \frac{Src_{Pwr}}{v_{bus}}$
Estimated rotor torque	$T_e = 1.5P[\psi_d i_q - \psi_q i_d]$
Power loss for single efficiency source to load	$Pwr_{Loss} = \frac{100 - Eff}{Eff} \cdot Ld_{Pwr}$
Power loss for single efficiency load to source	$Pwr_{Loss} = \frac{100 - Eff}{100} \cdot \lvert Ld_{Pwr}\rvert$
Power loss for tabulated efficiency	$Pwr_{Loss} = f(\omega_m, MtrTrq_{est})$

The equations use these variables.

v_a, v_b, v_c	Stator phase a, b, c voltages
v_{bus}	Estimated DC bus voltage
i_a, i_b, i_c	Stator phase a, b, c currents
i_{bus}	Estimated DC bus current
Eff	Overall inverter efficiency
ω_m	Rotor mechanical speed
L_q, L_d	*q*- and *d*-axis winding inductance, respectively
Ψ_q, Ψ_d	*q*- and *d*-axis magnet flux, respectively
i_q, i_d	*q*- and *d*-axis current, respectively
λ	Permanent magnet flux linkage
P	Rotor pole pairs

Electrical Losses

To specify the electrical losses, on the **Electrical Losses** tab, for **Parameterize losses by**, select one of these options.

Setting	Block Implementation
`Single efficiency measurement`	Electrical loss calculated using a constant value for inverter efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of motor speeds and load torques.
`Tabulated efficiency data`	Electrical loss calculated using inverter efficiency that is a function of motor speeds and load torques. • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

Ports

Input

SpdReq — Rotor speed command
`scalar`

Rotor speed command, ω^*_m, in rad/s.

Dependencies

To create this port, select `Speed Control` for the **Control Type** parameter.

`TrqCmd` — Torque command
`scalar`

Torque command, T^*, in N·m.

Dependencies

To create this port, select `Torque Control` for the **Control Type** parameter.

`BusVolt` — DC bus voltage
`scalar`

DC bus voltage, v_{bus}, in V.

`PhaseCurrA` — Current
`scalar`

Stator current phase a, i_a, in A.

`PhaseCurrB` — Current
`scalar`

Stator current phase b, i_b, in A.

`SpdFdbk` — Rotor speed
`scalar`

Rotor speed, ω_m, in rad/s.

`PosFdbk` — Rotor electrical angle
`scalar`

Rotor electrical angle, Θ_m, in rad.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
`SrcPwr`	Source power	W
`LdPwr`	Load power	W
`PwrLoss`	Power loss	W
`MtrTrqEst`	Estimated motor torque	N·m

`BusCurr` — Bus current
`scalar`

Estimated DC bus current, i_{bus}, in A.

PhaseVolt — Stator terminal voltages
array

Stator terminal voltages, V_a, V_b, and V_c, in V.

Parameters

Block Options

Control Type — Select control
Torque Control (default) | Speed Control

If you select Torque Control, the block does not implement the speed controller.

This table summarizes the port configurations.

Port Configuration	Creates Ports
Speed Control	SpdReq
Torque Control	TrqCmd

Motor Parameters

Number of pole pairs, PolePairs — Poles
4 (default) | scalar

Motor pole pairs, P.

Vector of d-axis current breakpoints, id_index — Current
vector

d-axis current, i_{d_index}, in A.

Vector of q-axis current breakpoints, iq_index — current
vector

q-axis current, i_{q_index}, in A.

Corresponding d-axis flux, lambda_d — Flux
vector

d-axis flux, λ_d, in Wb.

Corresponding q-axis flux, lambda_q — Flux
vector

q-axis flux, λ_q, in Wb.

Current Controller

Sample time for the torque control, Tst — Time
1e-4 (default) | scalar

Torque control sample time, T_{st}, in s.

D-axis proportional gain, Kp_d — Gain
2.4056 (default) | scalar

d-axis proportional gain, Kp_d, in V/A.

Q-axis proportional gain, Kp_q — Gain
2.4056 (default) | scalar

q-axis proportional gain, Kp_q, in V/A.

D-axis integral gain, Ki_d — Gain
192.45 (default) | scalar

d-axis integral gain, Ki_d, in V/A·s.

Q-axis integral gain, Ki_q — Gain
192.45 (default) | scalar

q- axis integral gain, Ki_q, in V/A·s.

Vector of speed breakpoints, wpb — Breakpoints
vector

Speed breakpoints, ω_{bp}, in rad/s.

Vector of torque breakpoints, tpb — Breakpoints
vector

Torque breakpoints, T_{bp}, in N·m.

Corresponding d-axis current reference, id_ref — Current
vector

d-axis reference current, i_{dref}, in A.

Corresponding q-axis current reference, iq_ref — Current
vector

q-axis reference current, i_{qref}, in A.

Speed Controller

Speed regulation time constant, Ksf — Time
.1 (default) | scalar

Speed regulator time constant, K_{sf}, in 1/s.

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

Proportional gain, Kp_w — Gain
0.40475 (default) | scalar

Proportional gain, Kp_ω, in N·m/(rad/s).

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

Integral gain, Ki_w — Gain
`10.1615` (default) | `scalar`

Integral gain, Ki_ω N·m/rad.

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

Inertia compensation, Jcomp — Inertia
`0.0027` (default) | `scalar`

Inertia compensation, in kg·m^2.

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

Static friction, Fs — Friction
`0` (default) | `scalar`

Static friction, in N·m.

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

Viscous damping compensation, Fv — Dampint
`0.0004924` (default) | `scalar`

Viscous damping compensation, in N·m/(rad/s).

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

Electrical Losses

Parameterize losses by — Select type
`Single efficiency measurement` (default) | `Tabulated loss data` | `Tabulated efficiency data`

Setting	Block Implementation
`Single efficiency measurement`	Electrical loss calculated using a constant value for inverter efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of motor speeds and load torques.

Setting	Block Implementation
`Tabulated efficiency data`	Electrical loss calculated using inverter efficiency that is a function of motor speeds and load torques. • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

`Overall inverter efficiency, eff` — Constant
`98` (default) | `scalar`

Overall inverter efficiency, *Eff*, in %.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Vector of speeds (w) for tabulated loss, w_loss_bp` — Breakpoints
`[0 200 400 600 800 1000]` (default) | 1-by-M vector

Speed breakpoints for lookup table when calculating losses, in rad/s.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Vector of torques (T) for tabulated loss, T_loss_bp` — Breakpoints
`[0 25 50 75 100]` (default) | 1-by-N vector

Torque breakpoints for lookup table when calculating losses, in N·m.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Corresponding losses, losses_table` — Table
`[100 100 100 100 100;100 150 200 250 300;100 200 300 400 500;100 250 400 550 700;100 300 500 700 900;100 350 600 850 1100]` (default) | M-by-N array

Array of values for electrical losses as a function of `M` speeds and `N` torques, in W. Each value specifies the losses for a specific combination of speed and torque. The matrix size must match the dimensions defined by the speed and torque vectors.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

`Vector of speeds (w) for tabulated efficiency, w_eff_bp` — Breakpoints
`[200 400 600 800 1000]` (default) | 1-by-`M` vector

Speed breakpoints for lookup table when calculating efficiency, in rad/s.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

`Vector of torques (T) for tabulated efficiency, T_eff_bp` — Breakpoints
`[25 50 75 100]` (default) | 1-by-`N` vector

Torque breakpoints for lookup table when calculating efficiency, in N·m.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

`Corresponding efficiency, efficiency_table` — Table
`[96.2 98.1 98.7 99;98.1 99 99.4 99.5;98.7 99.4 99.6 99.7;99 99.5 99.7 99.8;99.2 99.6 99.7 99.8]` (default) | `M`-by-`N` array

Array of efficiency as a function of `M` speeds and `N` torque, in %. Each value specifies the efficiency for a specific combination of speed and torque. The matrix size must match the dimensions defined by the speed and torque vectors.

The block ignores efficiency values for zero speed or zero torque. Losses are zero when either torque or speed is zero. The block uses linear interpolation.

To get the desired level of accuracy for lower power conditions, you can provide tabulated data for low speeds and low torques.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

References

[1] Hu, Dakai, Yazan Alsmadi, and Longya Xu. “High fidelity nonlinear IPM modeling based on measured stator winding flux linkage.” *IEEE Transactions on Industry Applications*, Vol. 51, No. 4, July/August 2015.

[2] Chen, Xiao, Jiabin Wang, Bhaskar Sen, Panagiotis Lasari, Tianfu Sun. “A High-Fidelity and Computationally Efficient Model for Interior Permanent-Magnet Machines Considering the Magnetic Saturation, Spatial Harmonics, and Iron Loss Effect.” *IEEE Transactions on Industrial Electronics*, Vol. 62, No. 7, July 2015.

[3] Ottosson, J., M. Alakula. “A compact field weakening controller implementation.” *International Symposium on Power Electronics, Electrical Drives, Automation and Motion*, July, 2006.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

Flux-Based PMSM | IM Controller | Interior PM Controller | Surface Mount PM Controller

Topics

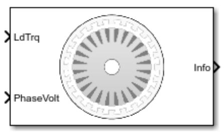
“Generate Parameters for Flux-Based Blocks”

Introduced in R2017b

Induction Motor

Three-phase induction motor

Library: Powertrain Blockset / Propulsion / Electric Motors and Inverters
Motor Control Blockset / Electrical Systems / Motors



Description

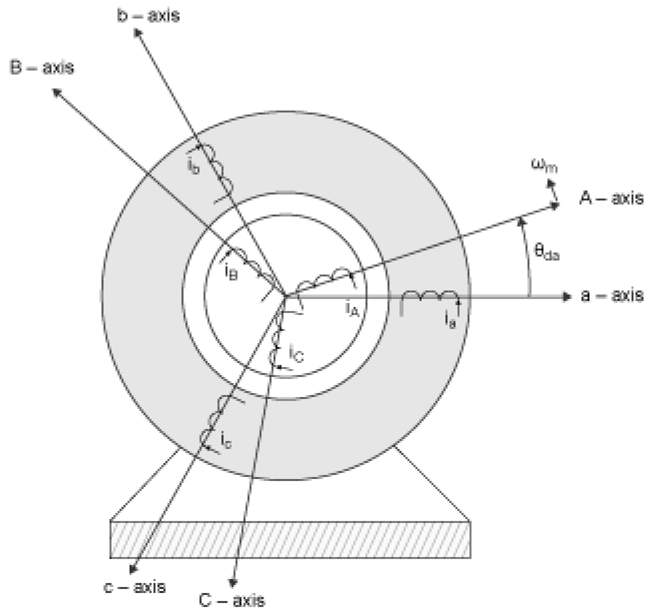
The Induction Motor block implements a three-phase induction motor. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

Note The block parameters use per-phase values of a star-equivalent induction motor.

By default, the block sets the **Simulation Type** parameter to `Continuous` to use a continuous sample time during simulation. If you want to generate code for fixed-step double- and single-precision targets, considering setting the parameter to `Discrete`. Then specify a **Sample Time, Ts** parameter.

Three-Phase Sinusoidal Model Electrical System

The block implements equations that are expressed in a stationary rotor reference (qd) frame. The d-axis aligns with the a-axis. All quantities in the rotor reference frame are referred to the stator.



The block uses these equations to calculate the electrical speed (ω_{em}) and slip speed (ω_{slip}).

$$\omega_{em} = P\omega_m$$

$$\omega_{slip} = \omega_{syn} - \omega_{em}$$

To calculate the dq rotor electrical speed with respect to the rotor A-axis (dA), the block uses the difference between the stator a-axis (da) speed and slip speed:

$$\omega_{dA} = \omega_{da} - \omega_{em}$$

To simplify the equations for the flux, voltage, and current transformations, the block uses a stationary reference frame:

$$\omega_{da} = 0$$

$$\omega_{dA} = -\omega_{em}$$

Calculation	Equation
Flux	$\frac{d}{dt}\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\end{bmatrix} = \begin{bmatrix}v_{sd}\\ v_{sq}\end{bmatrix} - R_s\begin{bmatrix}i_{sd}\\ i_{sq}\end{bmatrix} - \omega_{da}\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\end{bmatrix}$ $\frac{d}{dt}\begin{bmatrix}\lambda_{rd}\\ \lambda_{rq}\end{bmatrix} = \begin{bmatrix}v_{rd}\\ v_{rq}\end{bmatrix} - R_r\begin{bmatrix}i_{rd}\\ i_{rq}\end{bmatrix} - \omega_{dA}\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\begin{bmatrix}\lambda_{rd}\\ \lambda_{rq}\end{bmatrix}$ $\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\\ \lambda_{rd}\\ \lambda_{rq}\end{bmatrix} = \begin{bmatrix}L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix}\begin{bmatrix}i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix}$

Calculation	Equation
Current	$\begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix} = \left(\frac{1}{L_m^2 - L_r L_s}\right) \begin{bmatrix} -L_r & 0 & L_m & 0 \\ 0 & -L_r & 0 & L_m \\ L_m & 0 & -L_s & 0 \\ 0 & L_m & 0 & -L_s \end{bmatrix} \begin{bmatrix} \lambda_{sd} \\ \lambda_{sq} \\ \lambda_{rd} \\ \lambda_{rq} \end{bmatrix}$
Inductance	$L_s = L_{ls} + L_m$ $L_r = L_{lr} + L_m$
Electromagnetic torque	$T_e = PL_m(i_{sq} i_{rd} - i_{sd} i_{rq})$
Power invariant dq transformation to ensure that the dq and three phase powers are equal	$\begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} = \sqrt{\frac{2}{3}}$ $\begin{bmatrix} \cos(\Theta_{da}) & \cos(\Theta_{da} - \frac{2\pi}{3}) & \cos(\Theta_{da} + \frac{2\pi}{3}) \\ -\sin(\Theta_{da}) & -\sin(\Theta_{da} - \frac{2\pi}{3}) & -\sin(\Theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$ $\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\Theta_{da}) & -\sin(\Theta_{da}) \\ \cos(\Theta_{da} - \frac{2\pi}{3}) & -\sin(\Theta_{da} - \frac{2\pi}{3}) \\ \cos(\Theta_{da} + \frac{2\pi}{3}) & -\sin(\Theta_{da} + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix}$

The equations use these variables.

ω_m	Angular velocity of the rotor (rad/s)
ω_{em}	Electrical rotor speed (rad/s)
ω_{slip}	Electrical rotor slip speed (rad/s)
ω_{syn}	Synchronous rotor speed (rad/s)
ω_{da}	dq stator electrical speed with respect to the rotor a-axis (rad/s)
ω_{dA}	dq stator electrical speed with respect to the rotor A-axis (rad/s)
Θ_{da}	dq stator electrical angle with respect to the rotor a-axis (rad)
Θ_{dA}	dq stator electrical angle with respect to the rotor A-axis (rad)
L_q, L_d	q- and d-axis inductances (H)
L_s	Stator inductance (H)
L_r	Rotor inductance (H)
L_m	Magnetizing inductance (H)
L_{ls}	Stator leakage inductance (H)
L_{lr}	Rotor leakage inductance (H)
v_{sq}, v_{sd}	Stator q- and d-axis voltages (V)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
λ_{sq}, λ_{sd}	Stator q- and d-axis flux (Wb)
i_{rq}, i_{rd}	Rotor q- and d-axis currents (A)

λ_{rq}, λ_{rd}	Rotor q- and d-axis flux (Wb)
v_a, v_b, v_c	Stator voltage phases a, b, c (V)
i_a, i_b, i_c	Stator currents phases a, b, c (A)
R_s	Resistance of the stator windings (Ohm)
R_r	Resistance of the rotor windings (Ohm)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)

Mechanical System

The motor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}\left(T_e - T_f - F\omega_m - T_m\right)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm^2)
F	Combined viscous friction of motor and load (N·m/(rad/s))
θ_m	Motor mechanical angular position (rad)
T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Power Accounting

For the power accounting, the block implements these equations.

<table>
<tr><th colspan="3">Bus Signal</th><th>Description</th><th>Variable</th><th>Equations</th></tr>
<tr><td rowspan="3">PwrInfo</td><td rowspan="2">PwrTrnsfrd — Power transferred between blocks
• Positive signals indicate flow into block
• Negative signals indicate flow out of block</td><td>PwrMtr</td><td>Mechanical power</td><td>P_{mot}</td><td>$P_{mot} = -\omega_m T_e$</td></tr>
<tr><td>PwrBus</td><td>Electrical power</td><td>P_{bus}</td><td>$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$</td></tr>
<tr><td>PwrNotTrnsfrd — Power crossing the block boundary, but not transferred
• Positive signals indicate an input</td><td>PwrElecLoss</td><td>Resistive power loss</td><td>P_{elec}</td><td>$P_{elec} = -(R_s i_{sd}^2 + R_s i_{sq}^2 + -R_r i_{rd}^2 + R_r i_{rq}^2)$</td></tr>
</table>

Bus Signal			Description	Variable	Equations
	• Negative signals indicate a loss	PwrMechLoss	Mechanical power loss	P_{mech}	When **Port Configuration** is set to `Torque`: $P_{mech} = -\left(\omega_m^2 F + \lvert\omega_m\rvert T_f\right)$ When **Port Configuration** is set to `Speed`: $P_{mech} = 0$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrMtrStored	Stored motor power	P_{str}	$P_{str} = P_{bus} + P_{mot} + P_{elec} + P_{mech}$

The equations use these variables.

R_s	Stator resistance (Ohm)
R_r	Motor resistance (Ohm)
i_a, i_b, i_c	Stator phase a, b, and c current (A)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
v_{an}, v_{bn}, v_{cn}	Stator phase a, b, and c voltage (V)
ω_m	Angular mechanical velocity of the rotor (rad/s)
F	Combined motor and load viscous damping (N·m/(rad/s))
T_e	Electromagnetic torque (Nm)
T_f	Combined motor and load friction torque (Nm)

Ports

Input

`LdTrq` — Load torque on motor
`scalar`

Load torque on the motor shaft, T_m, in N·m.

Dependencies

To create this port, select `Torque` for the **Port configuration** parameter.

`Spd` — Rotor shaft speed
`scalar`

Angular velocity of the rotor, ω_m, in rad/s.

Dependencies

To create this port, select `Speed` for the **Port configuration** parameter.

`PhaseVolt` — Stator terminal voltages

1-by-3 array

Stator terminal voltages, V_a, V_b, and V_c, in V.

Output

`Info` — Bus signal

bus

The bus signal contains these block calculations.

Signal			Description	Variable	Units
`IaStator`			Stator phase current A	i_a	A
`IbStator`			Stator phase current B	i_b	A
`IcStator`			Stator phase current C	i_c	A
`IdSync`			Direct axis current	i_d	A
`IqSync`			Quadrature axis current	i_q	A
`VdSync`			Direct axis voltage	v_d	V
`VqSync`			Quadrature axis voltage	v_q	V
`MtrSpd`			Angular mechanical velocity of the rotor	ω_m	rad/s
`MtrMechPos`			Rotor mechanical angular position	θ_m	rad
`MtrPos`			Rotor electrical angular position	θ_e	rad
`MtrTrq`			Electromagnetic torque	T_e	N·m
`PwrInfo`	`PwrTrnsfrd`	`PwrMtr`	Mechanical power	P_{mot}	W
		`PwrBus`	Electrical power	P_{bus}	W
	`PwrNotTrnsfrd`	`PwrElecLoss`	Resistive power loss	P_{elec}	W
		`PwrMechLoss`	Mechanical power loss	P_{mech}	W
	`PwrStored`	`PwrMtrStored`	Stored motor power	P_{str}	W

`PhaseCurr` — Phase a, b, c current

1-by-3 array

Phase a, b, c current, i_a, i_b, and i_c, in A.

`MtrTrq` — Motor torque

`scalar`

Motor torque, T_{mtr}, in N·m.

Dependencies

To create this port, select `Speed` for the **Port configuration** parameter.

`MtrSpd` — Motor speed
`scalar`

Angular speed of the motor, ω_{mtr}, in rad/s.

Dependencies

To create this port, select `Torque` for the **Port configuration** parameter.

Parameters

Block Options

`Simulation type` — Select simulation type
`Continuous` (default) | `Discrete`

By default, the block uses a continuous sample time during simulation. If you want to generate code for single-precision targets, considering setting the parameter to `Discrete`.

Dependencies

Setting **Simulation Type** to `Discrete` creates the **Sample Time, Ts** parameter.

`Sample time, Ts` — Sample time for discrete integration
`0.001` (default) | `scalar`

Integration sample time for discrete simulation, in s.

Dependencies

Setting **Simulation Type** to `Discrete` creates the **Sample Time, Ts** parameter.

`Port configuration` — Select port configuration
`Torque` (default) | `Speed`

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
`Torque`	`LdTrq`	`MtrSpd`
`Speed`	`Spd`	`MtrTrq`

Parameters

`Number of pole pairs, P` — Pole pairs
`2` (default) | `scalar`

Motor pole pairs, P.

`Stator resistance and leakage inductance, Zs` — Resistance and inductance
`[1.77 0.0139]` (default) | `vector`

Stator resistance, R_S, in ohms and leakage inductance, L_{ls}, in H.

Rotor resistance and leakage inductance, Zr — Resistance and inductance
[1.34 0.0121] (default) | vector

Rotor resistance, R_r, in ohms and leakage inductance, L_{lr}, in H.

Magnetizing inductance, Lm — Inductance
0.3687 (default) | scalar

Magnetizing inductance, L_m, in H.

Physical inertia, viscous damping, static friction, mechanical — Inertia, damping, friction
[0.001 0 0] (default) | vector

Mechanical properties of the rotor:

- Inertia, J, in kg·m^2
- Viscous damping, F, in N·m/(rad/s)
- Static friction, T_f, in N·m

Dependencies

To enable this parameter, select Torque for the **Port configuration**.

Initial Values

Initial mechanical position, theta_init — Angular position
0 (default) | scalar

Initial rotor angular position, θ_{m0}, in rad.

Initial mechanical speed, omega_init — Angular speed
0 (default) | scalar

Initial angular velocity of the rotor, ω_{m0}, in rad/s.

Dependencies

To enable this parameter, select Torque for the **Port configuration**.

References

[1] Mohan, Ned. *Advanced Electric Drives: Analysis, Control and Modeling Using Simulink*. Minneapolis, MN: MNPERE, 2001.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

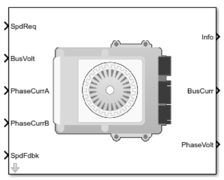
IM Controller | Flux-Based PMSM | Interior PMSM | Mapped Motor | Surface Mount PMSM

Introduced in R2017a

IM Controller

Internal torque-based, field-oriented controller for an induction motor with an optional outer-loop speed controller

Library: Powertrain Blockset / Propulsion / Electric Motor Controllers

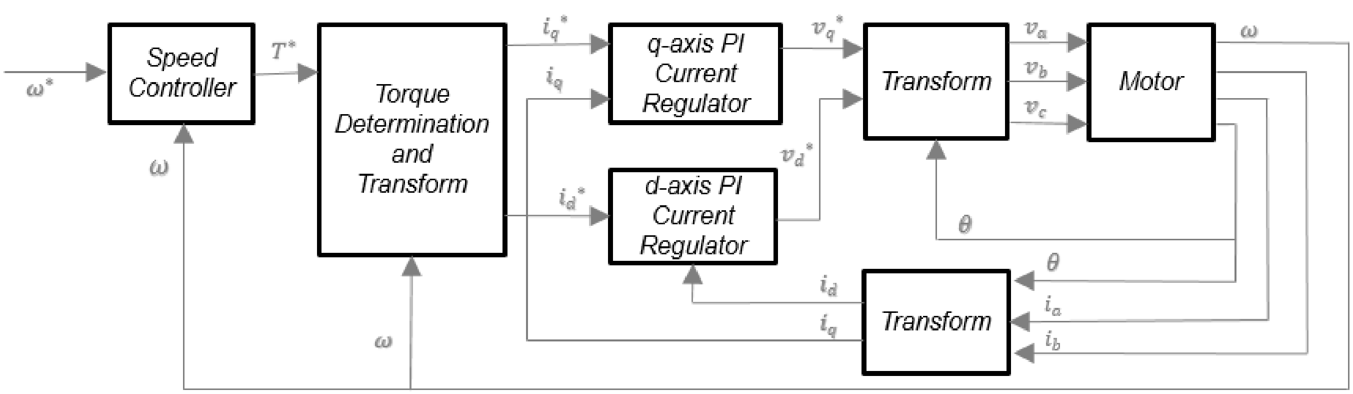


Description

The IM Controller block implements an internal torque-based, field-oriented controller for an induction motor (IM) with an optional outer-loop speed controller. The torque control implements a strategy to control the motor flux. You can specify either speed or torque control.

The IM Controller implements equations for speed control, torque determination, regulators, transforms, and motors.

The figure illustrates the information flow in the block.



The block implements equations that use these variables.

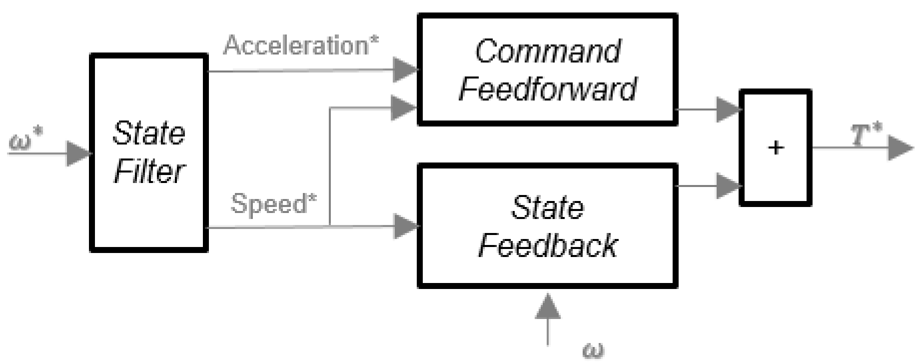
ω	Rotor speed
ω^*	Rotor speed command
T^*	Torque command
i_d	d-axis current
i^*_d	d-axis current command
i_q	q-axis current
i^*_q	q-axis current command

v_d,	d-axis voltage
v^*_d	d-axis voltage command
v_q	q-axis voltage
v^*_q	q-axis voltage command
v_a, v_b, v_c	Stator phase a, b, c voltages
i_a, i_b, i_c	Stator phase a, b, c currents

Speed Controller

To implement the speed controller, select the **Control Type** parameter `Speed Control`. If you select the **Control Type** parameter `Torque Control`, the block does not implement the speed controller.

The speed controller determines the torque command by implementing a state filter, and calculating the feedforward and feedback commands. If you do not implement the speed controller, input a torque command to the IM Controller block.



State Filter

The state filter is a low-pass filter that generates the acceleration command based on the speed command. On the **Speed Controller** tab:

- To make the speed-command lag time negligible, specify a **Bandwidth of the state filter** parameter.
- To calculate a **Speed regulation time constant, Ksf** gain based on the state filter bandwidth, select **Calculate Speed Regulator Gains**.

The discrete form of characteristic equation is given by:

$$z + K_{sf}T_{sm} - 1$$

The filter calculates the gain using this equation.

$$K_{sf} = \frac{1 - \exp\left(-T_{sm}2\pi EV_{sf}\right)}{T_{sm}}$$

The equation uses these variables.

EV_{sf}	Bandwidth of the speed command filter
T_{sm}	Motion controller sample time
K_{sf}	Speed regulator time constant

State Feedback

To generate the state feedback torque, the block uses the filtered speed error signal from the state filter. The feedback torque calculation also requires gains for speed regulator.

On the **Speed Controller** tab, select **Calculate Speed Regulator Gains** to compute:

- **Proportional gain, ba**
- **Angular gain, Ksa**
- **Rotational gain, Kisa**

For the gain calculations, the block uses the inertia from the **Physical inertia, viscous damping, static friction** parameter value on the **Motor Parameter** tab.

The gains for the state feedback are calculated using these equations.

Calculation	Equations
Discrete forms of characteristic equation	$z^3 + \frac{\left(-3J_p + T_s b_a + T_s^2 K_{sa} + T_s^3 K_{isa}\right)}{J_p} z^2 + \frac{\left(3J_p - 2T_s b_a - T_s^2 K_{sa}\right)}{J_p} z + \frac{-J_p + T_s b_a}{J_p}$ $(z - p_1)(z - p_2)(z - p_3) = z^3 + (p_1 + p_2 + p_3)z^2 + (p_1 p_2 + p_2 p_3 + p_1 3)z^2 - p_1 p_2 p_3$
Speed regulator proportional gain	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$
Speed regulator integral gain	$K_{sa} = \frac{J_p(p_1 p_2 + p_2 p_3 + p_3 p_1) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$
Speed regulator double integral gain	$K_{isa} = \frac{-J_p(p_1 + p_2 + p_3) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$

The equations use these variables.

P	Motor pole pairs
b_a	Speed regulator proportional gain
K_{sa}	Speed regulator integral gain
K_{isa}	Speed regulator double integral gain
J_p	Motor inertia
T_{sm}	Motion controller sample time

Command Feedforward

To generate the state feedforward torque, the block uses the filtered speed and acceleration from the state filter. Also, the feedforward torque calculation uses the inertia, viscous damping, and static friction. To achieve zero tracking error, the torque command is the sum of the feedforward and feedback torque commands.

Selecting **Calculate Speed Regulator Gains** on the **Speed Controller** tab updates the inertia, viscous damping, and static friction with the **Physical inertia, viscous damping, static friction** parameter values on the **Motor Parameter** tab.

The feedforward torque command uses this equation.

$$T_{cmd\_ff} = J_p\dot{\omega}_m + F_v\omega_m + F_s\frac{\omega_m}{|\omega_m|}$$

The equation uses these variables.

J_p	Motor inertia
T_{cmd_ff}	Torque command feedforward
F_s	Static friction torque constant
F_v	Viscous friction torque constant
F_s	Static friction torque constant
ω_m	Rotor mechanical speed

Torque Determination

The block uses a quadrature current to determine the base speed and the current commands. The motor ratings determine the rated electrical speed.

Calculation	Equations

Current commands	$i_{qref} = \frac{T_{cmd}}{i_{sq\_0} \cdot P \cdot \left(\frac{L^2{}_m}{L_r}\right)}$
	`If` $\lvert\omega_e\rvert \leq \omega_{rated}$
	$i_{dref} = i_{sd\_0}$
	`Else`
	$i_{dref} = \frac{i_{sd\_0} \cdot \omega_{rated}}{\lvert\omega_e\rvert}$
	`End`

Inductance	$L_r = L_{lr} + L_m$ $L_s = L_{ls} + L_m$

The equations use these variables.

i_{dref}	d-axis reference current
i_{qref}	q-axis reference current
i_{sd_0}	d-axis rated current
i_{sq_0}	q-axis rated current
ω_e	Rotor electrical speed
ω_{rated}	Rated electrical speed
L_{lr}	Rotor leaking inductance

L_r	Rotor winding inductance
L_{ls}	Stator leaking inductance
L_s	Stator winding inductance
L_m	Motor magnetizing inductance
P	Motor pole pairs
T_{cmd}	Commanded motor maximum torque

Current Regulators

The block regulates the current with an anti-windup feature. Classic proportional-integrator (PI) current regulators do not consider the d-axis and q-axis coupling or the back-electromagnetic force (EMF) coupling. As a result, transient performance deteriorates. To account for the coupling, the block implements the complex vector current regulator (CVCR) in the scalar format of the rotor reference frame. The CVCR decouples:

- d-axis and q-axis current cross-coupling
- Back-EMF cross-coupling

The current frequency response is a first-order system, with a bandwidth of $EV_{current}$.

The block implements these equations.

Calculation	Equations
Motor voltage, in the stator reference frame	$\sigma = 1 - \frac{L^2{}_m}{L_s L_r}$ $v_{sd} = R_s i_{sd} + \sigma L_s \frac{di_{sd}}{dt} + \frac{L_m}{L_r}\frac{d\lambda_{rd}}{dt} - P\omega_m \sigma L_s i_{sq}$ $v_{sq} = R_s i_{sq} + \sigma L_s \frac{di_{sq}}{dt} + \omega_d \frac{L_m}{L_r}\frac{d\lambda_{rd}}{dt} + P\omega_m \sigma L_s i_{sd}$
Current regulator gains	$\omega_b = 2\pi EV_{current}$ $K_p = \sigma L_d \omega_b$ $K_i = R_s \omega_b$
Transfer functions	$\frac{i_d}{i_{dref}} = \frac{\omega_b}{s + \omega_b}$ $\frac{i_q}{i_{qref}} = \frac{\omega_b}{s + \omega_b}$

The equations use these variables.

$EV_{current}$	Current regulator bandwidth
i_d	d-axis current
i_q	q-axis current
i_{sq}	Stator q-axis current
i_{sd}	Stator d-axis current
v_{sd}	Stator d-axis voltage

v_{sq}	Stator q-axis voltage
K_p	Current regulator d-axis gain
K_i	Current regulator integrator gain
L_s	Stator winding inductance
L_m	Motor magnetizing inductance
L_r	Rotor winding inductance
R_s	Stator phase winding resistance
λ_{rd}	Rotor d-axis magnetic flux
σ	Leakage factor
p	Motor pole pairs

Transforms

To calculate the voltages and currents in balanced three-phase (a, b) quantities, quadrature two-phase (α, β) quantities, and rotating (d, q) reference frames, the block uses the Clarke and Park Transforms.

In the transform equations.

$$\omega_e = P\omega_m$$

$$\frac{d\theta_e}{dt} = \omega_e$$

Transform	Description	Equations
Clarke	Converts balanced three-phase quantities (a, b) into balanced two-phase quadrature quantities (α, β).	$x_\alpha = \frac{2}{3}x_a - \frac{1}{3}x_b - \frac{1}{3}x_c$ $x_\beta = \frac{\sqrt{3}}{2}x_b - \frac{\sqrt{3}}{2}x_c$
Park	Converts balanced two-phase orthogonal stationary quantities (α, β) into an orthogonal rotating reference frame (d, q).	$x_d = x_\alpha\cos\theta_e + x_\beta\sin\theta_e$ $x_q = -x_\alpha\sin\theta_e + x_\beta\cos\theta_e$
Inverse Clarke	Converts balanced two-phase quadrature quantities (α, β) into balanced three-phase quantities (a, b).	$x_a = x_a$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$
Inverse Park	Converts an orthogonal rotating reference frame (d, q) into balanced two-phase orthogonal stationary quantities (α, β).	$x_\alpha = x_d\cos\theta_e - x_q\sin\theta_e$ $x_\beta = x_d\sin\theta_e + x_q\cos\theta_e$

The transforms use these variables.

ω_m	Rotor mechanical speed
P	Motor pole pairs
ω_e	Rotor electrical speed

Θ_e	Rotor electrical angle
x	Phase current or voltage

Motor

The block uses the phase currents and phase voltages to estimate the DC bus current. Positive current indicates battery discharge. Negative current indicates battery charge. The block uses these equations.

Load power	$Ld_{Pwr} = v_a \quad i_a + \quad v_b \quad i_b + \quad v_c \quad i_c$
Source power	$Src_{Pwr} = \quad Ld_{Pwr} + Pwr_{Loss}$
DC bus current	$i_{bus} = \quad \frac{Src_{Pwr}}{v_{bus}}$
Estimated rotor torque	$MtrTrq_{est} = P\lambda_{rd} i_{sq} \frac{L_m}{L_r}$
Power loss for single efficiency source to load	$Pwr_{Loss} = \frac{100 - Eff}{Eff} \cdot Ld_{Pwr}$
Power loss for single efficiency load to source	$Pwr_{Loss} = \frac{100 - Eff}{100} \cdot \lvert Ld_{Pwr} \rvert$
Power loss for tabulated efficiency	$Pwr_{Loss} = \quad f(\omega_m, MtrTrq_{est})$

The equations use these variables.

v_a, v_b, v_c	Stator phase a, b, c voltages
v_{bus}	Estimated DC bus voltage
i_a, i_b, i_c	Stator phase a, b, c currents
i_{bus}	Estimated DC bus current
Eff	Overall inverter efficiency
ω_m	Rotor mechanical speed
L_r	Rotor winding inductance
L_m	Motor magnetizing inductance
λ_{rd}	Rotor d-axis magnetic flux
i_{sq}	q-axis current
P	Motor pole pairs

Electrical Losses

To specify the electrical losses, on the **Electrical Losses** tab, for **Parameterize losses by**, select one of these options.

Setting	Block Implementation
`Single efficiency measurement`	Electrical loss calculated using a constant value for inverter efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of motor speeds and load torques.

Setting	Block Implementation
`Tabulated efficiency data`	Electrical loss calculated using inverter efficiency that is a function of motor speeds and load torques. • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

Ports

Input

SpdReq — Rotor mechanical speed command
`scalar`

Rotor mechanical speed command, ω^*_m, in rad/s.

Dependencies

To create this port, select `Speed Control` for the **Control Type** parameter.

`TrqCmd` — Torque command
`scalar`

Torque command, T^*, in N·m.

Dependencies

To create this port, select `Torque Control` for the **Control Type** parameter.

`BusVolt` — DC bus voltage
`scalar`

DC bus voltage v_{bus}, in V.

`PhaseCurrA` — Current
`scalar`

Stator current phase a, i_a, in A.

`PhaseCurrB` — Current
`scalar`

Stator current phase b, i_b, in A.

SpdFdbk — Rotor mechanical speed
scalar

Rotor mechanical speed, ω_m, in rad/s.

Output

Info — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
SrcPwr	Source power	W
LdPwr	Load power	W
PwrLoss	Power loss	W
MtrTrqEst	Estimated motor torque	N·m

BusCurr — Bus current
scalar

Estimated DC bus current, i_{bus}, in A.

PhaseVolt — Stator terminal voltages
array

Stator terminal voltages, V_a, V_b, and V_c, in V.

Parameters

Block Options

Control Type — Select control
Speed Control (default) | Torque Control

If you select `Torque Control`, the block does not implement the speed controller.

This table summarizes the port configurations.

Port Configuration	Creates Ports
Speed Control	SpdReq
Torque Control	TrqCmd

Motor

Stator resistance, Rs — Resistance
1.77 (default) | scalar

Stator phase winding resistance, R_s, in ohm.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Stator resistance, Rs	**D-axis rated current, Isd_0** **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Id and Iq Calculation**
	D and Q axis integral gain, Ki	**Current Controller**

`Stator leakage inductance, Lls` — Inductance
`0.0139` (default) | `scalar`

Stator leakage inductance, L_{ls}, in H.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Stator leakage inductance, Lls	**D-axis rated current, Isd_0** **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Id and Iq Calculation**
	D and Q axis proportional gain, Kp **D and Q axis integral gain, Ki**	**Current Controller**

`Rotor resistance, Rr` — Resistance
`1.34` (default) | `scalar`

Rotor resistance, R_r, in ohm.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Rotor resistance, Rr	**D-axis rated current, Isd_0** **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Id and Iq Calculation**

`Rotor leakage inductance, Llr` — Inductance
`0.0121` (default) | `scalar`

Rotor leakage inductance, L_{lr}, in H.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Rotor leakage inductance, Llr	D-axis rated current, Isd_0 Q-axis rated current, Isq_0 Torque at rated current, Tem	Id and Iq Calculation
	D and Q axis proportional gain, Kp	Current Controller

`Rotor magnetizing inductance, Lm` — Inductance
`0.3687` (default) | `scalar`

Rotor magnetizing inductance, L_m, in H.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Rotor leakage inductance, Llr	D-axis rated current, Isd_0 Q-axis rated current, Isq_0 Torque at rated current, Tem	Id and Iq Calculation
	D and Q axis proportional gain, Kp	Current Controller

`Number of pole pairs, PolePairs` — Poles
`2` (default) | `scalar`

Motor pole pairs, P.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Rotor leakage inductance, Llr	Torque at rated current, Tem	Id and Iq Calculation

`Physical inertia, viscous damping, static friction, Mechanical` — Mechanical properties of motor
`[0.025, 0, 0]` (default) | `vector`

Mechanical properties of the motor:

- Motor inertia, F_v, in kgm^2
- Viscous friction torque constant, F_v, in N·m/(rad/s)
- Static friction torque constant, F_s, in N·m

Dependencies

To enable this parameter, set the **Control Type** parameter to `Speed Control`.

For the gain calculations, the block uses the inertia from the **Physical inertia, viscous damping, static friction** parameter value that is on the **Motor Parameters** tab.

Parameter	Used to Derive	
	Parameter	Tab
Physical inertia, viscous damping, static friction, Mechanical	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa** **Inertia compensation, Jcomp** **Viscous damping compensation, Fv** **Static friction, Fs**	**Speed Controller**

Id and Iq Calculation

`Rated synchronous speed, Frate` — Motor frequency
`60` (default) | `scalar`

Motor-rated electrical frequency, F_{rate}, in Hz.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Rated synchronous speed, Frate	**D-axis rated current, Isd_0** **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Id and Iq Calculation**

`Rated line to line voltage RMS, Vrate` — Motor voltage
`460` (default) | `scalar`

Motor-rated line-to-line voltage, V_{rate}, in V.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Rated synchronous speed, Frate	**D-axis rated current, Isd_0** **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Id and Iq Calculation**

`Rated slip, Srate` — Motor slip speed

`0.0172` (default) | `scalar`

Motor-rated slip speed, S_{rate}, dimensionless.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Rated slip, Srate	**D-axis rated current, Isd_0** **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Id and Iq Calculation**

`Calculate Rated Stator Flux Current` — Derive parameters

button

Click to derive parameters.

Dependencies

On the **Id and Iq Calculation** tab, when you select **Calculate Rated Stator Flux Current**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Id and Iq Calculation tab	Dependency	
	Parameter	Tab
D-axis rated current, Isd_0 **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Rated synchronous speed, Frate** **Rated line to line voltage RMS, Vrate** **Rated slip, Srate**	**Id and Iq Calculation**

Derived Parameter on Id and Iq Calculation tab	Dependency	
	Parameter	Tab
	Stator resistance, Rs **Stator leakage inductance, Lls** **Rotor resistance, Rr** **Rotor leakage inductance, Llr** **Rotor magnetizing inductance, Lm**	**Motor Parameters**

`D-axis rated current, Isd_0` — Derived
`3.1004` (default) | `scalar`

Derived d-axis rated current, in A.

Dependencies

On the **Id and Iq Calculation** tab, when you select **Calculate Rated Stator Flux Current**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Id and Iq Calculation tab	Dependency	
	Parameter	Tab
D-axis rated current, Isd_0 **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Rated synchronous speed, Frate** **Rated line to line voltage RMS, Vrate** **Rated slip, Srate**	**Id and Iq Calculation**
	Stator resistance, Rs **Stator leakage inductance, Lls** **Rotor resistance, Rr** **Rotor leakage inductance, Llr** **Rotor magnetizing inductance, Lm**	**Motor Parameters**

`Q-axis rated current, Isq_0` — Derived
`5.7131` (default) | `scalar`

Derived q-axis rated current, in A.

Dependencies

On the **Id and Iq Calculation** tab, when you select **Calculate Rated Stator Flux Current**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Id and Iq Calculation tab	Dependency	
	Parameter	Tab
D-axis rated current, Isd_0 **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Rated synchronous speed, Frate** **Rated line to line voltage RMS, Vrate** **Rated slip, Srate**	**Id and Iq Calculation**
	Stator resistance, Rs **Stator leakage inductance, Lls** **Rotor resistance, Rr** **Rotor leakage inductance, Llr** **Rotor magnetizing inductance, Lm**	**Motor Parameters**

`Torque at rated current, Tem` — Derived

`12.6467` (default) | `scalar`

Torque at rated current, in N·m.

Dependencies

On the **Id and Iq Calculation** tab, when you select **Calculate Rated Stator Flux Current**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Id and Iq Calculation tab	Dependency	
	Parameter	Tab
D-axis rated current, Isd_0 **Q-axis rated current, Isq_0** **Torque at rated current, Tem**	**Rated synchronous speed, Frate** **Rated line to line voltage RMS, Vrate** **Rated slip, Srate**	**Id and Iq Calculation**

Derived Parameter on Id and Iq Calculation tab	Dependency	
	Parameter	Tab
	Stator resistance, Rs **Stator leakage inductance, Lls** **Rotor resistance, Rr** **Rotor leakage inductance, Llr** **Rotor magnetizing inductance, Lm**	**Motor Parameters**

Current Controller

`Bandwidth of the current regulator, EV_current` — Bandwidth
`200` (default) | `scalar`

Current regulator bandwidth, in Hz.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the current regulator, EV_current	**D and Q axis integral gain, Ki** **D and Q axis proportional gain, Kp**	**Current Controller**

`Sample time for the torque control, Tst` — Time
`5e-5` (default) | `scalar`

Torque control sample time, in s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Sample time for the torque control, Tst	**Speed regulation time constant, Ksf**	**Speed Controller**

`Calculate Current Regulator Gains` — Derive parameters
button

Click to derive parameters.

Dependencies

On the **Current Controller** tab, when you select **Calculate Current Regulator Gains**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Current Controller tab	Dependency	
	Parameter	Tab
D and Q axis proportional gain, Kp **D and Q axis integral gain, Ki**	**Bandwidth of the current regulator, EV_current**	**Current Controller**
	Stator resistance, Rs **Stator leakage inductance, Lls** **Rotor resistance, Rr** **Rotor leakage inductance, Llr** **Rotor magnetizing inductance, Lm**	**Motor Parameters**

`D and Q axis proportional gain, Kp` — Derived

`32.1894` (default) | `scalar`

Derived proportional gain, in V/A.

Dependencies

On the **Current Controller** tab, when you select **Calculate Current Regulator Gains**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Current Controller tab	Dependency	
	Parameter	Tab
D and Q axis proportional gain, Kp **D and Q axis integral gain, Ki**	**Bandwidth of the current regulator, EV_current**	**Current Controller**
	Stator resistance, Rs **Stator leakage inductance, Lls** **Rotor resistance, Rr** **Rotor leakage inductance, Llr** **Rotor magnetizing inductance, Lm**	**Motor Parameters**

`D and Q axis integral gain, Ki` — Derived

`2224.2476` (default) | `scalar`

Derived integral gain, in V/A*s.

Dependencies

On the **Current Controller** tab, when you select **Calculate Current Regulator Gains**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Current Controller tab	Dependency	
	Parameter	Tab
D and Q axis proportional gain, Kp **D and Q axis integral gain, Ki**	**Bandwidth of the current regulator, EV_current**	**Current Controller**
	Stator resistance, Rs **Stator leakage inductance, Lls** **Rotor resistance, Rr** **Rotor leakage inductance, Llr** **Rotor magnetizing inductance, Lm**	**Motor Parameters**

Speed Controller

`Bandwidth of the motion controller, EV_motion` — Bandwidth

`[20, 4, 0.8]` (default) | `vector`

Motion controller bandwidth, in Hz. Set the first element of the vector to the desired cutoff frequency. Set the second and third elements of the vector to the higher-order cut off frequencies. You can set the value of the next element to `1/5` the value of the previous element. For example, if the desired cutoff frequency is `20` Hz, specify `[20 4 0.8]`.

Dependencies

The parameter is enabled when the **Control Type** parameter is set to `Speed Control`.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the motion controller, EV_motion	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa**	**Speed Controller**

`Bandwidth of the state filter, EV_sf` — Bandwidth

`200` (default) | `scalar`

State filter bandwidth, in Hz.

Dependencies

The parameter is enabled when the **Control Type** parameter is set to `Speed Control`.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the state filter, EV_sf	**Speed regulation time constant, Ksf**	**Speed Controller**

`Calculate Speed Regulator Gains` — Derive parameters
button

Click to derive parameters.

Dependencies

On the **Speed Controller** tab, when you select **Calculate Speed Regulator Gains**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Speed Controller tab		Depends On	
		Parameter	Tab
Proportional gain, ba	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$	**Bandwidth of the motion controller, EV_motion** **Bandwidth of the state filter, EV_sf**	**Speed Controller**
Angular gain, Ksa	$K_{sa} = \frac{J_p(p_1 p_2 + p_2 p_3 + p_3 p_1) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$	**Sample time for the torque control, Tst**	**Current Controller**
Rotational gain, Kisa	$K_{isa} = \frac{-J_p(p_1 + p_2 + p_3) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
Speed regulation time constant, Ksf	$K_{sf} = \frac{1 - \exp(-T_{sm} 2\pi EV_{sf})}{T_{sm}}$		
Inertia compensation, Jcomp	$J_{comp} = J_p$	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
Viscous damping compensation, Fv	F_v		
Static friction, Fs	F_s		

The equations use these variables.

P	Motor pole pairs
b_a	Speed regulator proportional gain
K_{sa}	Speed regulator integral gain
K_{isa}	Speed regulator double integral gain
K_{sf}	Speed regulator time constant
J_p	Motor inertia
EV_{sf}	State filter bandwidth
EV_{motion}	Motion controller bandwidth

Proportional gain, ba — Derived

3.7477 (default) | scalar

Derived proportional gain, in N·m/(rad/s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Proportional gain, ba	Physical inertia, viscous damping, static friction, Mechanical	Motor Parameters
	Bandwidth of the motion controller, EV_motion	Speed Controller

Angular gain, Ksa — Derived

94.0877 (default) | scalar

Derived angular gain, in N·m/rad.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Angular gain, Ksa	Physical inertia, viscous damping, static friction, Mechanical	Motor Parameters
	Bandwidth of the motion controller, EV_motion	Speed Controller

Rotational gain, Kisa — Derived

381.7822 (default) | scalar

Derived rotational gain, in N·m/(rad*s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Rotational gain, Kisa	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
	Bandwidth of the motion controller, EV_motion	**Speed Controller**

`Speed regulation time constant, Ksf` — Derived

`1217.9727` (default) | `scalar`

Derived speed regulation time constant, in 1/s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Speed regulation time constant, Ksf	**Sample time for the torque control, Tst**	**Current Controller**
	Bandwidth of the state filter, EV_sf	**Speed Controller**

`Inertia compensation, Jcomp` — Derived

`0.025` (default) | `scalar`

Derived inertia compensation, in kg·m^2.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Inertia compensation, Jcomp	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

`Viscous damping compensation, Fv` — Derived

`0` (default) | `scalar`

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Viscous damping compensation, Fv	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

`Static friction, Fs` — Derived

`0` (default) | `scalar`

Derived static friction, in N·m/(rad/s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Static friction, Fs	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

Electrical Losses

`Parameterize losses by` — Select type

`Single efficiency measurement` (default) | `Tabulated loss data` | `Tabulated efficiency data`

Setting	Block Implementation
`Single efficiency measurement`	Electrical loss calculated using a constant value for inverter efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of motor speeds and load torques.
`Tabulated efficiency data`	Electrical loss calculated using inverter efficiency that is a function of motor speeds and load torques. • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.

- You can account for fixed losses that are still present for zero speed or torque.

Overall inverter efficiency, eff — Constant
98 (default) | scalar

Overall inverter efficiency, *Eff*, in %.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

Vector of speeds (w) for tabulated loss, w_loss_bp — Breakpoints
[0 200 400 600 800 1000] (default) | 1-by-M vector

Speed breakpoints for lookup table when calculating losses, in rad/s.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

Vector of torques (T) for tabulated loss, T_loss_bp — Breakpoints
[0 25 50 75 100] (default) | 1-by-N vector

Torque breakpoints for lookup table when calculating losses, in N·m.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

Corresponding losses, losses_table — Table
[100 100 100 100 100;100 150 200 250 300;100 200 300 400 500;100 250 400 550 700;100 300 500 700 900;100 350 600 850 1100] (default) | M-by-N array

Array of values for electrical losses as a function of `M` speeds and `N` torques, in W. Each value specifies the losses for a specific combination of speed and torque. The matrix size must match the dimensions defined by the speed and torque vectors.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

Vector of speeds (w) for tabulated efficiency, w_eff_bp — Breakpoints
[200 400 600 800 1000] (default) | 1-by-M vector

Speed breakpoints for lookup table when calculating efficiency, in rad/s.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

Vector of torques (T) for tabulated efficiency, T_eff_bp — Breakpoints
[25 50 75 100] (default) | 1-by-N vector

Torque breakpoints for lookup table when calculating efficiency, in N·m.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

Corresponding efficiency, efficiency_table — Table
[96.2 98.1 98.7 99;98.1 99 99.4 99.5;98.7 99.4 99.6 99.7;99 99.5 99.7 99.8;99.2 99.6 99.7 99.8] (default) | M-by-N array

Array of efficiency as a function of M speeds and N torque, in %. Each value specifies the efficiency for a specific combination of speed and torque. The matrix size must match the dimensions defined by the speed and torque vectors.

The block ignores efficiency values for zero speed or zero torque. Losses are zero when either torque or speed is zero. The block uses linear interpolation.

To get the desired level of accuracy for lower power conditions, you can provide tabulated data for low speeds and low torques.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

References

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[3] Muyang Li. *Flux-Weakening Control for Permanent-Magnet Synchronous Motors Based on Z-Source Inverters*. Master's Thesis, Marquette University, e-Publications@Marquette, Fall 2014.

[4] Briz, Fernando, Michael W. Degner, and Robert D. Lorenz. "Analysis and design of current regulators using complex vectors." *IEEE Transactions on Industry Applications*, Vol. 36, Issue 3, May/June 2000, pp. 817–825.

[5] Briz, Fernando, et al. "Current and flux regulation in field-weakening operation [of induction motors]."*IEEE Transactions on Industry Applications*, Vol. 37, Issue 1, Jan/Feb 2001, pp. 42–50.

[6] Mohan, Ned. *Advanced Electric Drives: Analysis, Control and Modeling Using Simulink*. Minneapolis, MN: MNPERE, 2001.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

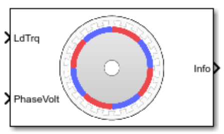
Induction Motor | Flux-Based PM Controller | Interior PM Controller | Surface Mount PM Controller

Introduced in R2017a

Surface Mount PMSM

Three-phase exterior permanent magnet synchronous motor with sinusoidal back electromotive force

Library: Powertrain Blockset / Propulsion / Electric Motors and Inverters
Motor Control Blockset / Electrical Systems / Motors



Description

The Surface Mount PMSM block implements a three-phase exterior permanent magnet synchronous motor (PMSM) with sinusoidal back electromotive force. The block uses the three-phase input voltages to regulate the individual phase currents, allowing control of the motor torque or speed.

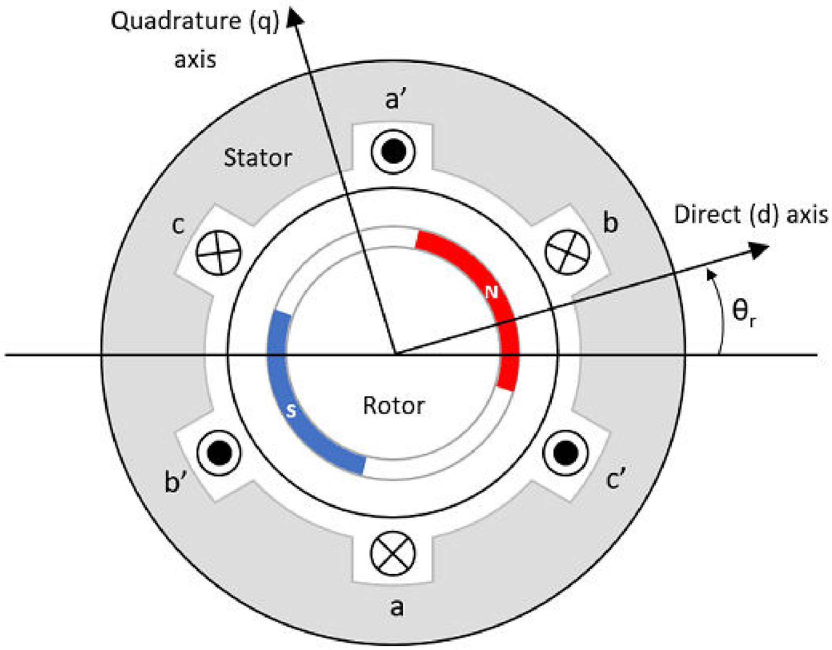
By default, the block sets the **Simulation type** parameter to `Continuous` to use a continuous sample time during simulation. If you want to generate code for fixed-step double- and single-precision targets, considering setting the parameter to `Discrete`. Then specify a **Sample Time, Ts** parameter.

On the **Parameters** tab, if you select `Back-emf` or `Torque constant`, the block implements one of these equations to calculate the permanent flux linkage constant.

Setting	Equation
`Back-emf`	$\lambda_{pm} = \frac{1}{\sqrt{3}} \cdot \frac{K_e}{1000P} \cdot \frac{60}{2\pi}$
`Torque constant`	$\lambda_{pm} = \frac{2}{3} \cdot \frac{K_t}{P}$

Motor Construction

This figure shows the motor construction with a single pole pair on the motor.



The motor magnetic field due to the permanent magnets creates a sinusoidal rate of change of flux with motor angle.

For the axes convention, the a-phase and permanent magnet fluxes are aligned when motor angle θ_r is zero.

Three-Phase Sinusoidal Model Electrical System

The block implements these equations, expressed in the motor flux reference frame (dq frame). All quantities in the motor reference frame are referred to the stator.

$$\omega_e = P\omega_m$$

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}P\omega_m i_q$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}P\omega_m i_d - \frac{\lambda_{pm}P\omega_m}{L_q}$$

$$T_e = 1.5P[\lambda_{pm}i_q + (L_d - L_q)i_d i_q]$$

The L_q and L_d inductances represent the relation between the phase inductance and the motor position due to the saliency of the motor magnets. For the surface mount PMSM, $L_d = L_q$.

The equations use these variables.

L_q, L_d	q- and d-axis inductances (H)
R	Resistance of the stator windings (ohm)
i_q, i_d	q- and d-axis currents (A)
v_q, v_d	q- and d-axis voltages (V)

ω_m	Angular mechanical velocity of the motor (rad/s)
ω_e	Angular electrical velocity of the motor (rad/s)
λ_{pm}	Permanent magnet flux linkage (Wb)
K_e	Back electromotive force (EMF) (Vpk_LL/krpm, where Vpk_LL is the peak voltage line-to-line measurement)
K_t	Torque constant (N·m/A)
P	Number of pole pairs
T_e	Electromagnetic torque (Nm)
Θ_e	Electrical angle (rad)

Mechanical System

The motor angular velocity is given by:

$$\frac{d}{dt}\omega_m = \frac{1}{J}\left(T_e - T_f - F\omega_m - T_m\right)$$

$$\frac{d\theta_m}{dt} = \omega_m$$

The equations use these variables.

J	Combined inertia of motor and load (kgm^2)
F	Combined viscous friction of motor and load (N·m/(rad/s))
θ_m	Motor mechanical angular position (rad)
T_m	Motor shaft torque (Nm)
T_e	Electromagnetic torque (Nm)
T_f	Motor shaft static friction torque (Nm)
ω_m	Angular mechanical velocity of the motor (rad/s)

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrMtr`	Mechanical power	P_{mot}	$P_{mot} = -\omega_m T_e$
		`PwrBus`	Electrical power	P_{bus}	$P_{bus} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred	`PwrElecLoss`	Resistive power loss	P_{elec}	$P_{elec} = -\frac{3}{2}(R_s i_{sd}^2 + R_s i_{sq}^2)$

Bus Signal			Description	Variable	Equations
	• Positive signals indicate an input • Negative signals indicate a loss	PwrMechLoss	Mechanical power loss	P_{mech}	When **Port Configuration** is set to `Torque`: $P_{mech} = -\left(\omega_m^2 F + \lvert\omega_m\rvert T_f\right)$ When **Port Configuration** is set to `Speed`: $P_{mech} = 0$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrMtrStored	Stored motor power	P_{str}	$P_{str} = P_{bus} + P_{mot} + P_{elec} + P_{mech}$

The equations use these variables.

R_s	Stator resistance (ohm)
i_a, i_b, i_c	Stator phase a, b, and c current (A)
i_{sq}, i_{sd}	Stator q- and d-axis currents (A)
v_{an}, v_{bn}, v_{cn}	Stator phase a, b, and c voltage (V)
ω_m	Angular mechanical velocity of the motor (rad/s)
F	Combined motor and load viscous damping N·m/(rad/s)
T_e	Electromagnetic torque (Nm)
T_f	Combined motor and load friction torque (Nm)

Ports

Input

`LdTrq` — Load torque on motor
`scalar`

Load torque on the motor shaft, T_m, in N·m.

Dependencies

To create this port, select `Torque` for the **Port Configuration** parameter.

Spd — Motor shaft speed
`scalar`

Angular velocity of the motor, ω_m, in rad/s.

Dependencies

To create this port, select `Speed` for the **Port Configuration** parameter.

`PhaseVolt` — Stator terminal voltages

1-by-3 array

Stator terminal voltages, V_a, V_b, and V_c, in V.

Output

`Info` — Bus signal

bus

The bus signal contains these block calculations.

Signal			Description	Variable	Units
`IaStator`			Stator phase current A	i_a	A
`IbStator`			Stator phase current B	i_b	A
`IcStator`			Stator phase current C	i_c	A
`IdSync`			Direct axis current	i_d	A
`IqSync`			Quadrature axis current	i_q	A
`VdSync`			Direct axis voltage	v_d	V
`VqSync`			Quadrature axis voltage	v_q	V
`MtrSpd`			Angular mechanical velocity of the motor	ω_m	rad/s
`MtrPos`			Motor mechanical angular position	θ_m	rad
`MtrTrq`			Electromagnetic torque	T_e	N·m
`PwrInfo`	`PwrTrnsfrd`	`PwrMtr`	Mechanical power	P_{mot}	W
		`PwrBus`	Electrical power	P_{bus}	W
	`PwrNotTrnsfrd`	`PwrElecLoss`	Resistive power loss	P_{elec}	W
		`PwrMechLoss`	Mechanical power loss	P_{mech}	W
	`PwrStored`	`PwrMtrStored`	Stored motor power	P_{str}	W

`PhaseCurr` — Phase a, b, c current

1-by-3 array

Phase a, b, c current, i_a, i_b, and i_c, in A.

`MtrTrq` — Motor torque

`scalar`

Motor torque, T_{mtr}, in N·m.

Dependencies

To create this port, select `Speed` for the **Mechanical input configuration** parameter.

`MtrSpd` — Motor speed
`scalar`

Angular speed of the motor, ω_{mtr}, in rad/s.

Dependencies

To create this port, select `Torque` for the **Mechanical input configuration** parameter.

Parameters

Block Options

`Mechanical input configuration` — Select port configuration
`Torque` (default) | `Speed`

This table summarizes the port configurations.

Port Configuration	Creates Input Port	Creates Output Port
`Torque`	`LdTrq`	`MtrSpd`
`Speed`	`Spd`	`MtrTrq`

`Simulation type` — Select simulation type
`Continuous` (default) | `Discrete`

By default, the block uses a continuous sample time during simulation. If you want to generate code for single-precision targets, considering setting the parameter to `Discrete`.

Dependencies

Setting **Simulation type** to `Discrete` creates the **Sample Time, Ts** parameter.

`Sample Time (Ts)` — Sample time for discrete integration
`scalar`

Integration sample time for discrete simulation, in s.

Dependencies

Setting **Simulation type** to `Discrete` creates the **Sample Time, Ts** parameter.

Parameters

`Number of pole pairs (P)` — Pole pairs
`scalar`

Motor pole pairs, P.

`Stator phase resistance per phase (Rs)` — Resistance
`scalar`

Stator phase resistance per phase, R_s, in ohm.

`Stator d-axis inductance (Ldq_)` — Inductance
`scalar`

Stator inductance, L_{dq}, in H.

`Permanent flux linkage constant (lambda_pm)` — Flux
`scalar`

Permanent flux linkage constant, λ_{pm}, in Wb.

`Back-emf constant (Ke)` — Back electromotive force
`scalar`

Back electromotive force, EMF, K_e, in peak Vpk_LL/krpm. Vpk_LL is the peak voltage line-to-line measurement.

To calculate the permanent flux linkage constant, the block implements this equation.

$$\lambda_{pm} = \frac{1}{\sqrt{3}} \cdot \frac{K_e}{1000P} \cdot \frac{60}{2\pi}$$

`Torque constant (Kt)` — Torque constant
`scalar`

Torque constant, K_t, in N·m/A.

To calculate the permanent flux linkage constant, the block implements this equation.

$$\lambda_{pm} = \frac{2}{3} \cdot \frac{K_t}{P}$$

`Physical inertia, viscous damping, and static friction (mechanical)` — Inertia, damping, friction
`vector`

Mechanical properties of the motor:

- Inertia, J, in kg.m^2
- Viscous damping, F, in N·m/(rad/s)
- Static friction, T_f, in N·m

Dependencies

To enable this parameter, select the `Torque` configuration parameter.

Initial Values

`Initial d-axis and q-axis current (idq0)` — Current
`vector`

Initial q- and d-axis currents, i_q, i_d, in A.

`Initial mechanical position (theta_init)` — Angle
`scalar`

Initial motor angular position, θ_{m0}, in rad.

Initial mechanical speed (omega_init) — Speed
scalar

Initial angular velocity of the motor, ω_{m0}, in rad/s.

Dependencies

To enable this parameter, select the Torque configuration parameter.

References

[1] Kundur, P. *Power System Stability and Control.* New York, NY: McGraw Hill, 1993.

[2] Anderson, P. M. *Analysis of Faulted Power Systems.* Hoboken, NJ: Wiley-IEEE Press, 1995.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

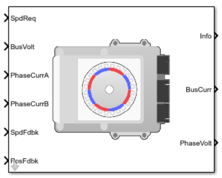
Surface Mount PM Controller | Flux-Based PMSM | Induction Motor | Interior PMSM | Mapped Motor

Introduced in R2017a

Surface Mount PM Controller

Torque-based, field-oriented controller for a surface mount permanent magnet synchronous motor

Library: Powertrain Blockset / Propulsion / Electric Motors and Inverters
Motor Control Blockset / Electrical Systems / Motors

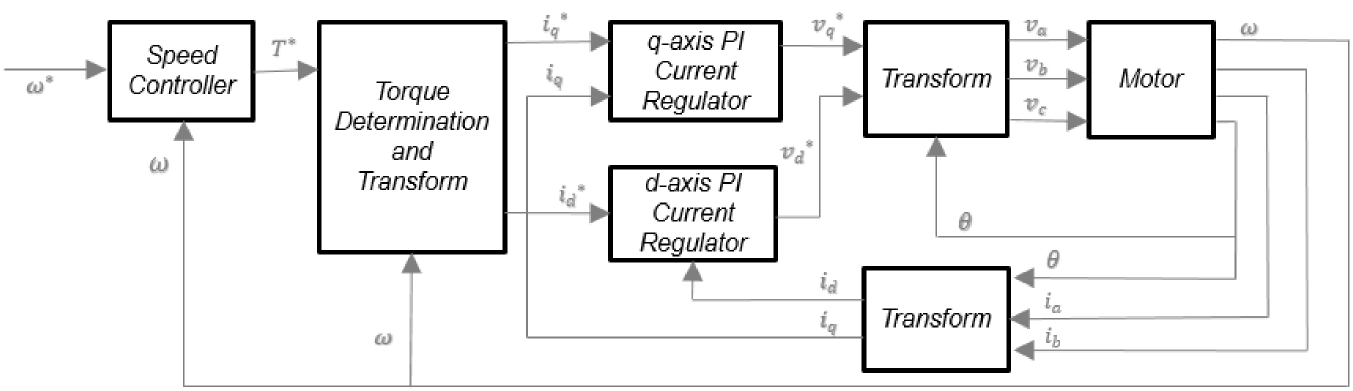


Description

The Surface Mount PM Controller block implements a torque-based, field-oriented controller for a surface mount permanent magnet synchronous motor (PMSM) with an optional outer-loop speed controller. The torque control utilizes quadrature current and does not weaken the magnetic flux. You can specify either speed or torque control.

The Surface Mount PM Controller implements equations for speed control, torque determination, regulators, transforms, and motors.

The figure illustrates the information flow in the block.



The block implements equations that use these variables.

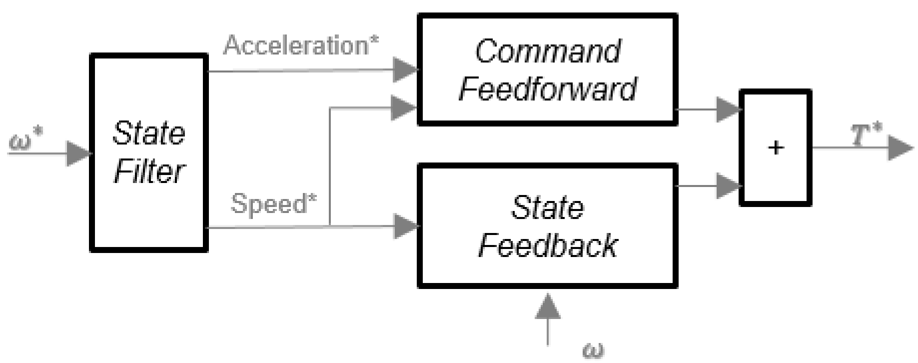
ω	Rotor speed
ω*	Rotor speed command
T*	Torque command
i_d	d-axis current
$i*_d$	d-axis current command
i_q	q-axis current
$i*_q$	q-axis current command

v_d,	d-axis voltage
v^*_d	d-axis voltage command
v_q	q-axis voltage
v^*_q	q-axis voltage command
v_a, v_b, v_c	Stator phase a, b, c voltages
i_a, i_b, i_c	Stator phase a, b, c currents

Speed Controller

To implement the speed controller, select the **Control Type** parameter `Speed Control`. If you select the **Control Type** parameter `Torque Control`, the block does not implement the speed controller.

The speed controller determines the torque command by implementing a state filter, and calculating the feedforward and feedback commands. If you do not implement the speed controller, input a torque command to the Surface Mount PM Controller block.



State Filter

The state filter is a low-pass filter that generates the acceleration command based on the speed command. On the **Speed Controller** tab:

- To make the speed-command lag time negligible, specify a **Bandwidth of the state filter** parameter.
- To calculate a **Speed regulation time constant, Ksf** gain based on the state filter bandwidth, select **Calculate Speed Regulator Gains**.

The discrete form of characteristic equation is given by:

$$z + K_{sf}T_{sm} - 1$$

The filter calculates the gain using this equation.

$$K_{sf} = \frac{1 - \exp\left(-T_{sm}2\pi EV_{sf}\right)}{T_{sm}}$$

The equations use these variables.

EV_{sf}	Bandwidth of the speed command filter
T_{sm}	Motion controller sample time
K_{sf}	Speed regulator time constant

State Feedback

To generate the state feedback torque, the block uses the filtered speed error signal from the state filter. The feedback torque calculation also requires gains for speed regulator.

On the **Speed Controller** tab, select **Calculate Speed Regulator Gains** to calculate:

- **Proportional gain, ba**
- **Angular gain, Ksa**
- **Rotational gain, Kisa**

For the gain calculations, the block uses the inertia from the **Physical inertia, viscous damping, static friction** parameter value on the **Motor Parameters** tab.

The gains for the state feedback are calculated using these equations.

Calculation	Equations
Discrete forms of characteristic equation	$z^3 + \frac{\left(-3J_p + T_s b_a + T_s^2 K_{sa} + T_s^3 K_{isa}\right)}{J_p} z^2 + \frac{\left(3J_p - 2T_s b_a - T_s^2 K_{sa}\right)}{J_p} z + \frac{-J_p + T_s b_a}{J_p}$ $(z - p_1)(z - p_2)(z - p_3) = z^3 + (p_1 + p_2 + p_3)z^2 + (p_1 p_2 + p_2 p_3 + p_1 3)z^2 - p_1 p_2 p_3$
Speed regulator proportional gain	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$
Speed regulator integral gain	$K_{sa} = \frac{J_p(p_1 p_2 + p_2 p_3 + p_3 p_1) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$
Speed regulator double integral gain	$K_{isa} = \frac{-J_p(p_1 + p_2 + p_3) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$

The equations use these variables.

P	Motor pole pairs
b_a	Speed regulator proportional gain
K_{sa}	Speed regulator integral gain
K_{isa}	Speed regulator double integral gain
J_p	Motor inertia
T_{sm}	Motion controller sample time

Command Feedforward

To generate the state feedforward torque, the block uses the filtered speed and acceleration from the state filter. Also, the feedforward torque calculation uses the inertia, viscous damping, and static friction. To achieve zero tracking error, the torque command is the sum of the feedforward and feedback torque commands.

Selecting **Calculate Speed Regulator Gains** on the **Speed Controller** tab updates the inertia, viscous damping, and static friction with the **Physical inertia, viscous damping, static friction** parameter values on the **Motor Parameters** tab.

The feedforward torque command uses this equation.

$$T_{cmd\_ff} = J_p\dot{\omega}_m + F_v\omega_m + F_s\frac{\omega_m}{|\omega_m|}$$

The equation uses these variables.

J_p	Motor inertia
T_{cmd_ff}	Torque command feedforward
F_s	Static friction torque constant
F_v	Viscous friction torque constant
F_s	Static friction torque constant
ω_m	Rotor speed

Torque Determination

The block uses a quadrature current to determine the base speed and the current commands. The available bus voltage determines the base speed. The direct (d) and quadrature (q) permanent magnet (PM) determines the induced voltage.

Calculation	Equations
Motor maximum torque	$T_{max} = \frac{3}{2}P\left(\lambda_{pm}i_q + \left(L_d - L_q\right)i_d i_q\right)$
Maximum q-axis phase current	$i_{q\_max} = \frac{T_{cmd}}{\frac{3}{2}P\lambda_{pm}}$
Electrical base speed	$\omega_{base} = \frac{v_{max}}{\sqrt{\left(L_q i_q\right)^2 + \left(\lambda_{pm}\right)^2}}$
d-axis voltage	$v_d = -\omega_e L_q i_{q\_max}$
q-axis voltage	$v_q = \omega_e\lambda_{pm}$
Maximum phase current	$i_{max} = \left\|i_{q\_max}\right\|$
Maximum voltage	$v_{max} = \frac{v_{bus}}{\sqrt{3}}$

Calculation	Equations

Current command	$i_{dref} = 0$
	$i_{q\_tmp} = \min(i_{q\_max}, \frac{T_{cmd}}{\frac{3}{2}P\lambda_{pm}})$
	If $\lvert\omega_e\rvert \leq \omega_{base}$
	    $i_{qref} = i_{q\_tmp}$
	Else
	    $i_{qfw} = sqrt(\min(0, \frac{1}{L_q}((\frac{v_{max}}{\omega_e})^2 - (\lambda_{pm})^2))$
	    If $i_{q\_tmp} < i_{qfw}$
	        $i_{qref} = i_{q\_tmp}$
	    Else
	        $i_{qref} = i_{qfw}$
	    End
	End

The equations use these variables.

i_{max}	Maximum phase current
i_d	d-axis current
i_q	q-axis current
i_{dref}	d-axis reference current
i_{qref}	q-axis reference current
i_{q_max}	Maximum q-axis phase current
ω_e	Rotor electrical speed
λ_{pm}	Permanent magnet flux linkage
v_d	d-axis voltage
v_q	q-axis voltage
v_{max}	Maximum line to neutral voltage
v_{bus}	DC bus voltage
L_d	d-axis winding inductance
L_q	q-axis winding inductance
P	Motor pole pairs
T_{max}	Motor maximum torque
T_{cmd}	Commanded motor maximum torque

Current Regulators

The block regulates the current with an anti-windup feature. Classic proportional-integrator (PI) current regulators do not consider the d-axis and q-axis coupling or the back-electromagnetic force (EMF) coupling. As a result, transient performance deteriorates. To account for the coupling, the block implements the complex vector current regulator (CVCR) in the scalar format of the rotor reference frame. The CVCR decouples:

- d-axis and q-axis current cross-coupling

- back-EMF cross-coupling

The current frequency response is a first-order system, with a bandwidth of $EV_{current}$.

The block implements these equations.

Calculation	Equations
Motor voltage, in the rotor reference frame	$L_d \frac{di_d}{dt} = v_d - R_s i_d + p\omega_m L_q i_q$ $L_q \frac{di_q}{dt} = v_q - R_s i_q - p\omega_m L_d i_d - p\omega_m \lambda_{pm}$
Current regulator gains	$\omega_b = 2\pi EV_{current}$ $K_{p\_d} = L_d \omega_b$ $K_{p\_q} = L_q \omega_b$ $K_i = R_s \omega_b$
Transfer functions	$\frac{i_d}{i_{dref}} = \frac{\omega_b}{s + \omega_b}$ $\frac{i_q}{i_{qref}} = \frac{\omega_b}{s + \omega_b}$

The equations use these variables.

$EV_{current}$	Current regulator bandwidth
i_d	d-axis current
i_q	q-axis current
K_{p_d}	Current regulator d-axis gain
K_{p_q}	Current regulator q-axis gain
K_i	Current regulator integrator gain
L_d	d-axis winding inductance
L_q	q-axis winding inductance
R_s	Stator phase winding resistance
ω_m	Rotor speed
v_d	d-axis voltage
v_q	q-axis voltage
λ_{pm}	Permanent magnet flux linkage
P	Motor pole pairs

Transforms

To calculate the voltages and currents in balanced three-phase (a, b) quantities, quadrature two-phase (α, β) quantities, and rotating (d, q) reference frames, the block uses the Clarke and Park Transforms.

In the transform equations.

$$\omega_e = P\omega_m$$

$$\frac{d\theta_e}{dt} = \omega_e$$

Transform	Description	Equations
Clarke	Converts balanced three-phase quantities (a, b) into balanced two-phase quadrature quantities (α, β).	$x_\alpha = \frac{2}{3}x_a - \frac{1}{3}x_b - \frac{1}{3}x_c$ $x_\beta = \frac{\sqrt{3}}{2}x_b - \frac{\sqrt{3}}{2}x_c$
Park	Converts balanced two-phase orthogonal stationary quantities (α, β) into an orthogonal rotating reference frame (d, q).	$x_d = x_\alpha \cos\theta_e + x_\beta \sin\theta_e$ $x_q = -x_\alpha \sin\theta_e + x_\beta \cos\theta_e$
Inverse Clarke	Converts balanced two-phase quadrature quantities (α, β) into balanced three-phase quantities (a, b).	$x_a = x_a$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$
Inverse Park	Converts an orthogonal rotating reference frame (d, q) into balanced two-phase orthogonal stationary quantities (α, β).	$x_\alpha = x_d \cos\theta_e - x_q \sin\theta_e$ $x_\beta = x_d \sin\theta_e + x_q \cos\theta_e$

The transforms use these variables.

ω_m	Rotor speed
P	Motor pole pairs
ω_e	Rotor electrical speed
Θ_e	Rotor electrical angle
x	Phase current or voltage

Motor

The block uses the phase currents and phase voltages to estimate the DC bus current. Positive current indicates battery discharge. Negative current indicates battery charge. The block uses these equations.

Load power	$Ld_{Pwr} = v_a i_a + v_b i_b + v_c i_c$
Source power	$Src_{Pwr} = Ld_{Pwr} + Pwr_{Loss}$
DC bus current	$i_{bus} = \frac{Src_{Pwr}}{v_{bus}}$
Estimated rotor torque	$MtrTrq_{est} = 1.5P[\lambda i_q + (L_d - L_q)i_d i_q]$
Power loss for single efficiency source to load	$Pwr_{Loss} = \frac{100 - Eff}{Eff} \cdot Ld_{Pwr}$
Power loss for single efficiency load to source	$Pwr_{Loss} = \frac{100 - Eff}{100} \cdot \lvert Ld_{Pwr} \rvert$

Power loss for tabulated efficiency	$Pwr_{Loss} = f(\omega_m, MtrTrq_{est})$

The equations use these variables.

v_a, v_b, v_c	Stator phase a, b, c voltages
v_{bus}	Estimated DC bus voltage
i_a, i_b, i_c	Stator phase a, b, c currents
i_{bus}	Estimated DC bus current
Eff	Overall inverter efficiency
ω_m	Rotor mechanical speed
L_q	q-axis winding inductance
L_d	d-axis winding inductance
i_q	q-axis current
i_d	d-axis current
λ	Permanent magnet flux linkage
P	Motor pole pairs

Electrical Losses

To specify the electrical losses, on the **Electrical Losses** tab, for **Parameterize losses by**, select one of these options.

Setting	Block Implementation
`Single efficiency measurement`	Electrical loss calculated using a constant value for inverter efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of motor speeds and load torques.
`Tabulated efficiency data`	Electrical loss calculated using inverter efficiency that is a function of motor speeds and load torques. • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

Ports

Input

SpdReq — Rotor speed command
`scalar`

Rotor speed command, ω^*_m, in rad/s.

Dependencies

To create this port, select `Speed Control` for the **Control Type** parameter.

`TrqCmd` — Torque command
`scalar`

Torque command, T^*, in N·m.

Dependencies

To create this port, select `Torque Control` for the **Control Type** parameter.

`BusVolt` — DC bus voltage
`scalar`

DC bus voltage v_{bus}, in V.

`PhaseCurrA` — Current
`scalar`

Stator current phase a, i_a, in A.

`PhaseCurrB` — Current
`scalar`

Stator current phase b, i_b, in A.

SpdFdbk — Rotor speed
`scalar`

Rotor speed, ω_m, in rad/s.

PosFdbk — Rotor electrical angle
`scalar`

Rotor electrical angle, Θ_m, in rad.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
SrcPwr	Source power	W
LdPwr	Load power	W
PwrLoss	Power loss	W
MtrTrqEst	Estimated motor torque	N·m

BusCurr — Bus current
scalar

Estimated DC bus current, i_{bus}, in A.

PhaseVolt — Stator terminal voltages
array

Stator terminal voltages, V_a, V_b, and V_c, in V.

Parameters

Configuration

Control Type — Select control
Speed Control (default) | Torque Control

If you select Torque Control, the block does not implement the speed controller.

This table summarizes the port configurations.

Port Configuration	Creates Ports
Speed Control	SpdReq
Torque Control	TrqCmd

Motor Parameters

Stator resistance, Rs — Resistance
0.02 (default) | scalar

Stator phase winding resistance, R_s, in ohm.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Stator resistance, Rs	**D and Q axis integral gain, Ki**	**Current Controller**

DQ axis inductance, Ldq — Inductance
1.7e-3 (default) | scalar

D-axis winding inductance, L_{dq}, in H.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
DQ axis inductance, Ldq	**D-axis proportional gain, Kp_d** **Q-axis proportional gain, Kp_q** **D and Q axis integral gain, Ki**	**Current Controller**

`Permanent magnet flux, lambda_pm` — Flux

`0.2205` (default) | `scalar`

Permanent magnet flux, λ_{pm}, in Wb.

`Number of pole pairs, PolePairs` — Poles

`4` (default) | `scalar`

Motor pole pairs, P.

`Physical inertia, viscous damping, static friction, Mechanical` — Inertia, damping, friction

`[0.0027, 4.924e-4, 0]` (default) | `vector`

Mechanical properties of the motor:

- Motor inertia, F_v, in kgm^2
- Viscous friction torque constant, F_v, in N·m/(rad/s)
- Static friction torque constant, F_s, in N·m

Dependencies

To enable this parameter, set the **Control Type** parameter to `Speed Control`.

For the gain calculations, the block uses the inertia from the **Physical inertia, viscous damping, static friction** parameter value that is on the **Motor Parameters** tab.

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Physical inertia, viscous damping, static friction, Mechanical	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa** **Inertia compensation, Jcomp** **Viscous damping compensation, Fv** **Static friction, Fs**	**Speed Controller**

Id and Iq Calculation

`Maximum torque, T_max` — Torque
`60` (default) | `scalar`

Maximum torque, in N·m.

Current Controller

`Bandwidth of the current regulator, EV_current` — Bandwidth
`200` (default) | `scalar`

Current regulator bandwidth, in Hz.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the current regulator, EV_current	**D-axis proportional gain, Kp_d** **Q-axis proportional gain, Kp_q** **D and q axis proportional gain, Ki**	**Current Controller**

`Sample time for the torque control, Tst` — Time
`5e-5` (default) | `scalar`

Torque control sample time, in s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Used to Derive	
	Parameter	Tab
Sample time for the torque control, Tst	**Speed regulation time constant, Ksf**	**Speed Controller**

`Calculate Current Regulator Gains` — Derive parameters
button

Click to derive parameters.

Dependencies

On the **Current Controller** tab, when you select **Calculate Current Regulator Gains**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Current Controller tab	Dependency	
	Parameter	Tab
D-axis proportional gain, Kp_d **Q-axis proportional gain, Kp_q** **D and Q axis integral gain, Ki**	**Bandwidth of the current regulator, EV_current**	**Current Controller**
	Stator resistance, Rs **DQ-axis inductance, Ldq**	**Motor Parameters**

`D-axis proportional gain, Kp_d` — Derived
`0.47149` (default) | `scalar`

Derived d-axis proportional gain, in V/A.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
D-axis proportional gain, Kp_d	**Bandwidth of the current regulator, EV_current**	**Current Controller**
	DQ-axis inductance, Ldq	**Motor Parameters**

`Q-axis proportional gain, Kp_q` — Derived
`0.52125` (default) | `scalar`

Derived q-axis proportional gain, in V/A.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Q-axis proportional gain, Kp_q	**Bandwidth of the current regulator, EV_current**	**Current Controller**
	DQ-axis inductance, Ldq	**Motor Parameters**

D and Q axis integral gain, Ki — Derived
251.3274 (default) | scalar

Derived axis integral gain, in V/A*s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
D and Q axis integral gain, Ki	**Bandwidth of the current regulator, EV_current**	**Current Controller**
	Stator resistance, Rs **DQ-axis inductance, Ldq**	**Motor Parameters**

Speed Controller

Bandwidth of the motion controller, EV_motion — Bandwidth
[20, 4, 0.8] (default) | vector

Motion controller bandwidth, in Hz. Set the first element of the vector to the desired cutoff frequency. Set the second and third elements of the vector to the higher-order cut off frequencies. You can set the value of the next element to 1/5 the value of the previous element. For example, if the desired cutoff frequency is 20 Hz, specify [20 4 0.8].

Dependencies

The parameter is enabled when the **Control Type** parameter is set to Speed Control.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the motion controller, EV_motion	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa**	**Speed Controller**

Bandwidth of the state filter, EV_sf — Bandwidth
200 (default) | scalar

State filter bandwidth, in Hz.

Dependencies

The parameter is enabled when the **Control Type** parameter is set to Speed Control.

Parameter	Used to Derive	
	Parameter	Tab
Bandwidth of the state filter, EV_sf	**Speed regulation time constant, Ksf**	**Speed Controller**

`Calculate Speed Regulator Gains` — Derive parameters
button

Click to derive parameters.

Dependencies

On the **Speed Controller** tab, when you select **Calculate Speed Regulator Gains**, the block calculates derived parameters. The table summarizes the derived parameters that depend on other block parameters.

Derived Parameter on Speed Controller tab		Depends On	
		Parameter	Tab
Proportional gain, ba	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$	**Bandwidth of the motion controller, EV_motion** **Bandwidth of the state filter, EV_sf**	**Speed Controller**
Angular gain, Ksa	$K_{sa} = \frac{J_p(p_1 p_2 + p_2 p_3 + p_3 p_1) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$	**Sample time for the torque control, Tst**	**Current Controller**
Rotational gain, Kisa	$K_{isa} = \frac{-J_p(p_1 + p_2 + p_3) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
Speed regulation time constant, Ksf	$K_{sf} = \frac{1 - \exp\left(-T_{sm} 2\pi EV_{sf}\right)}{T_{sm}}$		
Inertia compensation, Jcomp	$J_{comp} = J_p$	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
Viscous damping compensation, Fv	F_v		
Static friction, Fs	F_s		

The equations use these variables.

P	Motor pole pairs
b_a	Speed regulator proportional gain
K_{sa}	Speed regulator integral gain
K_{isa}	Speed regulator double integral gain
K_{sf}	Speed regulator time constant
J_p	Motor inertia
EV_{sf}	State filter bandwidth
EV_{motion}	Motion controller bandwidth

`Proportional gain, ba` — Derived
`3.7477` (default) | `scalar`

Derived proportional gain, in N·m/(rad/s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Proportional gain, ba	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
	Bandwidth of the motion controller, EV_motion	**Speed Controller**

`Angular gain, Ksa` — Derived
`94.0877` (default) | `scalar`

Derived angular gain, in N·m/rad.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Angular gain, Ksa	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
	Bandwidth of the motion controller, EV_motion	**Speed Controller**

`Rotational gain, Kisa` — Derived
`381.7822` (default) | `scalar`

Derived rotational gain, in N·m/(rad*s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	**Tab**
Rotational gain, Kisa	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
	Bandwidth of the motion controller, EV_motion	**Speed Controller**

`Speed regulation time constant, Ksf` — Derived

`1217.9727` (default) | `scalar`

Derived speed regulation time constant, in 1/s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	**Tab**
Speed regulation time constant, Ksf	**Sample time for the torque control, Tst**	**Current Controller**
	Bandwidth of the state filter, EV_sf	**Speed Controller**

`Inertia compensation, Jcomp` — Derived

`0.025` (default) | `scalar`

Derived inertia compensation, in kg·m^2.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	**Tab**
Inertia compensation, Jcomp	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

`Viscous damping compensation, Fv` — Derived

`0` (default) | `scalar`

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Viscous damping compensation, Fv	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

`Static friction, Fs` — Derived
`0` (default) | `scalar`

Derived static friction, in N·m/(rad/s).

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Static friction, Fs	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**

Electrical Losses

`Parameterize losses by` — Select type
`Single efficiency measurement` (default) | `Tabulated loss data` | `Tabulated efficiency data`

Setting	Block Implementation
`Single efficiency measurement`	Electrical loss calculated using a constant value for inverter efficiency.
`Tabulated loss data`	Electrical loss calculated as a function of motor speeds and load torques.
`Tabulated efficiency data`	Electrical loss calculated using inverter efficiency that is a function of motor speeds and load torques. • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.

- You can account for fixed losses that are still present for zero speed or torque.

Overall inverter efficiency, eff — Constant
98 (default) | scalar

Overall inverter efficiency, *Eff*, in %.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

Vector of speeds (w) for tabulated loss, w_loss_bp — Breakpoints
[0 200 400 600 800 1000] (default) | 1-by-M vector

Speed breakpoints for lookup table when calculating losses, in rad/s.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

Vector of torques (T) for tabulated loss, T_loss_bp — Breakpoints
[0 25 50 75 100] (default) | 1-by-N vector

Torque breakpoints for lookup table when calculating losses, in N·m.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

Corresponding losses, losses_table — Table
[100 100 100 100 100;100 150 200 250 300;100 200 300 400 500;100 250 400 550 700;100 300 500 700 900;100 350 600 850 1100] (default) | M-by-N array

Array of values for electrical losses as a function of `M` speeds and `N` torques, in W. Each value specifies the losses for a specific combination of speed and torque. The matrix size must match the dimensions defined by the speed and torque vectors.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated loss data`.

Vector of speeds (w) for tabulated efficiency, w_eff_bp — Breakpoints
[200 400 600 800 1000] (default) | 1-by-M vector

Speed breakpoints for lookup table when calculating efficiency, in rad/s.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

Vector of torques (T) for tabulated efficiency, T_eff_bp — Breakpoints
[25 50 75 100] (default) | 1-by-N vector

Torque breakpoints for lookup table when calculating efficiency, in N·m.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

`Corresponding efficiency, efficiency_table` — Table
`[96.2 98.1 98.7 99;98.1 99 99.4 99.5;98.7 99.4 99.6 99.7;99 99.5 99.7 99.8;99.2 99.6 99.7 99.8]` (default) | `M`-by-`N` array

Array of efficiency as a function of `M` speeds and `N` torque, in %. Each value specifies the efficiency for a specific combination of speed and torque. The matrix size must match the dimensions defined by the speed and torque vectors.

The block ignores efficiency values for zero speed or zero torque. Losses are zero when either torque or speed is zero. The block uses linear interpolation.

To get the desired level of accuracy for lower power conditions, you can provide tabulated data for low speeds and low torques.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

References

[1] Lorenz, Robert D., Thomas Lipo, and Donald W. Novotny. “Motion control with induction motors.” *Proceedings of the IEEE*, Vol. 82, Issue 8, August 1994, pp. 1215–1240.

[2] Shigeo Morimoto, Masayuka Sanada, Yoji Takeda. “Wide-speed operation of interior permanent magnet synchronous motors with high-performance current regulator.” *IEEE Transactions on Industry Applications*, Vol. 30, Issue 4, July/August 1994, pp. 920–926.

[3] Muyang Li. “Flux-Weakening Control for Permanent-Magnet Synchronous Motors Based on Z-Source Inverters.” Master’s Thesis, Marquette University, e-Publications@Marquette, Fall 2014.

[4] Briz, Fernando, Michael W. Degner, and Robert D. Lorenz. "Analysis and design of current regulators using complex vectors." *IEEE Transactions on Industry Applications*, Vol. 36, Issue 3, May/June 2000, pp. 817–825.

[5] Briz, Fernando, et al. "Current and flux regulation in field-weakening operation [of induction motors]."*IEEE Transactions on Industry Applications*, Vol. 37, Issue 1, Jan/Feb 2001, pp. 42–50.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

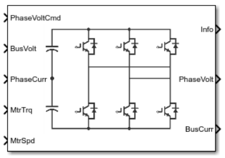
Surface Mount PMSM | Flux-Based PM Controller | IM Controller | Interior PM Controller

Introduced in R2017a

Three-Phase Voltage Source Inverter

Three-phase voltage source inverter

Library: Powertrain Blockset / Propulsion / Electric Motors and Inverters



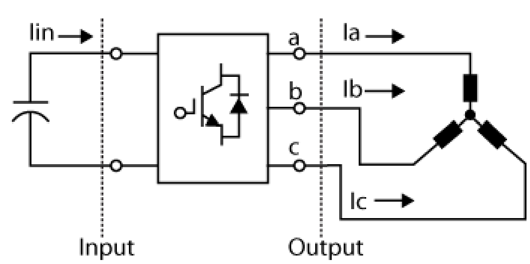
Description

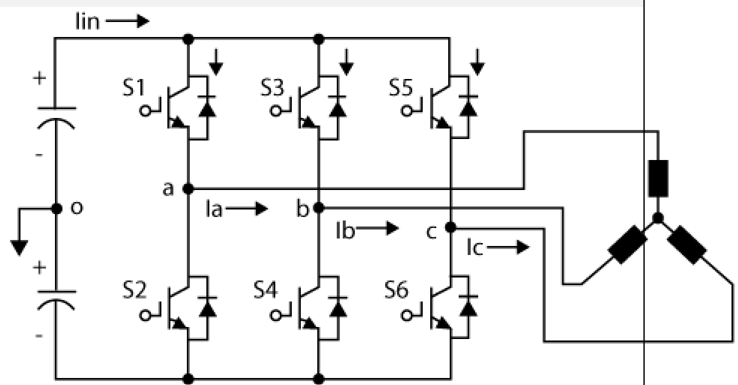
The Three-Phase Voltage Source Inverter block implements a three-phase voltage source inverter that generates neutral voltage commands for a balanced three-phase load. Configure the voltage switching function for continuous vector modulation or inverter switch input signals. You can incorporate the block into a closed-loop model to simulate a power inverter. The block controls the ideal switch states.

To enable power loss calculations suitable for code generation targets that limit memory, select **Enable memory optimized 2D LUT**. Click **Calibrate Maps** to virtually calibrate an inverter power loss lookup table as a function of motor torque and motor speed.

If you select **Input inverter temperature**, click **Calibrate Maps** to virtually calibrate the power loss table as a function of motor torque, motor speed, and inverter temperature. You cannot enable memory optimization for the 3D power loss lookup table.

Use the **Switching voltage function** parameter to set the switching voltage function.

Setting	Implementation	Illustration
Commanded phase voltage	Phase a, b, c line-to-neutral voltage command input. Suitable for continuous sinusoidal or space vector modulation input signals.	

Setting	Implementation	Illustration
Switch inputs (default)	Inverter switch input command. Suitable for hardware-in-the-loop (HIL) simulation. The inverter switches S1, S3, and S5 using complimented control for S2, S4, and S6.	

Virtual Calibration

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the lookup tables using measured data. The dialog box steps through these tasks.

Task	Description
Import Loss Data	Import this loss data from a file. For example, open `<*matlabroot*>/toolbox/autoblks/autoblksshared/mbctemplates/MappedInverterDataset.xlsx`. For more information, see “Using Data” (Model-Based Calibration Toolbox). **Input inverter temperature Setting** — **Required Data** `off`: • Motor speed, rad/s • Motor torque, N·m • Power loss, W `on`: • Motor speed, rad/s • Motor torque, N·m • Motor temperature, K • Power loss, W Collect inverter data at steady-state operating conditions. Data should cover the inverter speed, torque, and temperature operating range. To filter or edit the data, select **Edit in Application**. The Model-Based Calibration Toolbox Data Editor opens.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Generate Response Models</td><td>Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).

To assess or adjust the response model fit, select Edit in Application. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</td></tr>
<tr><td>Generate Calibration</td><td>Model-Based Calibration Toolbox calibrates the response models and generates calibrated tables.

To assess or adjust the calibration, select Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</td></tr>
<tr><td>Update block parameters</td><td>Update these parameters with the calibration.
<table>
<tr><th>Input inverter temperature Setting</th><th>Parameters</th></tr>
<tr><td><code>off</code></td><td>Vector of speeds (w) for tabulated losses, w_eff_bp
Vector of torques (T) for tabulated losses, T_eff_bp
Corresponding power loss, ploss_table</td></tr>
<tr><td><code>on</code></td><td>Vector of speeds (w) for tabulated losses, w_eff_bp
Vector of torques (T) for tabulated losses, T_eff_bp
Vector of temperatures for tabulated losses, Temp_eff_bp
Corresponding power loss, ploss_table_3d</td></tr>
</table></td></tr>
</table>

Switching Function

For the switch voltage, the block implementation depends on the **Switching voltage function** setting.

<table>
<tr><th>Setting</th><th>Calculation</th><th>Equations</th></tr>
<tr><td rowspan="2"><code>Commanded phase voltage</code></td><td>Continuous line-to-neutral voltage commands set to phase a, b, c line-to-neutral voltage command input</td><td>$v_{an} = v_{a\_cmd}$
$v_{bn} = v_{b\_cmd}$
$v_{cn} = v_{c\_cmd}$</td></tr>
<tr><td>Line-to-line voltage</td><td>$v_{ab} = v_{an} - v_{bn}$
$v_{bc} = v_{bn} - v_{cn}$
$v_{ca} = v_{cn} - v_{an}$</td></tr>
</table>

Setting	Calculation	Equations
`Switch inputs`	Switching function	$SF_a = \begin{cases} 1 & \text{S1 on and S2 off} \\ -1 & \text{S1 off and S2 on} \end{cases}$ $SF_b = \begin{cases} 1 & \text{S3 on and S4 off} \\ -1 & \text{S3 off and S4 on} \end{cases}$ $SF_c = \begin{cases} 1 & \text{S5 on and S6 off} \\ -1 & \text{S5 off and S6 on} \end{cases}$
	Line-to-center point voltage	$v_{ao} = \frac{v_{bus}}{2} SF_a$ $v_{bo} = \frac{v_{bus}}{2} SF_b$ $v_{co} = \frac{v_{bus}}{2} SF_c$
	Line-to-neutral voltage	$v_{an} = v_{ao} - v_{no}$ $v_{bn} = v_{bo} - v_{no}$ $v_{cn} = v_{co} - v_{no}$ $v_{an} + v_{bn} + v_{cn} = 0$ $v_{no} = \frac{1}{3}(v_{ao} + v_{bo} + v_{co})$ $v_{an} = v_{ao} - \frac{1}{3}(v_{ao} + v_{bo} + v_{co})$ $v_{bn} = v_{bo} - \frac{1}{3}(v_{ao} + v_{bo} + v_{co})$ $v_{cn} = v_{co} - \frac{1}{3}(v_{ao} + v_{bo} + v_{co})$
	Line-to-line voltage	$v_{ab} = v_{an} - v_{bn}$ $v_{bc} = v_{bn} - v_{cn}$ $v_{ca} = v_{cn} - v_{an}$

The equations use these variables.

SF_a, SF_b, SF_c	Phase a, b, c line switching functions, respectively
v_{bus}	Power source bus voltage
V_{ao}, V_{bo}, V_{co}	Phase a, b, c line-to-center voltage, respectively
V_{an}, V_{bn}, V_{cn}	Phase a, b, c line-to-neutral voltage, respectively
V_{ab}, V_{bc}, V_{ca}	Phase ab, bc, ca line-to-neutral voltage, respectively
V_{a_cmd}, V_{b_cmd}, V_{c_cmd}	Phase a, b, c line-to-neutral voltage commands, respectively

Current and Power Loss

For the line-to-center, line-to-neutral, and line-to-line voltage, the block implements these equations.

Calculation	Equations
Motor and bus power	$P_{mtr} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c$ $P_{bus} = v_{bus}i_{bus}$
Inverter power loss and bus current	$P_{in} = P_{bus} = v_{bus}i_{bus}$ $P_{out} = P_{mtr} = v_{an}i_a + v_{bn}i_b + v_{cn}i_c + P_{LossInv}$ $i_{bus} = \frac{v_{an}i_a + v_{bn}i_b + v_{cn}i_c + P_{LossInv}}{v_{bus}}$

The equations use these variables.

P_{mtr}	Power delivered to the motor
P_{bus}	Power from input bus
P_{loss}	Power loss
i_{bus}	Power source bus current
i_a, i_b, i_c	Phase a, b, c line current, respectively
V_{an}, V_{bn}, V_{cn}	Phase a, b, c line-to-neutral voltage, respectively
v_{bus}	Power source bus voltage

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equation
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrMtr`	Power delivered to the motor	$P_{TrnsfrdMtr}$	$P_{TrnsfrdMtr} = -(v_{an}i_a + v_{bn}i_b + v_{cn}i_c)$
		`PwrBus`	Power from input bus	$P_{TrnsfrdBus}$	$P_{TrnsfrdBus} = P_{bus}$

Bus Signal			Description	Variable	Equation
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrLoss`	Power loss Negative value indicates power loss	$P_{NotTrnsfrd}$	$P_{NotTrnsfrd} = -(P_{TrnsfrdBus} + P_{TrnsfrdMtr})$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease		*Not used*		

Lookup Table Memory Optimization

The inverter power loss table parameter **Corresponding power loss, ploss_table** data is a function of motor torque and motor speed at different battery voltages. Positive current indicates battery discharge. Negative current indicates battery charge.

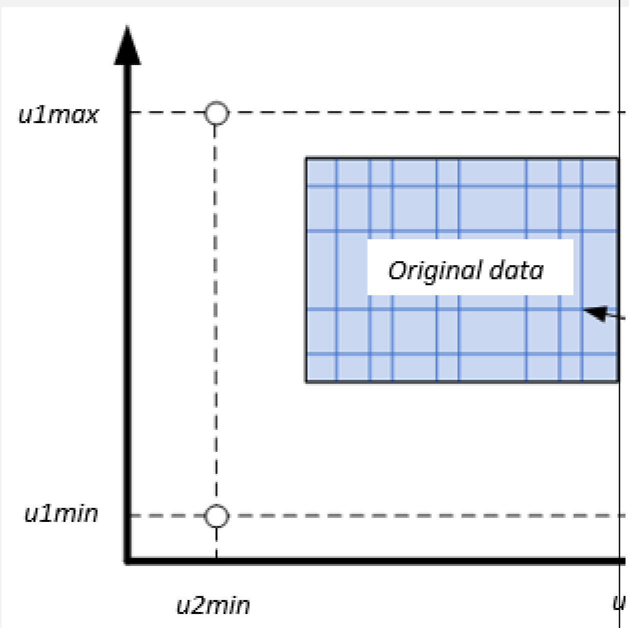
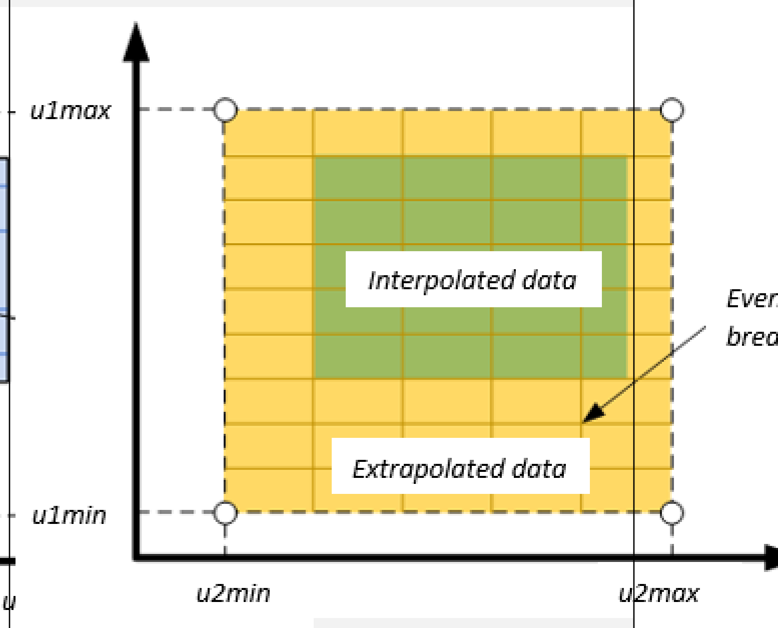
To enable power loss calculations suitable for code generation targets that limit memory, select **Enable memory optimized 2D LUT**. The block uses linear interpolation to optimize the inverter power loss lookup table values for code generation. This table summarizes the optimization implementation.

Use Case	Implementation
Motor speed and torque input align with the lookup table breakpoint values.	Memory-optimized power loss is power loss lookup table value at intersection of motor speed and torque.
Motor speed and torque input do not align with the lookup table breakpoint values, but are within range.	Memory-optimized power loss is linear interpolation between corresponding motor speed and torque.
Motor speed and torque input do not align with the lookup table breakpoint values, and are out of range.	Cannot compute a memory-optimized power loss. Block uses extrapolated data.

Extrapolation

The lookup tables optimized for code generation do not support extrapolation for data that is out of range. However, you can include pre-calculated extrapolation values in the power loss lookup table by selecting **Specify Extrapolation**.

The block uses the endpoint parameters to resize the table data.

<table>
<tr><th>User Input</th><th>Extrapolation</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Ports

Input

`PhaseVoltCmd` — Phase a, b, c line-to-neutral voltage command
1-by-3 array

Phase a, b, c line-to-neutral voltage command, V_{a_cmd}, V_{b_cmd}, and V_{c_cmd}, in V.

Dependencies

To create this port, set **Switching voltage function** to `Commanded phase voltage`.

`SwitchCmd` — Switch commands
1-by-3 array

Switch commands, S_a, S_b, and S_c, dimensionless.

Dependencies

To create this port, set **Switching voltage function** to `Switch inputs`.

`BusVolt` — Power source bus voltage
bus

Power source bus voltage, V_{bus}, in V.

`PhaseCurr` — Phase a, b, c current
1-by-3 array

Phase a, b, c current, i_a, i_b, and i_c, in A.

MtrTrq — Motor torque
scalar

Motor torque, T_{mtr}, in N·m.

MtrSpd — Motor speed
scalar

Angular speed of the motor, ω_{mtr}, in rad/s.

InvrtrTemp — Inverter operating temperature
scalar

Inverter operating temperature, $Temp_{Invrtr}$, in K.

Dependencies

To create this port, select **Input inverter temperature**.

Output

Info — Bus signal
bus

The bus signal contains these block calculations.

Signal			Description	Variable	Units
BusCurr			Power source bus current	i_{bus}	A
PwrLossInv			Inverter power loss	ε_{inv}	dimensionless
PwrInfo	PwrTrnsfrd	PwrMtr	Power delivered to the motor	$P_{TrnsfrdMtr}$	W
		PwrBus	Power from input bus	$P_{TrnsfrdBus}$	W
	PwrNotTrnsfrd	PwrLoss	Power loss	$P_{NotTrnsfrd}$	W
	PwrStored		*Not used*		

PhaseVolt — Phase a, b, c line-to-neutral voltage
1-by-3 array

Phase a, b, c line-to-neutral voltage, V_{an}, V_{bn}, and V_{cn}, in V.

BusCurr — Power source bus current
scalar

Power source bus current, i_{bus}, in A.

Parameters

Block Options

Input inverter temperature — Create input port
off (default) | on

Select this parameter to create the `InvrtrTemp` input port.

The block enables you to specify inverter power loss lookup tables that are functions of motor torque, T_{mtr}, and motor speed, ω_{mtr}. If you select **Input inverter temperature**, the tables are also a function of the inverter temperature, $Temp_{Invrtr}$.

Input Inverter Temperature Parameter Setting	Enables Efficiency Table	Function Of
`off`	**Corresponding power loss, ploss_table**	$f(T_{mtr}, \omega_{mtr})$
`on`	**Corresponding power loss, ploss_table_3d**	$f(T_{mtr}, \omega_{mtr}, Temp_{Invrtr})$

Dependencies

If you select **Input inverter temperature** to specify a 3D power loss lookup table as a function of motor torque, motor speed, and inverter temperature, you cannot select **Enable memory optimized 2D LUT** to enable a memory optimization.

`Enable memory optimized 2D LUT` — Selection

`off` (default) | `on`

Enable generation of memory-optimized lookup tables, suitable code generation targets that limit memory.

Dependencies

If you select **Enable memory optimized 2D LUT**, you cannot select **Input inverter temperature**.

`Calibrate Maps` — Calibrate tables with measured data

`selection`

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the lookup tables using measured data. The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import Loss Data</td><td>Import this loss data from a file. For example, open `<matlabroot>/toolbox/autoblks/autoblksshared/mbctemplates/MappedInverterDataset.xlsx`.

For more information, see “Using Data” (Model-Based Calibration Toolbox).

<table>
<tr><th>Input inverter temperature Setting</th><th>Required Data</th></tr>
<tr><td>off</td><td>• Motor speed, rad/s
• Motor torque, N·m
• Power loss, W</td></tr>
<tr><td>on</td><td>• Motor speed, rad/s
• Motor torque, N·m
• Motor temperature, K
• Power loss, W</td></tr>
</table>

Collect inverter data at steady-state operating conditions. Data should cover the inverter speed, torque, and temperature operating range.

To filter or edit the data, select **Edit in Application**. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
<tr><td>Generate Response Models</td><td>Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).

To assess or adjust the response model fit, select **Edit in Application**. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</td></tr>
<tr><td>Generate Calibration</td><td>Model-Based Calibration Toolbox calibrates the response models and generates calibrated tables.

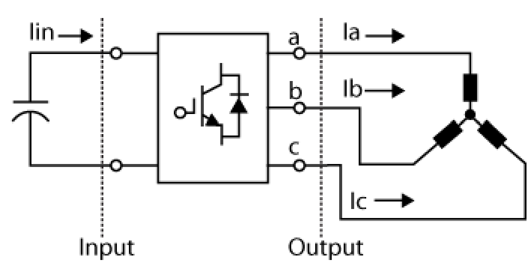
To assess or adjust the calibration, select **Edit in Application**. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</td></tr>
</table>

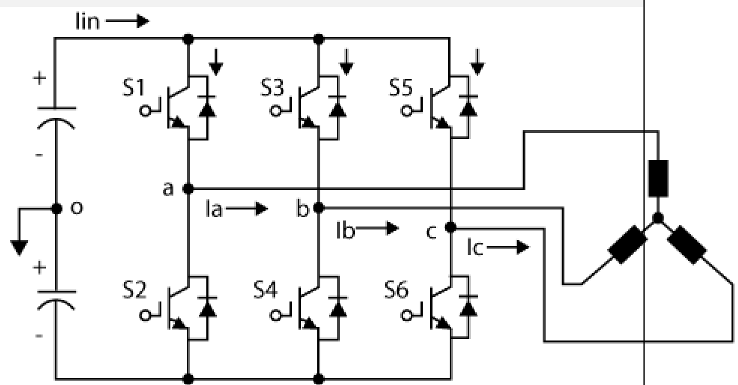
<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Update block parameters</td><td>Update these parameters with the calibration.
<table>
<tr><th>Input inverter temperature Setting</th><th>Parameters</th></tr>
<tr><td><code>off</code></td><td>Vector of speeds (w) for tabulated losses, w_eff_bp
Vector of torques (T) for tabulated losses, T_eff_bp
Corresponding power loss, ploss_table</td></tr>
<tr><td><code>on</code></td><td>Vector of speeds (w) for tabulated losses, w_eff_bp
Vector of torques (T) for tabulated losses, T_eff_bp
Vector of temperatures for tabulated losses, Temp_eff_bp
Corresponding power loss, ploss_table_3d</td></tr>
</table></td></tr>
</table>

Electrical Model

`Switching voltage function` — Selection
`Commanded phase voltage` (default) | `Switch inputs`

Use the **Switching voltage function** parameter to set the switching voltage function.

Setting	Implementation	Illustration
Commanded phase voltage	Phase a, b, c line-to-neutral voltage command input. Suitable for continuous sinusoidal or space vector modulation input signals.	

Setting	Implementation	Illustration
Switch inputs (default)	Inverter switch input command. Suitable for hardware-in-the-loop (HIL) simulation. The inverter switches S1, S3, and S5 using complimented control for S2, S4, and S6.	

`Vector of speeds (w) for tabulated losses, w_eff_bp` — Speed breakpoints
`[-1000 -500 0 500 1000]` (default) | 1-by-M vector

Vector of motor speed, ω_{mtr}, breakpoints for power loss, in rad/s. If you set **Enable memory optimized 2D LUT**, the block converts the data to single precision.

`Resample storage size for w_eff_bp, n1` — Speed bit size
128 (default) | 2 | 4 | 8 | 16 | 32 | 64 | 256

Speed breakpoint storage size, *n1*, dimensionless. The block resamples the **Corresponding power loss, ploss_table** data based on the storage size.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT**.

`Vector of torques (T) for tabulated losses, T_eff_bp` — Torque breakpoints
`[-200 -100 0 100 200]` (default) | 1-by-N vector

Vector of motor torque, T_{mtr}, breakpoints for power loss, in N·m. If you set **Enable memory optimized 2D LUT**, the block converts the data to single precision.

`Resample storage size for T_eff_bp, n2` — Torque bit size
128 (default) | 2 | 4 | 8 | 16 | 32 | 64 | 256

Torque breakpoint storage size, *n2*, dimensionless. The block resamples the **Corresponding power loss, ploss_table** data based on the storage size.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT**.

`Vector of temperatures for tabulated losses, Temp_eff_bp` — Temperature breakpoints
`[213.15 293.15 373.15]` (default) | 1-by-L vector

Vector of inverter temperature, $Temp_{Invrtr}$, breakpoints for power loss, in K.

Dependencies

To create this parameter, select **Input inverter temperature**.

`Corresponding power loss, ploss_table` — 2D lookup table

`[1 0.999 0.989 0.997 0.996;0.995 0.994 0.993 0.992 0.991;0.990 0.989 0.988 0.987 0.986;0.985 0.984 0.983 0.982 0.981;0.980 0.979 0.978 0.977 0.976]` (default) | `M`-by-`N` array

Array of values for power loss as a function of `M` motor speeds, ω_{mtr}, and `N` motor torques, T_{mtr}, in W. Each value specifies the power loss for a specific combination of motor speed and motor torque. The array size must match the dimensions defined by the speed and torque vectors.

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the lookup table using measured data.

If you set **Enable memory optimized 2D LUT**, the block converts the data to single precision.

Dependencies

To create this parameter, clear **Input inverter temperature**.

`Corresponding power loss, ploss_table_3d` — 3D lookup table

`M`-by-`N`-by-`L` array

Array of values for power loss as a function of `M` motor speeds, ω_{mtr}, `N` motor torques, T_{mtr}, and `L` motor temperatures, $Temp_{Invrtr}$, in W. Each value specifies the power loss for a specific combination of motor speed, motor torque, and temperature. The array size must match the dimensions defined by the speed, torque, and temperature vectors.

If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the lookup table using measured data.

Dependencies

To create this parameter, select **Input inverter temperature**.

Specify Extraction

`w_eff_bp max endpoint, u1max` — Speed breakpoint

`1000` (default) | `scalar`

Speed breakpoint maximum extrapolation endpoint, *u1max*, in rad/s.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT** and **Specify Extrapolation**.

`w_eff_bp min endpoint, u1min` — Speed breakpoint

`-1000` (default) | `scalar`

Speed breakpoint minimum extrapolation endpoint, *u1min*, in rad/s.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT** and **Specify Extrapolation**.

`T_eff_bp max endpoint, u2max` — Torque breakpoint
`200` (default) | `scalar`

Torque breakpoint maximum extrapolation endpoint, *u2max*, in rad/s.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT** and **Specify Extrapolation**.

`T_eff_bp min endpoint, u2min` — Torque breakpoint
`-200` (default) | `scalar`

Torque breakpoint minimum extrapolation endpoint, *u2min*, in rad/s.

Dependencies

To create this parameter, select **Enable memory optimized 2D LUT** and **Specify Extrapolation**.

References

[1] Lee, Byoung-Kuk and Mehrdad Ehsami. “A simplified functional simulation model for three-phase voltage-source inverter using switching function concept.” *IEEE Transactions on Industrial Electronics*, Vol. 48, No. 2, pp. 309-321, April 2001.

[2] Ziogas, Phoivas D., Eduardo P. Wiechmann, and Victor R. Stefanovic. “A Computer-Aided Analysis and Design Approach for Static Voltage Source Inverters.” *IEEE Transactions on Industrial Electronics. Transactions on Industry Applications*, Vol. IA-21, No. 5, September/October 1985.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

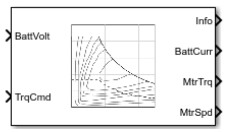
See Also
Flux-Based PM Controller | Induction Motor | Interior PMSM | Surface Mount PMSM

Introduced in R2019a

Mapped Motor

Mapped motor and drive electronics operating in torque-control mode

Library: Powertrain Blockset / Propulsion / Electric Motors and Inverters
Vehicle Dynamics Blockset / Powertrain / Propulsion



Description

The Mapped Motor block implements a mapped motor and drive electronics operating in torque-control mode. The output torque tracks the torque reference demand and includes a motor-response and drive-response time constant. Use the block for fast system-level simulations when you do not know detailed motor parameters, for example, for motor power and torque tradeoff studies. The block assumes that the speed fluctuations due to mechanical load do not affect the motor torque tracking.

You can specify:

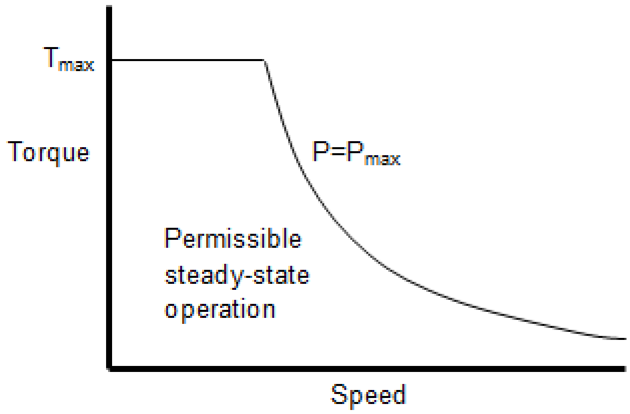
- Port configuration — Input torque or speed.
- Electrical torque range — Torque speed envelope or maximum motor power and torque.
- Electrical loss — Single operating point, measured efficiency, or measured loss. If you have Model-Based Calibration Toolbox, you can virtually calibrate the measured loss tables.

Electrical Torque

To specify the range of torque and speed that the block allows, on the **Electrical Torque** tab, for **Parametrized by**, select one of these options.

Setting	Block Implementation
`Tabulated torque-speed envelope`	Range specified as a set of speed data points and corresponding maximum torque values.
`Maximum torque and power`	Range specified with maximum torque and maximum power.

For either method, the block implements an envelope similar to this.



Electrical Losses

To specify the electrical losses, on the **Electrical Losses** tab, for **Parameterize losses by**, select one of these options.

Setting	Block Implementation
`Single efficiency measurement`	Sum of these terms, measured at a single measurement point: • Fixed losses independent of torque and speed, P_0. Use P_0 to account for fixed converter losses. • A torque-dependent electrical loss $k\tau^2$, where k is a constant and τ is the torque. Represents ohmic losses in the copper windings. • A speed-dependent electrical loss $k_w\omega^2$, where k_w is a constant and ω is the speed. Represents iron losses due to eddy currents.
`Tabulated loss data`	Loss lookup table that is a function of motor speeds and load torques. If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 2D lookup tables using measured data.
`Tabulated loss data with temperature`	Loss lookup table that is a function of motor speeds, load torques, and operating temperature. If you have Model-Based Calibration Toolbox, click **Calibrate Maps** to virtually calibrate the 3D lookup tables using measured data.

Setting	Block Implementation
`Tabulated efficiency data`	2D efficiency lookup table that is a function of motor speeds and load torques: • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.
`Tabulated efficiency data with temperature`	3D efficiency lookup table that is a function of motor speeds, load torques, and operating temperature: • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed, torque, or temperature magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

Note Due to system losses, the motor can draw a current when the motor torque is zero.

Virtual Calibration

If you have Model-Based Calibration Toolbox, you can virtually calibrate the measured loss lookup tables.

1. On the **Electrical Losses** tab, set **Parameterize losses by** to either:
   - `Tabulated loss data`
   - `Tabulated loss data with temperature`
2. Click **Calibrate Maps**.

The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import Loss Data</td><td>Import this loss data from a file. For example, open <<i>matlabroot</i>>/toolbox/autoblks/autoblksshared/mbctemplates/MappedMotorDataset.xlsx.

For more information, see “Using Data” (Model-Based Calibration Toolbox).

<table>
<tr><th>Parameterize losses by</th><th>Required Data</th></tr>
<tr><td>Tabulated loss data</td><td>• Motor speed, rad/s
• Motor torque, N·m
• Power loss, W</td></tr>
<tr><td>Tabulated loss data with temperature</td><td>• Motor speed, rad/s
• Motor torque, N·m
• Motor temperature, K
• Power loss, W</td></tr>
</table>

Collect motor data at steady-state operating conditions. Data should cover the motor speed, torque, and temperature operating range.

To filter or edit the data, select Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
<tr><td>Generate Response Models</td><td>Model-Based Calibration Toolbox uses test plans to fit data to Gaussian process models (GPMs).

To assess or adjust the response model fit, select Edit in Application. The Model-Based Calibration Toolbox Model Browser opens. For more information, see “Model Assessment” (Model-Based Calibration Toolbox).</td></tr>
<tr><td>Generate Calibration</td><td>Model-Based Calibration Toolbox calibrates the response models and generates calibrated tables.

To assess or adjust the calibration, select Edit in Application. The Model-Based Calibration Toolbox CAGE Browser opens. For more information, see “Calibration Lookup Tables” (Model-Based Calibration Toolbox).</td></tr>
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<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Update block parameters</td><td>Update these parameters with the calibration.
<table>
<tr><th>Parameterize losses by</th><th>Parameters</th></tr>
<tr><td><code>Tabulated loss data</code></td><td>Vector of speeds(w) for tabulated losses, w_eff_bp
Vector of torques (T) for tabulated losses, T_eff_bp
Corresponding losses, losses_table</td></tr>
<tr><td><code>Tabulated loss data with temperature</code></td><td>Vector of speeds(w) for tabulated losses, w_eff_bp
Vector of torques (T) for tabulated losses, T_eff_bp
Vector of temperatures for tabulated losses, Temp_eff_bp
Corresponding losses, losses_table_3d</td></tr>
</table>
</td></tr>
</table>

Battery Current

The block calculates the battery current using the mechanical power, power loss, and battery voltage. Positive current indicates battery discharge. Negative current indicates battery charge.

$$BattAmp = \frac{MechPwr + PwrLoss}{BattVolt}$$

The equation uses these variables.

BattVolt	Battery voltage
MechPwr	Mechanical power
PwrLoss	Power loss
BattCurr	Battery current

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` • Positive signals indicate power flow into the block. • Negative signals indicate power flow out of the block.	`PwrMtr`	Mechanical power	P_{mot}	$P_{mot} = \omega_m T_e$
		`PwrBus`	Electrical power	P_{bus}	$P_{bus} = P_{mot} + P_{loss}$
	`PwrNotTrnsfrd` • Negative signals indicate power loss.	`PwrLoss`	Motor power loss	P_{loss}	$P_{stored} = \omega_m \dot{\omega}_m J$

Bus Signal			Description	Variable	Equations
	PwrStored • Positive signals indicate power gain.	PwrStoredShft	Motor power stored	P_{str}	$P_{loss} = \quad -(P_{mot} + P_{loss} - \quad P_{stored})$

The equations use these variables.

T_e	Motor output shaft torque
ω	Motor shaft speed
J	Motor inertia

Ports

Input

`BattVolt` — Battery voltage
scalar

Battery voltage, *BattVolt*, in V.

`TrqCmd` — Commanded motor torque
scalar

Commanded motor torque, Trq_{cmd}, in N·m.

Dependencies

To create this input port, for the **Port configuration**, select `Torque`.

`MtrSpd` — Motor output shaft speed
scalar

Motor shaft speed, Mtr_{spd}, in rad/s.

Dependencies

To create this input port, for the **Port configuration**, select `Speed`.

Output

`Info` — Bus signal
bus

The bus signal contains these block calculations.

Signal			Description	Units
MechPwr			Mechanical power	rad
PwrLoss			Internal inverter and motor power loss	N·m
PwrInfo	PwrTrnsfrd	PwrMtr	Mechanical power	W
		PwrBus	Electrical power	W

Signal			Description	Units
	PwrNotTrnsfrd	PwrLoss	Motor power loss	W
	PwrStored	PwrStoredShft	Motor power stored	W

BattCurr — Battery current
scalar

Battery current draw or demand, I_{batt}, in A.

MtrTrq — Motor torque
scalar

Motor output shaft torque, Mtr_{trq}, in N·m.

MtrSpd — Motor shaft speed
scalar

Motor shaft speed, Mtr_{spd}, in rad/s.

Dependencies

To create this output port, for the **Port configuration**, select Torque.

Parameters

Block Options

Port configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Ports
Torque	Outpost MtrSpd
Speed	Input MtrSpd

Calibrate Maps — Calibrate tables with measured data
selection

If you have Model-Based Calibration Toolbox, you can virtually calibrate the measured loss lookup tables.

1 On the **Electrical Losses** tab, set **Parameterize losses by** to either:
   - Tabulated loss data
   - Tabulated loss data with temperature
2 Click **Calibrate Maps**.

The dialog box steps through these tasks.

<table>
<tr><th>Task</th><th>Description</th></tr>
<tr><td>Import Loss Data</td><td>Import this loss data from a file. For example, open <code><matlabroot>/toolbox/autoblks/autoblksshared/mbctemplates/MappedMotorDataset.xlsx</code>.

For more information, see “Using Data” (Model-Based Calibration Toolbox).

<table>
<tr><th>Parameterize losses by</th><th>Required Data</th></tr>
<tr><td><code>Tabulated loss data</code></td><td>• Motor speed, rad/s
• Motor torque, N·m
• Power loss, W</td></tr>
<tr><td><code>Tabulated loss data with temperature</code></td><td>• Motor speed, rad/s
• Motor torque, N·m
• Motor temperature, K
• Power loss, W</td></tr>
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Collect motor data at steady-state operating conditions. Data should cover the motor speed, torque, and temperature operating range.

To filter or edit the data, select Edit in Application. The Model-Based Calibration Toolbox Data Editor opens.</td></tr>
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Vector of torques (T) for tabulated losses, T_eff_bp
Vector of temperatures for tabulated losses, Temp_eff_bp
Corresponding losses, losses_table_3d</td></tr>
</table>
</td></tr>
</table>

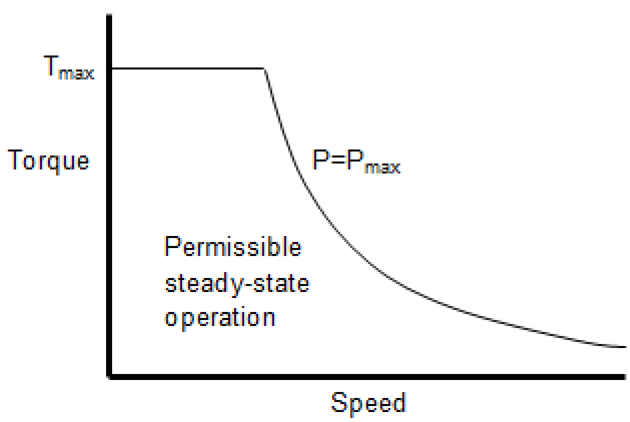
Electrical Torque

`Parameterized by` — Select type

`Tabulated torque-speed envelope` (default) | `Maximum torque and power`

Setting	Block Implementation
`Tabulated torque-speed envelope`	Range specified as a set of speed data points and corresponding maximum torque values.
`Maximum torque and power`	Range specified with maximum torque and maximum power.

For either method, the block implements an envelope similar to this.



`Vector of rotational speeds, w_t` — Rotational speeds

`[0 375 750 800]` (default) | `vector`

Rotational speeds for permissible steady-state operation, in rad/s. To avoid poor performance due to an infinite slope in the torque-speed curve, specify a vector of rotational speeds that does not contain duplicate consecutive values.

Dependencies

To create this parameter, for the **Parameterized by** parameter, select `Tabulated torque-speed envelope`.

`Vector of maximum torque values, T_t` — Torque

`[0.09 0.08 0.07 0]` (default) | `vector`

Maximum torque values for permissible steady state, in N·m.

Dependencies

To create this parameter, for the **Parameterized by** parameter, select `Tabulated torque-speed envelope`.

`Maximum torque, torque_max` — Torque

`.1` (default) | `scalar`

The maximum permissible motor torque, in N·m.

Dependencies

To create this parameter, for the **Parameterized by** parameter, select `Maximum torque and power`.

`Maximum power, power_max` — Power

`30` (default) | `scalar`

The maximum permissible motor power, in W.

Dependencies

To create this parameter, for the **Parameterized by** parameter, select `Maximum torque and power`.

`Torque control time constant, Tc` — Time constant

`0.02` (default) | `scalar`

Time constant with which the motor driver tracks a torque demand, in s.

Electrical Losses

`Parameterize losses by` — Select type

`Single efficiency measurement` (default) | `Tabulated loss data` | `Tabulated efficiency data`

<table>
<tr><th>Setting</th><th>Block Implementation</th></tr>
<tr><td><code>Single efficiency measurement</code></td><td>Sum of these terms, measured at a single measurement point:
Fixed losses independent of torque and speed, P_0. Use P_0 to account for fixed converter losses.
A torque-dependent electrical loss $k\tau^2$, where k is a constant and τ is the torque. Represents ohmic losses in the copper windings.
A speed-dependent electrical loss $k_w\omega^2$, where k_w is a constant and ω is the speed. Represents iron losses due to eddy currents.</td></tr>
<tr><td><code>Tabulated loss data</code></td><td>Loss lookup table that is a function of motor speeds and load torques.

If you have Model-Based Calibration Toolbox, click Calibrate Maps to virtually calibrate the 2D lookup tables using measured data.</td></tr>
<tr><td><code>Tabulated loss data with temperature</code></td><td>Loss lookup table that is a function of motor speeds, load torques, and operating temperature.

If you have Model-Based Calibration Toolbox, click Calibrate Maps to virtually calibrate the 3D lookup tables using measured data.</td></tr>
<tr><td><code>Tabulated efficiency data</code></td><td>2D efficiency lookup table that is a function of motor speeds and load torques:
Converts the efficiency values you provide into losses and uses the tabulated losses for simulation.
Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero.
Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions.
Does not extrapolate loss values for speed and torque magnitudes that exceed the range of the table.</td></tr>
</table>

Setting	Block Implementation
`Tabulated efficiency data with temperature`	3D efficiency lookup table that is a function of motor speeds, load torques, and operating temperature: • Converts the efficiency values you provide into losses and uses the tabulated losses for simulation. • Ignores efficiency values you provide for zero speed or zero torque. Losses are assumed zero when either torque or speed is zero. • Uses linear interpolation to determine losses. Provide tabulated data for low speeds and low torques, as required, to get the desired level of accuracy for lower power conditions. • Does not extrapolate loss values for speed, torque, or temperature magnitudes that exceed the range of the table.

For best practice, use `Tabulated loss data` instead of `Tabulated efficiency data`:

- Efficiency becomes ill defined for zero speed or zero torque.
- You can account for fixed losses that are still present for zero speed or torque.

Note Due to system losses, the motor can draw a current when the motor torque is zero.

`Motor and drive overall efficiency, eff` — Efficiency

`100` (default) | `scalar`

The block defines overall efficiency as:

$$\eta = 100\frac{\tau_0\omega_0}{\tau_0\omega_0 + P_0 + k\tau_0^2 + k_w\omega_0^2}$$

The equation uses these variables.

τ_0	Torque at which efficiency is measured
ω_0	Speed at which efficiency is measured
P_0	Fixed losses independent of torque or speed
$k\tau_0^2$	Torque-dependent electrical losses
$k_w\omega^2$	Speed-dependent iron losses

At initialization, the block solves the efficiency equation for *k*. The block neglects losses associated with the rotor damping.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Single efficiency measurement`.

`Speed at which efficiency is measured, w_eff` — Speed

`375` (default) | `scalar`

Speed at which efficiency is measured, in rad/s.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Single efficiency measurement`.

`Torque at which efficiency is measured, T_eff` — Torque
`0.08` (default) | `scalar`

Torque at which efficiency is measured, in N·m.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Single efficiency measurement`.

`Iron losses, Piron` — Power
`0` (default) | `scalar`

Iron losses at the speed and torque at which efficiency is defined, in W.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Single efficiency measurement`.

`Fixed losses independent of torque and speed, Pbase` — Power
`0` (default) | `scalar`

Fixed electrical loss associated with the driver when the motor current and torque are zero, in W.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Single efficiency measurement`.

`Vector of speeds (w) for tabulated losses, w_eff_bp` — Breakpoints
`[-8000 -4000 0 4000 8000]` (default) | 1-by-`M` vector

Speed breakpoints for lookup table when calculating losses, in rad/s. Array dimensions are `1` by the number of speed breakpoints, `M`.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select one of these:

- `Tabulated loss data`
- `Tabulated loss data with temperature`
- `Tabulated efficiency data`
- `Tabulated efficiency data with temperature`

`Vector of torques (T) for tabulated losses, T_eff_bp` — Breakpoints
`[0 0.03 0.06 0.09]` (default) | 1-by-`N` vector

Torque breakpoints for lookup table when calculating losses, in N·m. Array dimensions are `1` by the number of torque breakpoints, `N`.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select one of these:

- `Tabulated loss data`
- `Tabulated loss data with temperature`
- `Tabulated efficiency data`
- `Tabulated efficiency data with temperature`

Vector of temperatures for tabulated losses, Temp_eff_bp — Breakpoints

`[233.15 293.15 373.15]` (default) | 1-by-L vector

Temperature breakpoints for lookup table when calculating losses, in K. Array dimensions are `1` by the number of temperature breakpoints, `L`.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select one of these:

- `Tabulated loss data with temperature`
- `Tabulated efficiency data with temperature`

Corresponding losses, losses_table — 2D lookup table

M-by-N matrix

Array of values for electrical losses as a function of speed and torque, in W. Each value specifies the losses for a specific combination of speed and torque. The array dimensions must match the speed, `M`, and torque, `N`, breakpoint vector dimensions.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Tabulated loss data`.

Corresponding losses, losses_table_3d — 3D lookup table

M-by-N-by-L array

Array of values for electrical losses as a function of speed, torque, and temperature, in W. Each value specifies the losses for a specific combination of speed, torque, and temperature. The array dimensions must match the speed, `M`, torque, `N`, and temperature, `L`, breakpoint vector dimensions.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Tabulated loss data with temperature`.

Corresponding efficiency, efficiency_table — 2D lookup table

M-by-N matrix

Array of efficiency as a function of speed and torque, in %. Each value specifies the losses for a specific combination of speed and torque. The array dimensions must match the speed, `M`, and torque, `N`, breakpoint vector dimensions.

The block ignores efficiency values for zero speed or zero torque. Losses are zero when either torque or speed is zero. The block uses linear interpolation.

To get the desired level of accuracy for lower power conditions, you can provide tabulated data for low speeds and low torques.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Tabulated efficiency data`.

`Corresponding efficiency, efficiency_table_3d` — 3D lookup table

`M`-by-`N`-by-`L` array

Array of efficiency as a function of speed and torque, in %. Each value specifies the losses for a specific combination of speed and torque. The array dimensions must match the speed, `M`, torque, `N`, and temperature, `L`, breakpoint vector dimensions.

The block ignores efficiency values for zero speed or zero torque. Losses are zero when either torque or speed is zero. The block uses linear interpolation.

To get the desired level of accuracy for lower power conditions, you can provide tabulated data for low speeds and low torques.

Dependencies

To create this parameter, for the **Parameterize losses by** parameter, select `Tabulated efficiency data`.

Mechanical

`Rotor inertia, J` — Inertia

`5e-6` (default) | `scalar`

Rotor resistance to change in motor motion, in kg*m^2. The value can be zero.

Dependencies

To create this parameter, for the **Port configuration** parameter, select `Torque`.

`Rotor damping, b` — Damping

`1e-5` (default) | `scalar`

Rotor damping, in N·m/(rad/s). The value can be zero.

Dependencies

To create this parameter, for the **Port configuration** parameter, select `Torque`.

`Initial rotor speed, omega_o` — Speed

`0` (default) | `scalar`

Rotor speed at the start of the simulation, in rad/s.

Dependencies

To create this parameter, for the **Port configuration** parameter, select `Torque`.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

Flux-Based PMSM | Induction Motor | Interior PMSM | Surface Mount PMSM

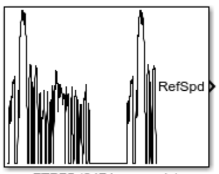
Introduced in R2017a

Scenario Creation Blocks

Drive Cycle Source

Standard or specified longitudinal drive cycle

Library: Powertrain Blockset / Vehicle Scenario Builder
Vehicle Dynamics Blockset / Vehicle Scenarios / Drive Cycle and Maneuvers



FTP75 (2474 seconds)

Description

The Drive Cycle Source block generates a standard or user-specified longitudinal drive cycle. The block output is the specified vehicle longitudinal speed, which you can use to:

- Predict the engine torque and fuel consumption that a vehicle requires to achieve desired speed and acceleration for a given gear shift reference.
- Produce realistic velocity and shift references for closed loop acceleration and braking commands for vehicle control and plant models.
- Study, tune, and optimize vehicle control, system performance, and system robustness over multiple drive cycles.
- Identify the faults within tolerances specified by standardized tests, including:
  - EPA dynamometer driving schedules[1]
  - Worldwide Harmonised Light Vehicle Test Procedure (WLTP) laboratory tests[2]

For the drive cycles, you can use:

- Drive cycles from predefined sources. By default, the block includes the `FTP–75` drive cycle. To install additional drive cycles from a support package, see "Install Drive Cycle Data". The support package has drive cycles that include the gear shift schedules, for example `JC08` and `CUEDC`.
- Workspace variables that define your own drive cycles.
- `.mat`, `.xls`, `.xlsx`, or `.txt` files.
- Wide open throttle (WOT) parameters, including initial and nominal reference speed, deceleration start time, and final reference speed.

To achieve the goals listed in the table, use the specified Drive Cycle Source block parameter options.

Goal	Action
Repeat the drive cycle if the simulation run time exceeds the drive cycle length.	Select **Repeat cyclically**.

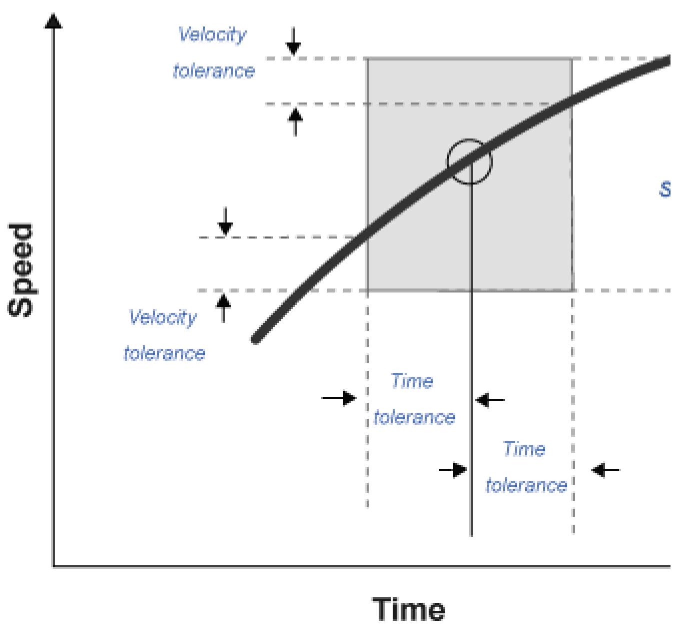
Goal	Action
Output the acceleration, as calculated by Savitzky-Golay differentiation.	Select **Output acceleration**.
Specify a sample period for discrete applications.	Specify a **Output sample period (0 for continuous), dt** parameter.
Update the simulation run time so that it equals the length of the drive cycle.	Click **Update simulation time**. If a model configuration reference exists, the block does not enable this option.
Plot the drive cycle in a MATLAB® figure.	Click **Plot drive cycle**.
Specify the drive cycle using a workspace variable.	Click **Specify variable**. The block: • Sets the **Drive cycle source** parameter to `Workspace variable`. • Enables the **From workspace** parameter. Specify the workspace variable so that it contains time, velocity, and, optionally, the gear shift schedule. For examples, see “Create Drive Cycles Using Workspace Variables” on page 6-5.
Specify the drive cycle using a file.	Click **Select file**. The block: • Sets the **Drive cycle source** parameter to `.mat, .xls, .xlsx or .txt file`. • Enables the **Drive cycle source file** parameter. Specify a file that contains time, velocity, and, optionally, the gear shift schedule.
Output drive cycle gear.	Specify a drive cycle that contains a gear shift schedule. You can use: • A support package to install standard drive cycles that include the gear shift schedules, for example `JC08` and `CUEDC`. • Workspace variables. • `.mat`, `.xls`, `.xlsx`, or `.txt` files. Click **Output gear shift data**.
Install additional drive cycles from a support package.	Click **Install additional drive cycles**. The block enables the parameter if you can install additional drive cycles from a support package.
Identify drive cycle faults within tolerances specified by standardized tests.	On the **Fault Tracking** tab, use the parameters to specify the fault tolerances. If the vehicle speed is not within the allowable speed range, the block sets a fault condition.

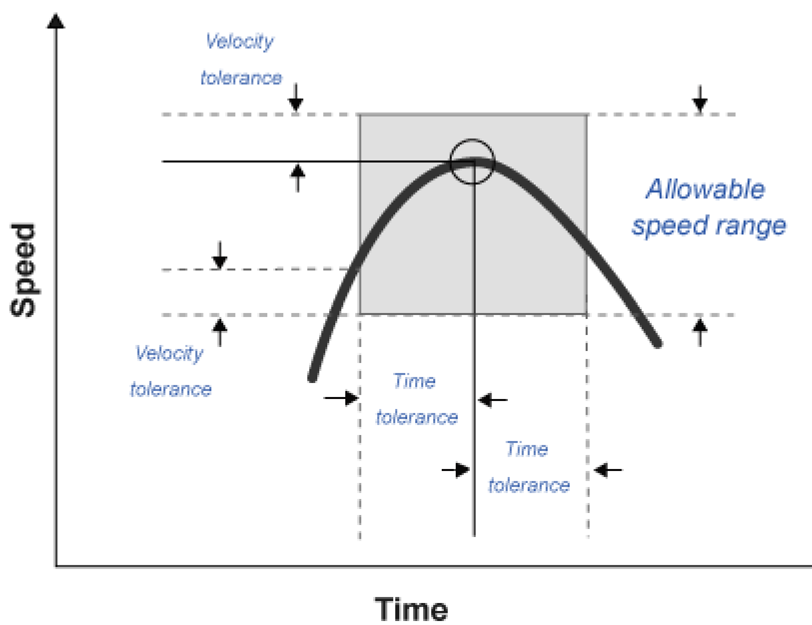
Fault and Failure Tracking

On the **Fault Tracking** tab, use the parameters to specify the fault tolerances. If the vehicle speed or time is not within the allowable range, the block sets a fault condition.

Parameter	Description	Setting	
		EPA Standard[1]	WLTP Tests[2]
Speed tolerance	Speed tolerance above the highest point and below the lowest point of the drive cycle speed trace within the time tolerance.	2.0 mph	2.0 km/h
Time tolerance	Time that the block uses to determine the speed tolerance.	1.0 s	1.0 s
Maximum number of faults	Maximum number of faults during the drive cycle.	*Not specified*	10
Maximum single fault time	Maximum fault duration.	2.0 s	1.0 s
Maximum total fault time	Maximum accumulated time spent under fault condition.	*Not specified*	*Not specified*

These figures illustrate how the block uses the velocity and time tolerances to determine the allowable speed range.



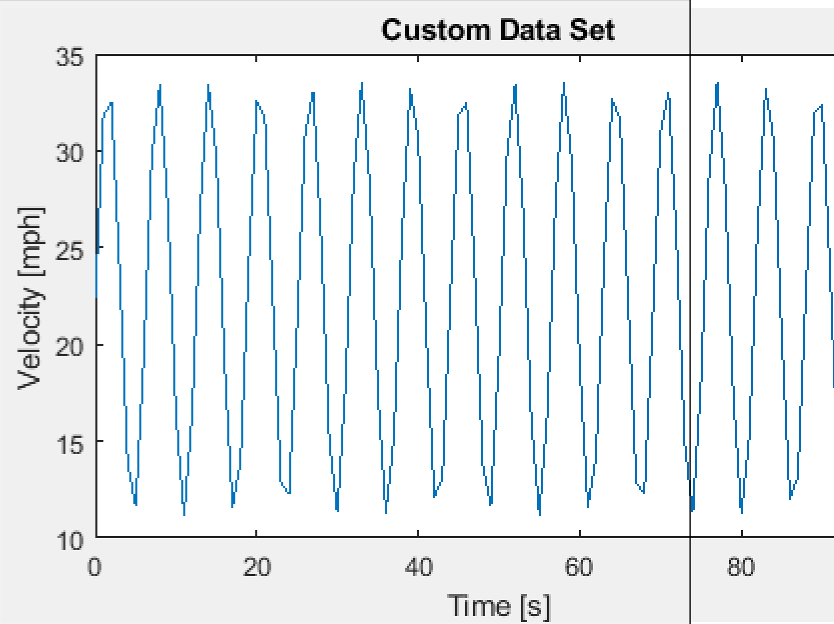


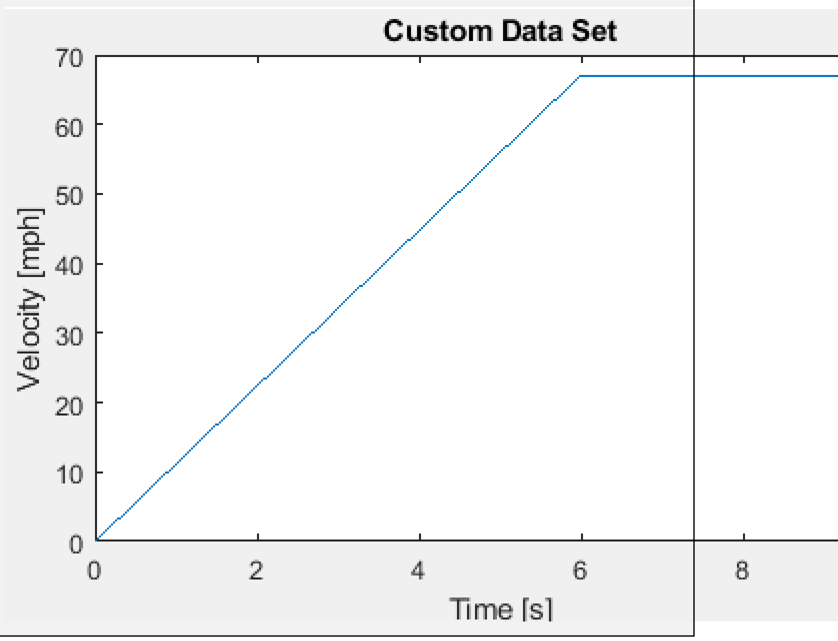
Create Drive Cycles Using Workspace Variables

If you set **Drive cycle source** to `Workspace variable`, you can specify a workspace variable that defines the drive cycle.

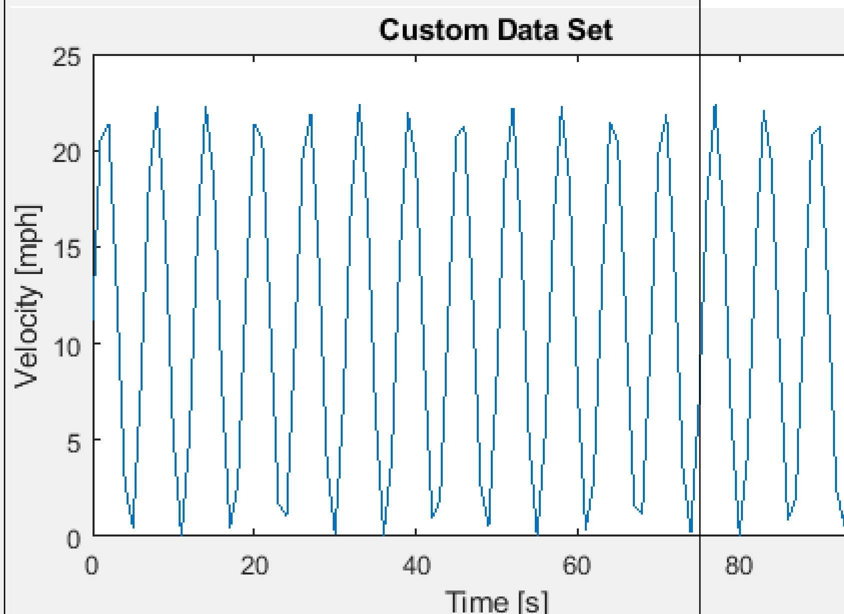
This table provides examples for using workspace variables to create your own drive cycles.

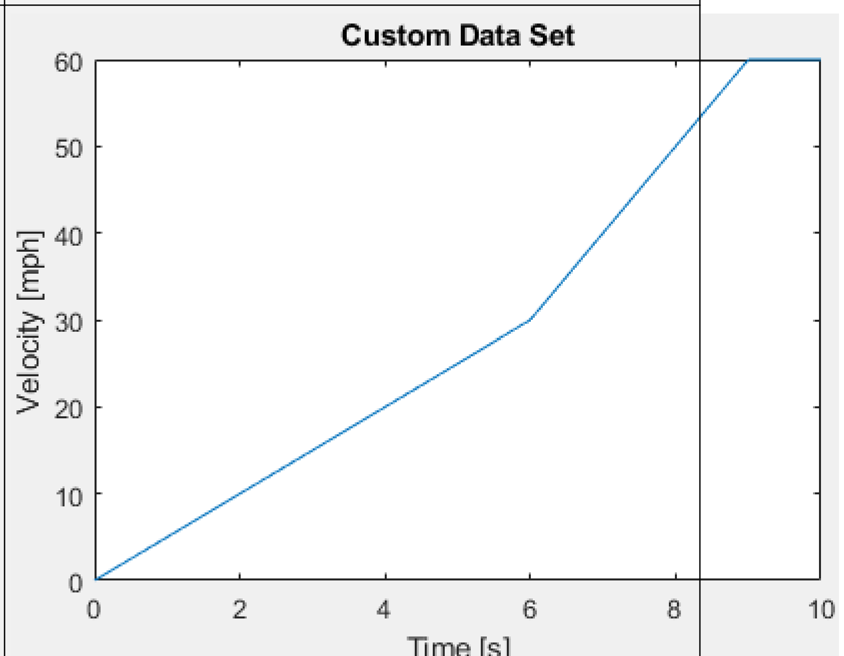
Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot

Structure without a gear shift schedule. **From workspace** set to `myCycleS`.
 	
`t = 0:1:100;`
`xdot = 5.*sin(t)+10;`
`myCycleS.time = t';`
`myCycleS.signals.values = xdot';`
	`m/s`	`mph`	

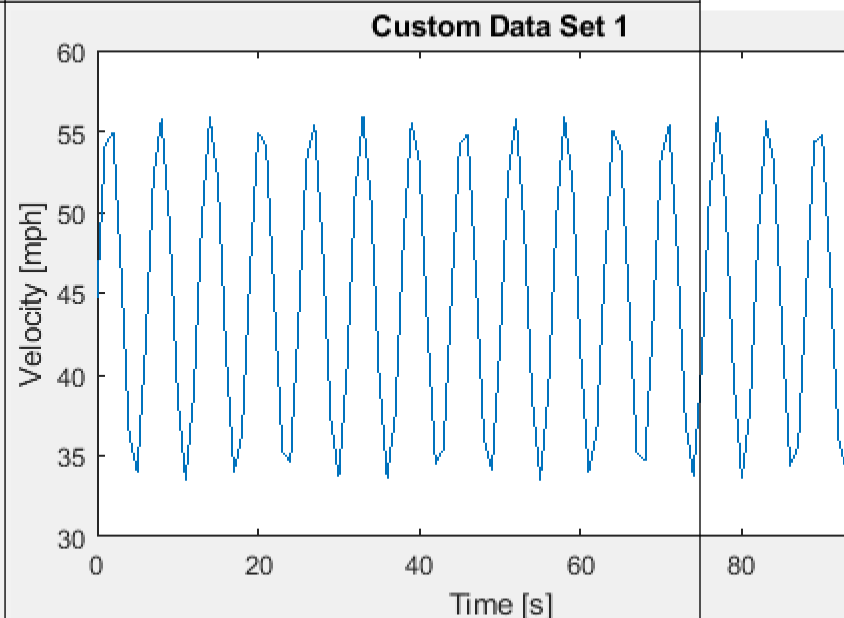
Structure with a gear shift schedule. **From workspace** set to `myCycleS`.
 	
`gears=[0, 1, 2, 3, 3, 4, 4, 4, 4, 4, 4];`
`t=0:1:10;`
`xdot=[0,5,10,15,20,25,30,30,30,30,30];`
`myCycleS.time=t';`
`myCycleS.signals.values=[xdot',gears'];`
	`m/s`	`mph`	

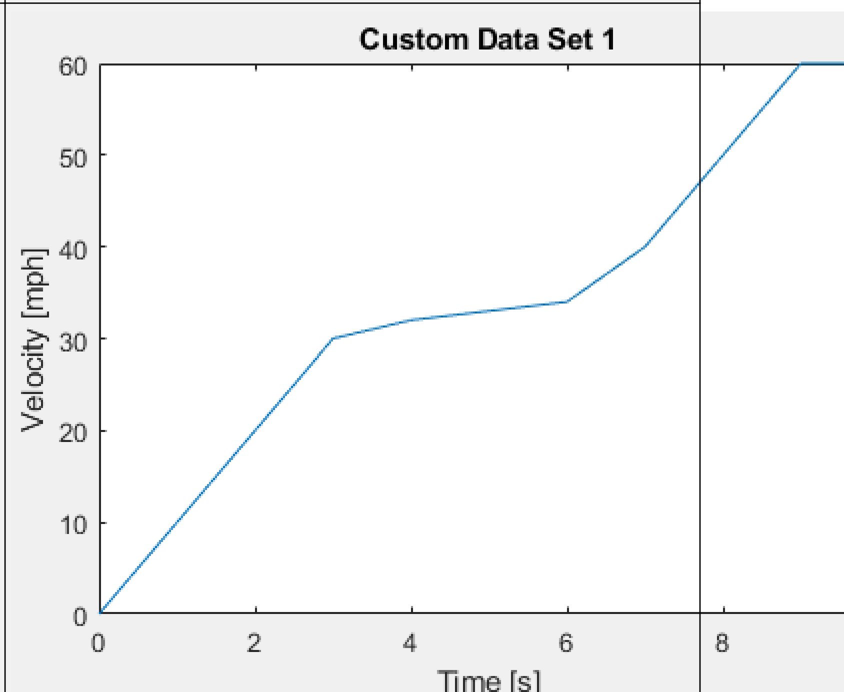
Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot

2-D array without a gear shift schedule. **From workspace** set to `myCycleA`.
 	
`t = 0:1:100;`
`xdot = 5.*sin(t)+5;`
`myCycleA = [t',xdot'];`
	`m/s`	`mph`	

2-D array with a gear shift schedule. **From workspace** set to `myCycleA`.
 	
`gears=[0, 1, 2, 3, 4, 4, 4, 5, 5, 5, 5];`
`t=0:1:10;`
`xdot=[0,5,10,15,20,25,30,40,50,60,60];`
`myCycleA=[t',xdot',gears'];`
	`mph`	`mph`	

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot

Time series object without a gear shift schedule. **From workspace** set to `myCycleT`.
 	
`myCycleT = timeseries;`
`t = 0:1:100;`
`xdot = 5.*sin(t)+20;`
`myCycleT.Data = xdot';`
`myCycleT.Time = t;`
	m/s	mph	

Time series object without a gear shift schedule. **From workspace** set to `myCycleT`.
 	
`myCycleT = timeseries;`
`gears=[0, 1, 2, 3, 4, 4, 4, 5, 5, 5, 5];`
`t=0:1:10;`
`xdot=[0,10,20,30,32,33,34,40,50,60,60];`
`myCycleT.Data = [xdot',gears'];`
`myCycleT.Time = t';`
	mph	mph	

Ports

Input

VelFdbk — Vehicle longitudinal speed
scalar

Longitudinal vehicle speed.

Dependencies

To enable this port, on the **Fault Tracking** tab, select **Enable fault tracking**. Set the **Velocity feedback units, inUnit** parameter to the `VelFdbk` input port signal units.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal		Description
`Reference Speed`		Vehicle reference speed
`Reference Accel`		Vehicle reference acceleration
`Gear`		Vehicle gear
`Fault`	`UpprBnd`	Upper bound of allowable vehicle speed range.
	`LowerBnd`	Lower bound of allowable vehicle speed range.
	`Fault`	Boolean value indicating fault condition: • 1 — Fault • 0 — No fault If the vehicle speed is not within the allowable speed range, the block sets a fault condition.
	`FaultCnt`	Number of faults.
	`CumFaultTime`	Cumulative time spent in fault condition.
	`SnglFaultTime`	Tim spent in a single fault.
	`Fail`	Boolean value indicating fault failure: • 1 — Failure • 0 — No failure If the fault conditions exceed the maximum number of faults, maximum single fault time, or maximum total fault time, the block sets a fault failure.

Dependencies

To enable this port, on the **Fault Tracking** tab, select **Enable fault tracking**.

`RefSpd` — Vehicle reference speed
`scalar`

Vehicle reference speed, in units that you specify. To specify the units, use the **Output velocity units** parameter.

`RefAcc` — Vehicle reference acceleration
`scalar`

To calculate the acceleration, the block implements Savitzky-Golay differentiation using a second-order polynomial with a three-sample point filter.

Dependencies

To create the output acceleration port, select **Output acceleration**. Selecting **Output acceleration** enables the **Output acceleration units** parameter.

Gear — Vehicle gear
scalar

Dependencies

To enable this port:

1. Specify a drive cycle that contains a gear shift schedule. You can use:
   - A support package to install standard drive cycles that include the gear shift schedules, for example `JC08` and `CUEDC`.
   - Workspace variables.
   - `.mat`, `.xls`, `.xlsx`, or `.txt` files.
2. Select **Output gear shift** data.

Parameters

Cycle Setup

Setup

`Drive cycle source` — Select the drive cycle source
`FTP75` (default) | `Wide Open Throttle (WOT)` | `Workspace variable` | `.mat, .xls, .xlsx or .txt file`

- `FTP75` — Load the FTP75 drive cycle from a `.mat` file into a 1-D Lookup Table block. The FTP75 represents a city drive cycle that you can use to determine tailpipe emissions and fuel economy of passenger cars. To install additional drive cycles from a support package, see "Install Drive Cycle Data".
- `Wide Open Throttle (WOT)` — Use WOT parameters to specify a drive cycle for performance testing.
- `Workspace variable` — Specify time, speed, and, optionally, gear data as a structure, 2-D array, or time series object.
- `.mat, .xls, .xlsx or .txt file` — Specify a file that contains time, speed and, optionally, gear data in column format.

Once you have installed additional cycles, you can use `set_param` to set the drive cycle. For example, to use drive cycle `US06`:

```
set_param([gcs '/Drive Cycle Source'],'cycleVar','US06')
```

Dependencies

The table summarizes the parameter dependencies.

Drive Cycle Source	Enables Parameter
`Wide Open Throttle (WOT)`	**Start time, t_wot1**
	Initial reference speed, xdot_woto
	Nominal reference speed, xdot_wot1
	Time to start deceleration, wot2
	Final reference speed, xdot_wot2
	WOT simulation time, t_wotend
	Source velocity units
`Workspace variable`	**From workspace**
	Source velocity units
	Output gear shift data, if drive cycle includes gear shift schedule
`.mat, .xls, .xlsx or .txt file`	**Drive cycle source file**
	Source velocity units
	Output gear shift data, if drive cycle includes gear shift schedule

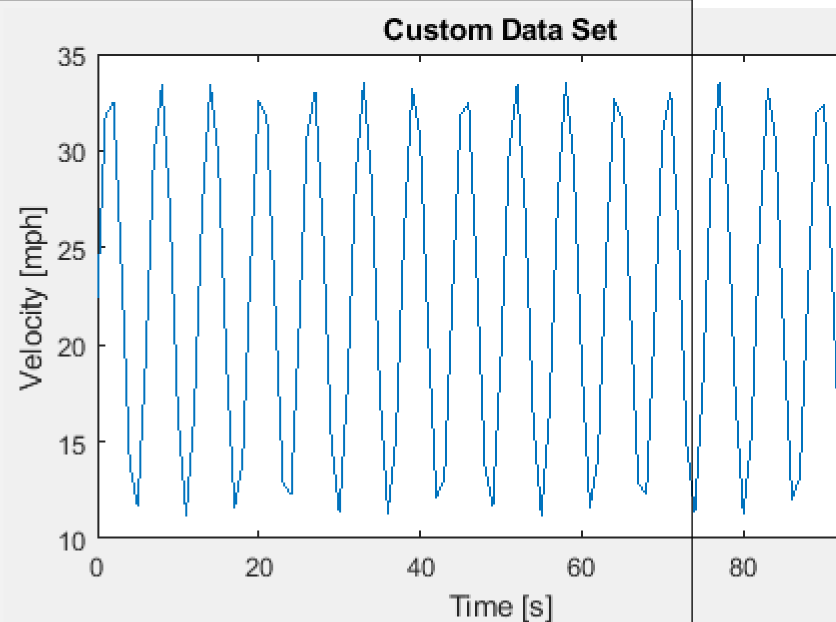
`From workspace` — Workspace
`variable`

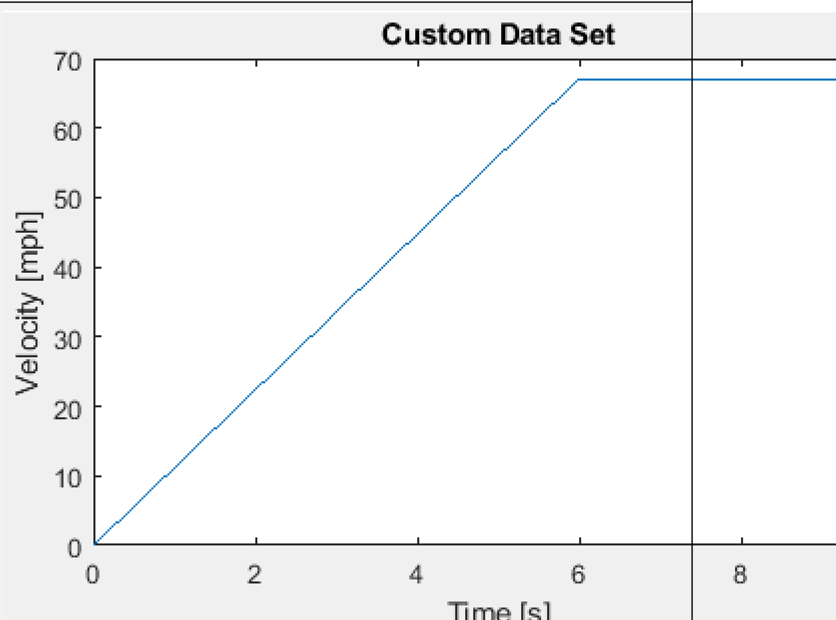
Monotonically increasing time, velocity, and, optionally, gear data, specified by a structure, 2-D array, or time series object. Enter units for velocity in the **Source velocity units** parameter field.

A valid point must exist for each corresponding time value. You cannot specify `inf`, `empty`, or `NaN`.

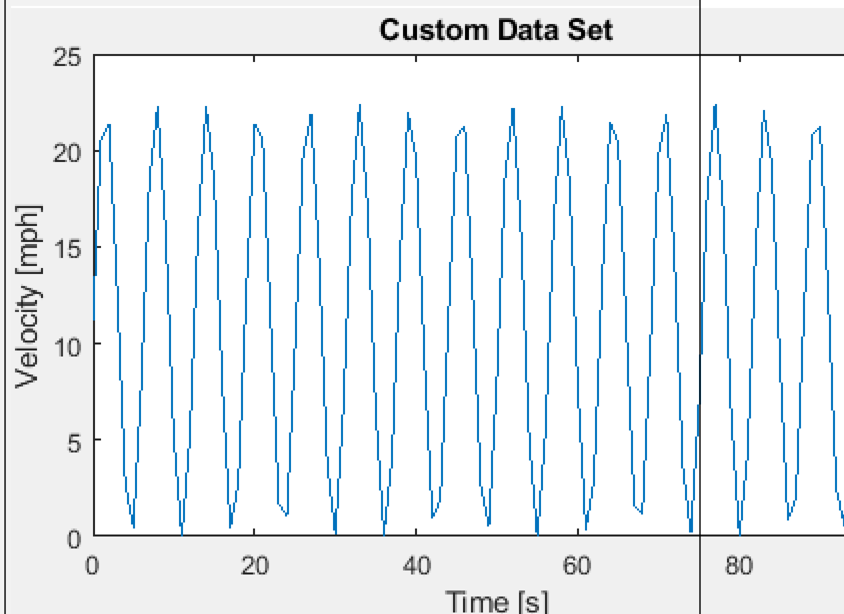
This table provides examples for using workspace variables to create your own drive cycles.

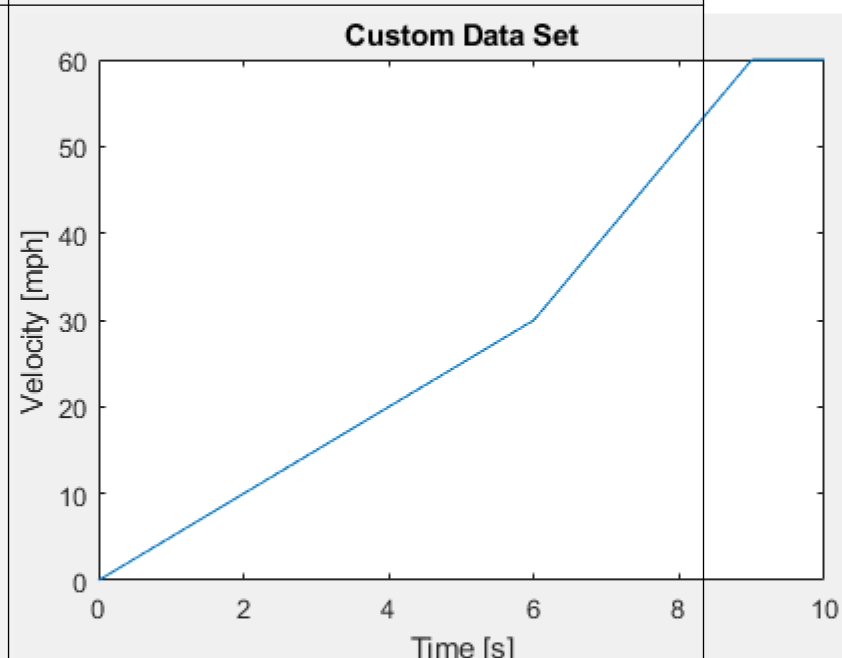
Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot

Structure without a gear shift schedule. **From workspace** set to `myCycleS`.
 	
`t = 0:1:100;`
`xdot = 5.*sin(t)+10;`
`myCycleS.time = t';`
`myCycleS.signals.values = xdot';`
	`m/s`	`mph`	

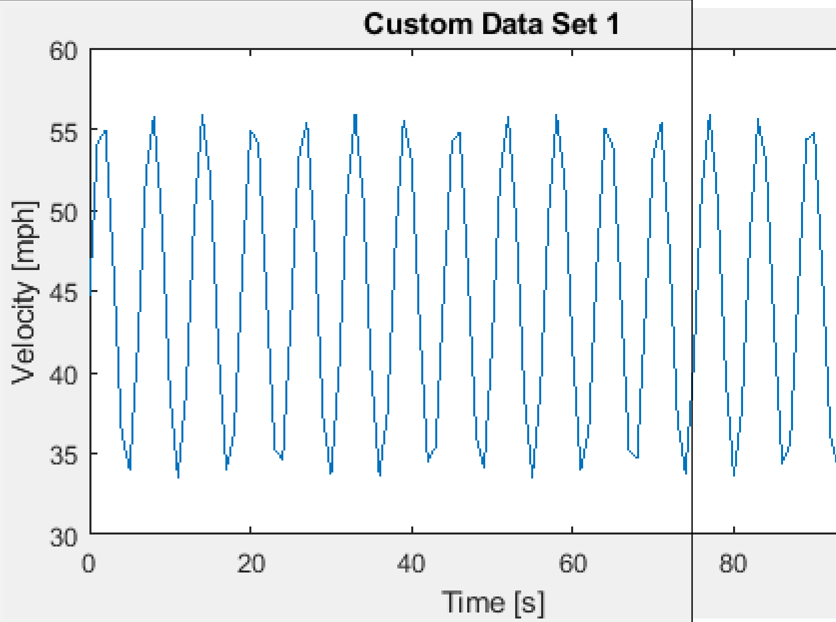
Structure with a gear shift schedule. **From workspace** set to `myCycleS`.
 	
`gears=[0, 1, 2, 3, 3, 4, 4, 4, 4, 4, 4];`
`t=0:1:10;`
`xdot=[0,5,10,15,20,25,30,30,30,30,30];`
`myCycleS.time=t';`
`myCycleS.signals.values=[xdot',gears'];`
	`m/s`	`mph`	

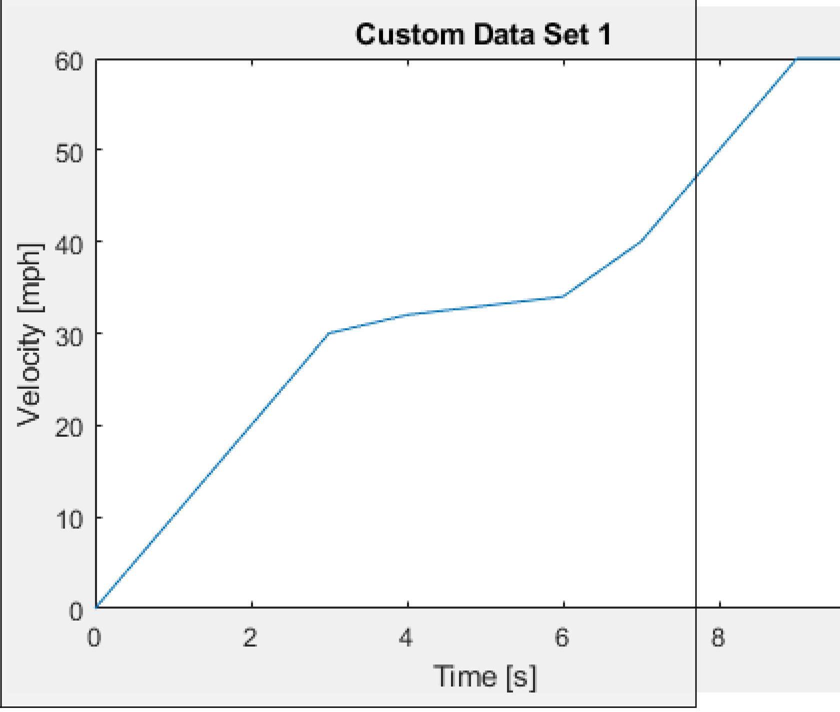
Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot

2-D array without a gear shift schedule. **From workspace** set to `myCycleA`.
 	
`t = 0:1:100;`
`xdot = 5.*sin(t)+5;`
`myCycleA = [t',xdot'];`
	`m/s`	`mph`	

2-D array with a gear shift schedule. **From workspace** set to `myCycleA`.
 	
`gears=[0, 1, 2, 3, 4, 4, 4, 5, 5, 5, 5];`
`t=0:1:10;`
`xdot=[0,5,10,15,20,25,30,40,50,60,60];`
`myCycleA=[t',xdot',gears'];`
	`mph`	`mph`	

Workspace Variable	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot

Time series object without a gear shift schedule. **From workspace** set to `myCycleT`.
 	
`myCycleT = timeseries;`
`t = 0:1:100;`
`xdot = 5.*sin(t)+20;`
`myCycleT.Data = xdot';`
`myCycleT.Time = t;`
	`m/s`	`mph`	

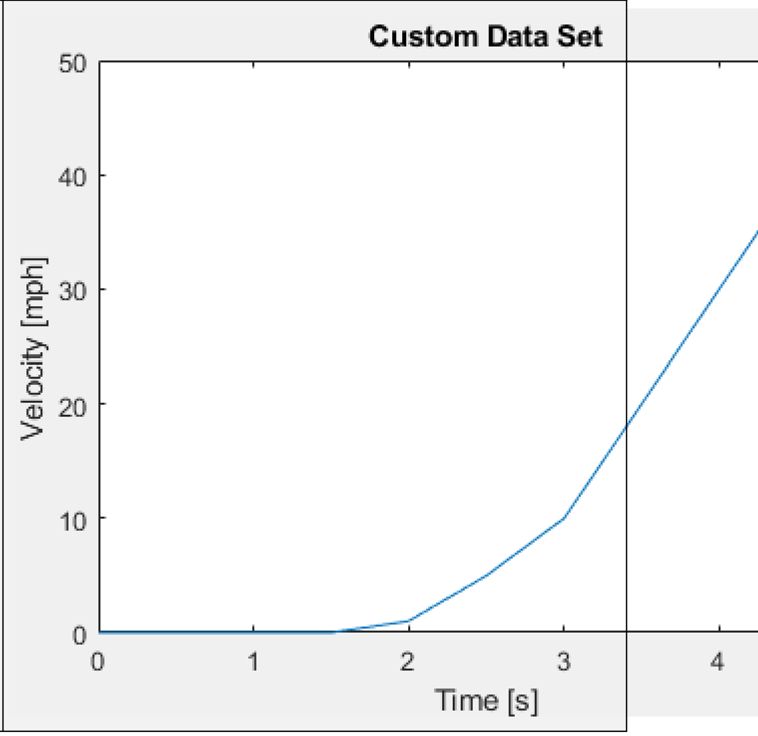
Time series object without a gear shift schedule. **From workspace** set to `myCycleT`.
 	
`myCycleT = timeseries;`
`gears=[0, 1, 2, 3, 4, 4, 4, 5, 5, 5, 5];`
`t=0:1:10;`
`xdot=[0,10,20,30,32,33,34,40,50,60,60];`
`myCycleT.Data = [xdot',gears'];`
`myCycleT.Time = t';`
	`mph`	`mph`	

Dependencies

To enable this parameter, select `Workspace variable` from **Drive cycle source**.

`Drive cycle source file` — File name
`.mat, .xls, .xlsx or .txt`

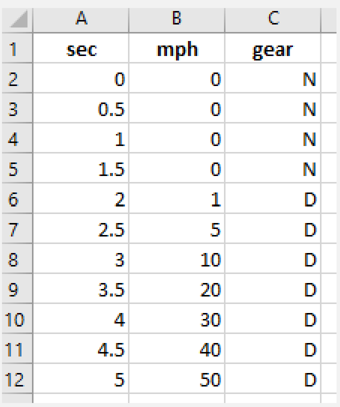
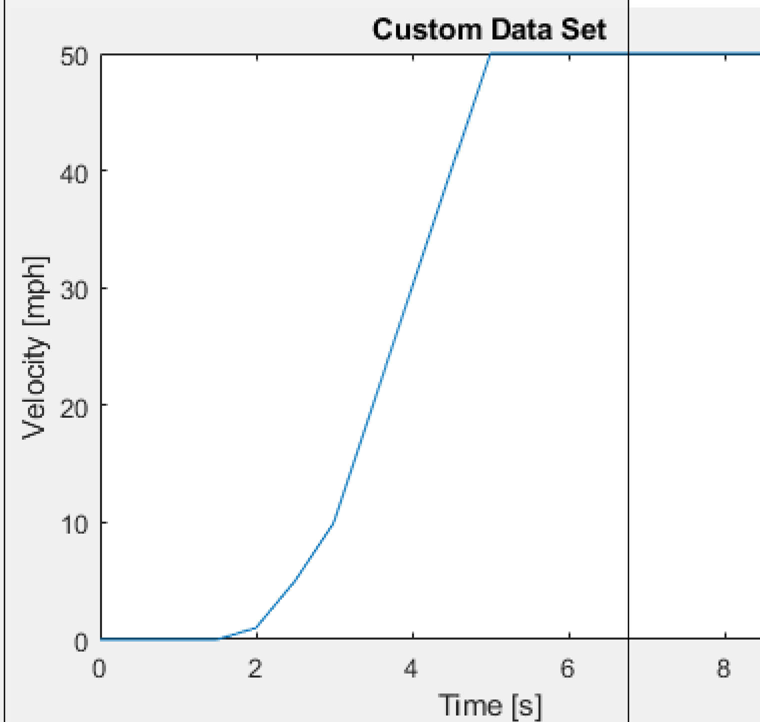
File containing monotonically increasing time, velocity, and, optionally, gear in column or comma-separated format. The block ignores units in the file. Enter units for velocity in the **Source velocity units** parameter field.

<table>
<tr><th>File</th><th>Source Velocity Unit</th><th>Output Velocity Unit</th><th>Drive Cycle Plot</th></tr>
<tr><td>An .xls or .xlsx file with time in column A and velocity in column B.
<table>
<tr><th></th><th>A</th><th>B</th></tr>
<tr><td>1</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>0.5</td><td>0</td></tr>
<tr><td>3</td><td>1</td><td>0</td></tr>
<tr><td>4</td><td>1.5</td><td>0</td></tr>
<tr><td>5</td><td>2</td><td>1</td></tr>
<tr><td>6</td><td>2.5</td><td>5</td></tr>
<tr><td>7</td><td>3</td><td>10</td></tr>
<tr><td>8</td><td>3.5</td><td>20</td></tr>
<tr><td>9</td><td>4</td><td>30</td></tr>
<tr><td>10</td><td>4.5</td><td>40</td></tr>
<tr><td>11</td><td>5</td><td>50</td></tr>
</table></td><td>mph</td><td>mph</td><td>
</td></tr>
</table>

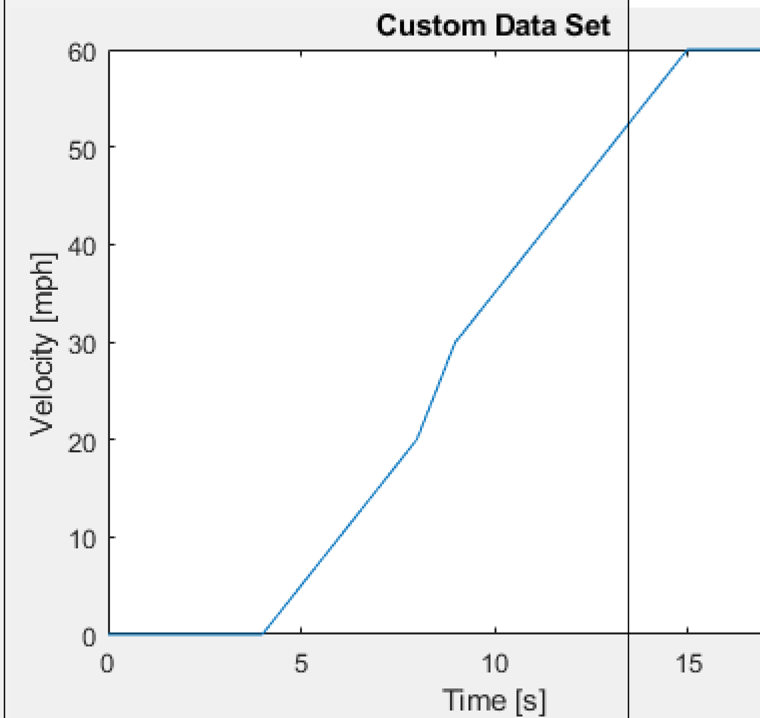
<table>
<tr><th>File</th><th>Source Velocity Unit</th><th>Output Velocity Unit</th><th>Drive Cycle Plot</th></tr>
<tr><td>An <code>.xls</code> or <code>.xlsx</code> file with time in column A, velocity in column B, and gear in column C. The block:

Ignores the units in the file.
Converts the gear information to integers:

N to 0
D to 2


<table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>1</td><td>sec</td><td>mph</td><td>gear</td></tr>
<tr><td>2</td><td>0</td><td>0</td><td>N</td></tr>
<tr><td>3</td><td>0.5</td><td>0</td><td>N</td></tr>
<tr><td>4</td><td>1</td><td>0</td><td>N</td></tr>
<tr><td>5</td><td>1.5</td><td>0</td><td>N</td></tr>
<tr><td>6</td><td>2</td><td>1</td><td>D</td></tr>
<tr><td>7</td><td>2.5</td><td>5</td><td>D</td></tr>
<tr><td>8</td><td>3</td><td>10</td><td>D</td></tr>
<tr><td>9</td><td>3.5</td><td>20</td><td>D</td></tr>
<tr><td>10</td><td>4</td><td>30</td><td>D</td></tr>
<tr><td>11</td><td>4.5</td><td>40</td><td>D</td></tr>
<tr><td>12</td><td>5</td><td>50</td><td>D</td></tr>
</table>
</td><td><code>mph</code></td><td><code>mph</code></td><td>
</td></tr>
</table>

File	Source Velocity Unit	Output Velocity Unit	Drive Cycle Plot

A `.txt` with time in column 1 and velocity in column 2. The block ignores the header and units information.
 	
`Time Speed`
`sec mph`
`0 0`
`1 0`
`2 0`
`3 0`
`4 0`
`5 5`
`6 10`
`7 15`
`8 20`
`9 30`
`10 35`
`11 40`
`12 45`
`13 50`
`14 55`
`15 60`
`16 60`
`17 60`
`18 60`
`19 60`
`20 60`
	`mph`	`mph`	

If you provide the gear schedule using **P**, **R**, **N**, **D**, **L**, **OD**, the block maps the gears to integers.

Gear	Integer
P	`80`
R	`-1`
N	`0`
L	`1`
D	`2`
OD	Next integer after highest specified gear.

For example, the block converts the gear schedule `P P N L D 3 4 5 6 5 4 5 6 7 OD 7` to `80 80 0 1 2 3 4 5 6 5 4 5 6 7 8 7`.

Dependencies

To enable this parameter, select `.mat, .xls, .xlsx or .txt file` from **Drive cycle source**.

`Repeat cyclically` — Repeat drive cycle
`off` (default) | `on`

Repeat the drive cycle if the simulation run time exceeds the length of the drive cycle.

`Output acceleration` — Output the acceleration

`off` (default)

To calculate the acceleration, the block implements Savitzky-Golay differentiation using a second-order polynomial with a three-sample point filter.

Dependencies

To create the output acceleration port, select **Output acceleration**. Selecting **Output acceleration** enables the **Output acceleration units** parameter.

`Output gear shift data` — Output the gear

`off` (default) | `on`

Dependencies

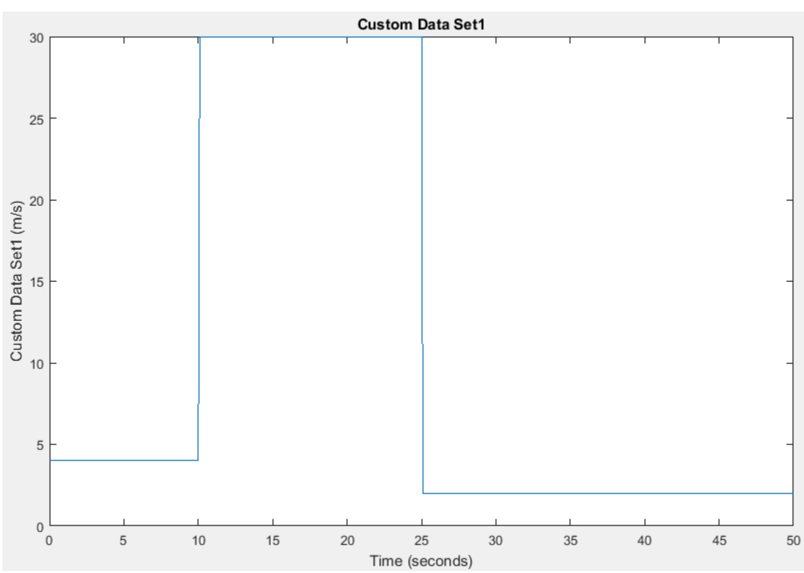
- Specify a drive cycle that contains a gear shift schedule. You can use:
  - A support package to install standard drive cycles that include the gear shift schedules, for example `JC08` and `CUEDC`.
  - Workspace variables.
  - `.mat`, `.xls`, `.xlsx`, or `.txt` files.
- Clicking this parameter creates input port **Gear**.

WOT

`Start time, t_wot1` — Drive cycle start time

`5` (default) | `scalar`

Drive cycle start time, in s. For example, this plot shows a drive cycle with a start time of `10` s.

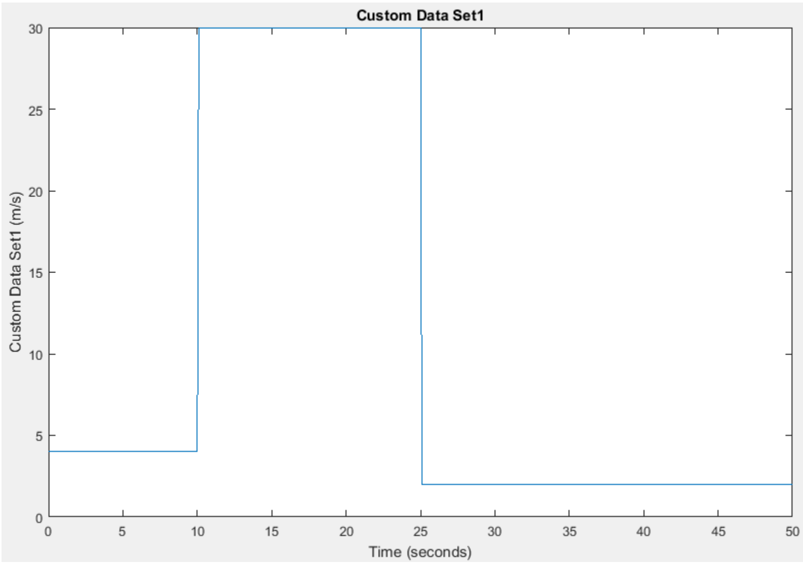


Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

Initial reference speed, xdot_woto — Speed
`0` (default) | `scalar`

Initial reference speed, in units that you specify with the **Source velocity units** parameter. For example, this plot shows a drive cycle with an initial reference speed of `4` m/s.

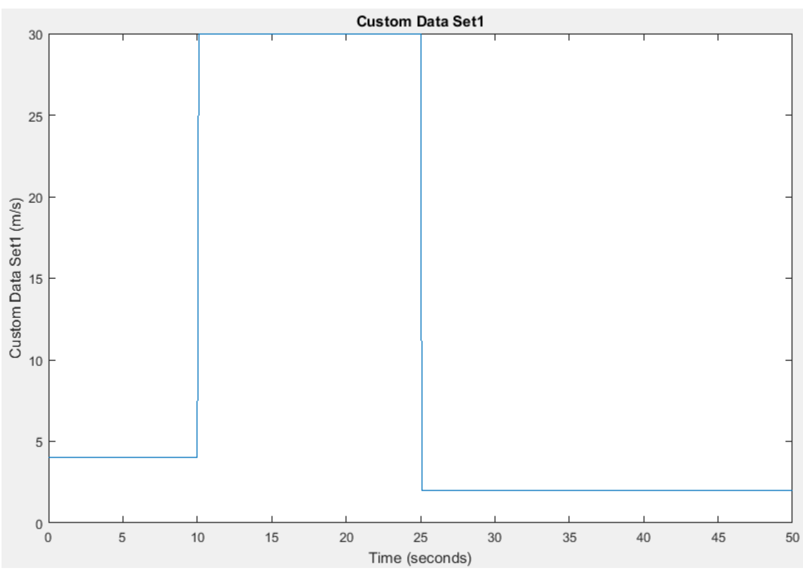


Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

Nominal reference speed, xdot_wot1 — Speed
`30` (default) | `scalar`

Nominal reference speed, in units that you specify with the **Source velocity units** parameter. For example, this plot shows a drive cycle with a nominal reference speed of `30` m/s.



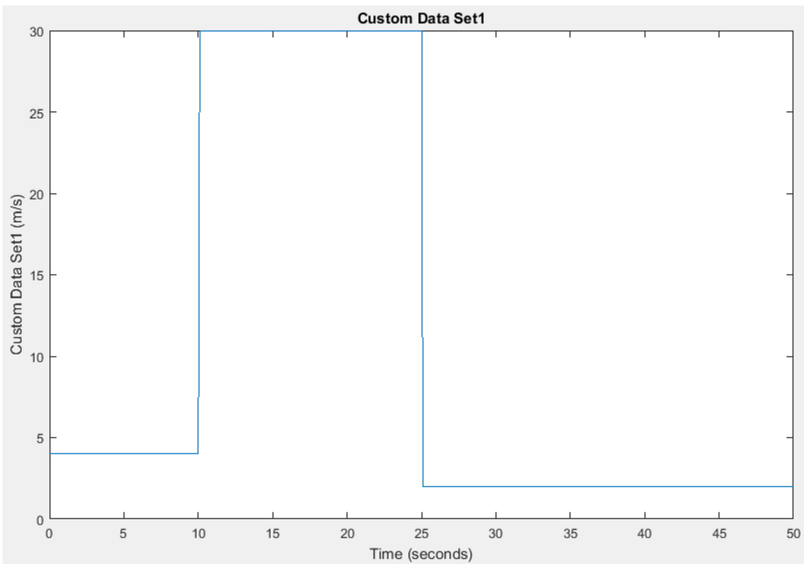
Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

`Time to start deceleration, wot2` — Time

`20` (default) | `scalar`

Time to start vehicle deceleration, in s. For example, this plot shows a drive cycle with vehicle deceleration starting at 25 s.



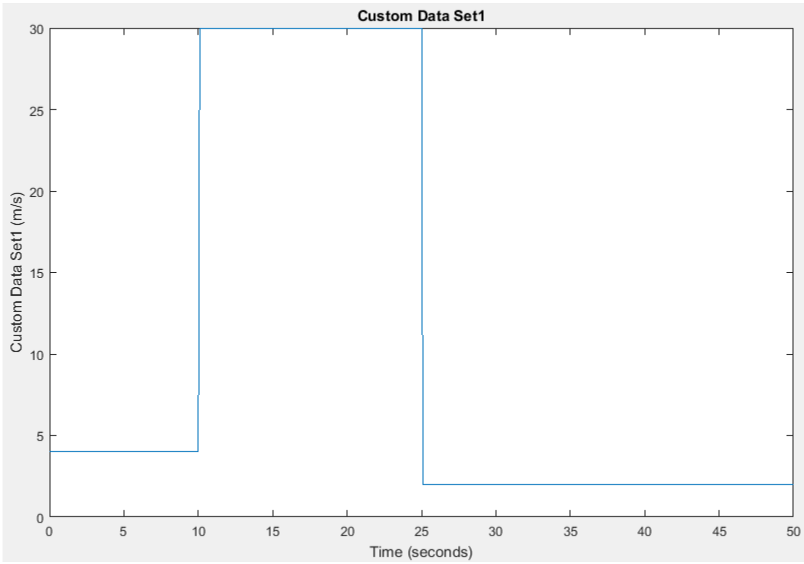
Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

`Final reference speed, xdot_wot2` — Speed

`0` (default) | `scalar`

Final reference speed, in units that you specify with the **Source velocity units** parameter. For example, this plot shows a drive cycle with a final reference speed of 2 m/s.



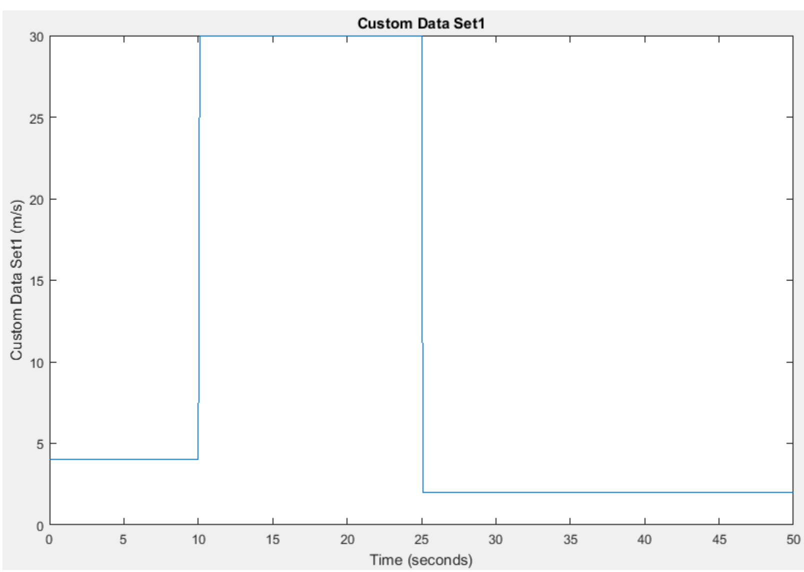
Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

`WOT simulation time, t_wotend` — Time

`30` (default) | `scalar`

Drive cycle WOT simulation time, in s. For example, this plot shows a drive cycle with a simulation time of `50` s.



Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

Units and Sample Period

`Source velocity units` — Specify velocity units
`m/s` (default)

Input velocity units.

Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`, `Workspace variable`, or `.mat, .xls, .xlsx or .txt file`.

`Output velocity units` — Specify velocity units
`m/s` (default)

Output velocity units.

`Output acceleration units` — Specify acceleration units
`m/s^2` (default)

Specify the output acceleration units.

Dependencies

To enable this parameter, select **Output acceleration**.

`Output sample period (0) for continuous` — Sample rate
`0` (default) | `scalar`

Sample rate. Set to `0` for continuous sample period. For a discrete period, specify a non-zero rate.

Fault Tracking

Fault Settings

`Enable fault tracking` — Enable fault tracking
`off` (default) | `on`

Select this parameter to enable drive cycle fault tracking. Use the parameters to specify the fault tolerances. If the vehicle speed is not within the allowable speed range, the block sets a fault condition.

Dependencies

Selecting this parameter enables these parameters:

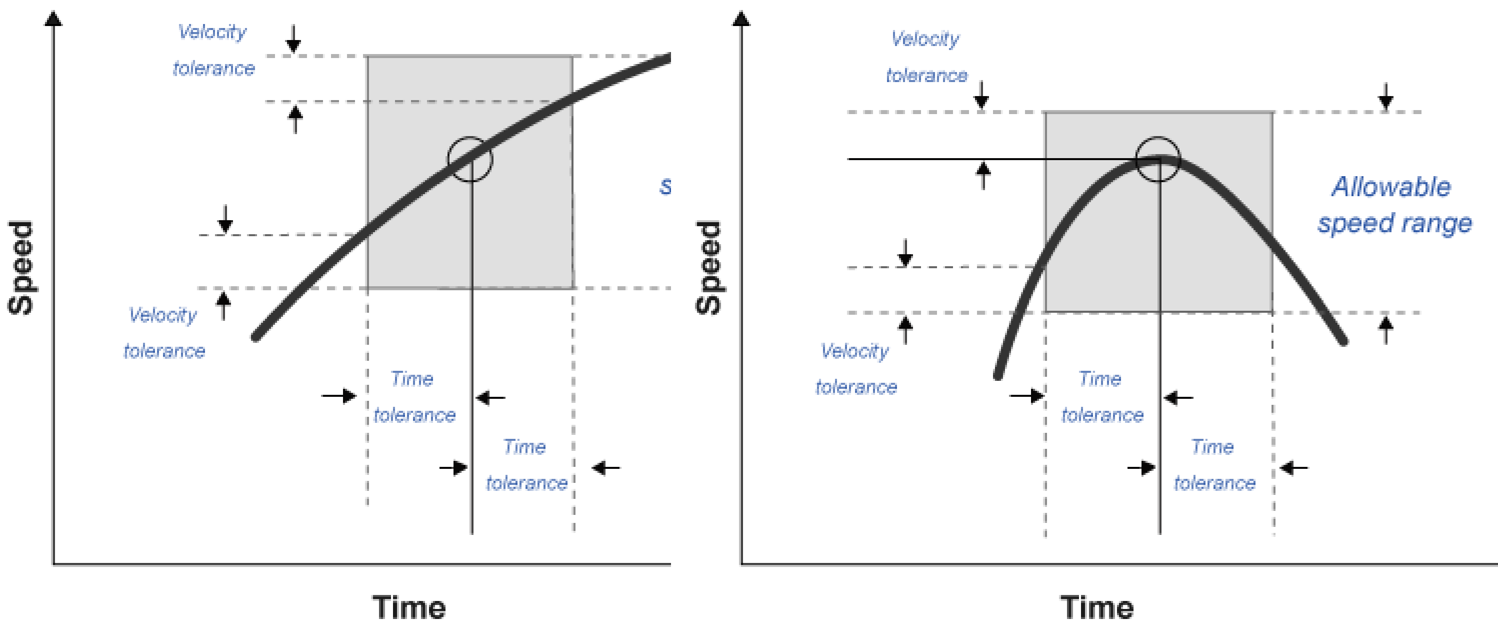
- **Speed tolerance, velBnd**
- **Speed tolerance units, velBndUnit**
- **Velocity feedback units, inUnit**
- **Time tolerance, timeBnd**

`Speed tolerance, velBnd` — Drive cycle speed tolerance
`2.0` (default) | `scalar`

The speed tolerance above the highest point and below the lowest point of the drive cycle speed trace within the time tolerance. If the vehicle speed is not within the allowable speed range, the block sets a fault condition. For the tolerances specified by the standardized tests, use these settings:

- EPA dynamometer driving schedules — `2.0`
- WLTP tests — `2.0`

These figures illustrate how the block uses the velocity and time tolerances to determine the allowable speed range.



Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable fault tracking**.

`Speed tolerance units, velBndUnit` — Set units

`mph` (default)

Speed tolerance units. For the units specified by the standardized tests, use these units:

- EPA dynamometer driving schedules — `m/s`
- WLTP tests — `km/h`

Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable fault tracking**.

`Velocity feedback units, inUnit` — Set velocity feedback units

`m/s` (default)

Velocity feedback units. Set the value to the `VelFdbk` input port signal units.

Dependencies

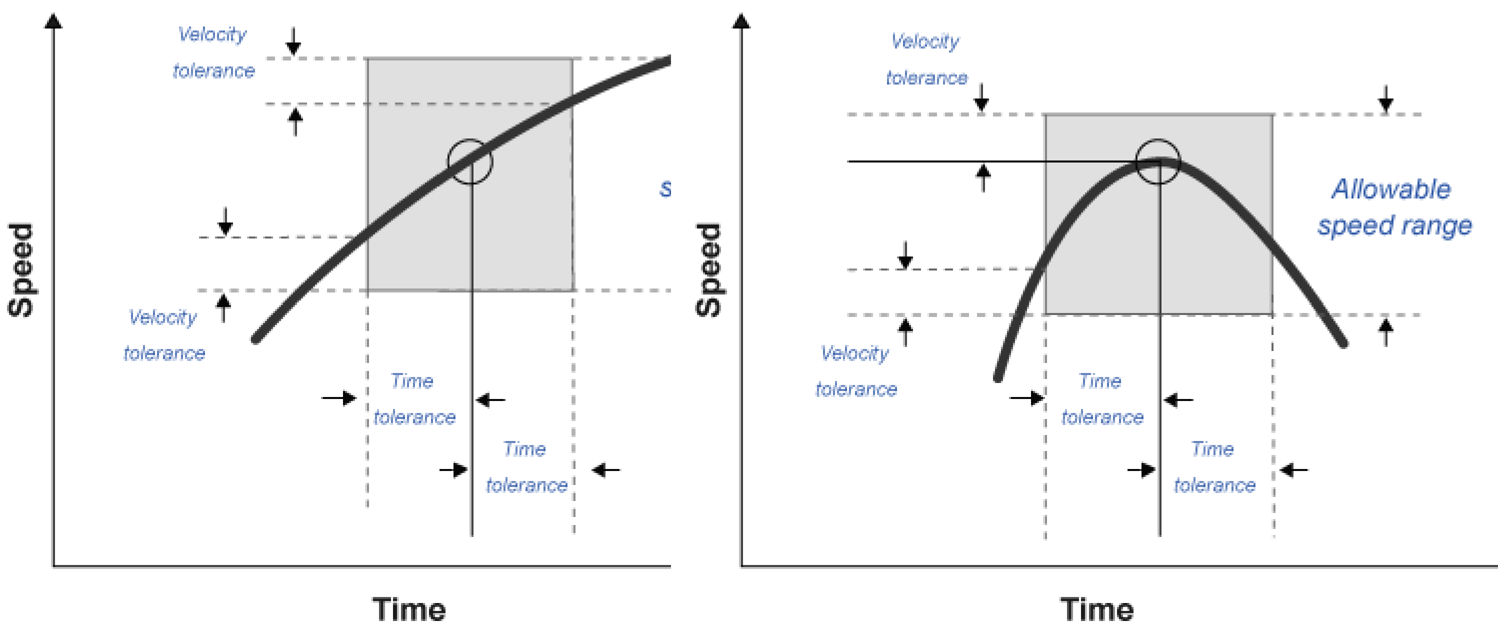
To enable this parameter, on the **Fault Tracking** tab, select **Enable fault tracking**.

`Time tolerance, timeBnd` — Time tolerance
`1.0` (default) | `scalar`

Time that the block uses to determine the speed tolerance. If the vehicle speed is not within the allowable speed range, the block sets a fault condition. For the time tolerances specified by the standardized tests, use these settings:

- EPA dynamometer driving schedules — `1.0`
- WLTP tests — `1.0`

These figures illustrate how the block uses the velocity and time tolerances to determine the allowable speed range.



Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable fault tracking**.

Failure Settings

`Enable failure tracking` — Enable failure tracking
`off` (default) | `on`

Select this parameter to enable drive cycle failure tracking.

Dependencies

To enable this parameter, select **Enable fault tracking**. Selecting **Enable failure tracking** parameter enables these parameters:

- **Stop simulation when trace fails, stopSim**
- **Maximum number of faults, maxFaultCnt**

- **Maximum single fault time, maxFaultTime**
- **Maximum total fault time, maxTotFaultTime**

`Maximum number of faults, maxFaultCnt` — Maximum number of faults
`10` (default) | `scalar`

Maximum number of faults during the drive cycle. For the number specified by the standardized tests, use these settings:

- EPA dynamometer driving schedules — *Not specified*
- WLTP tests — `10`

If the number of faults exceeds the maximum number of faults, the block sets a fault failure.

Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable failure tracking**.

`Maximum single fault time, maxFaultTime` — Maximum duration of single fault
`2.0` (default) | `scalar`

Maximum duration of single fault, in s. For the time specified by the standardized tests, use these settings:

- EPA dynamometer driving schedules — `2.0`
- WLTP tests — `1.0`

If the fault duration exceeds the maximum single fault time, the block sets a fault failure.

Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable failure tracking**.

`Maximum total fault time, maxTotFaultTime` — Maximum total fault time
`15.0` (default) | `scalar`

Maximum accumulated time spent under fault condition, in s.

If the accumulated time spent under fault condition exceeds the maximum total fault time, the block sets a fault failure.

Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Enable failure tracking**.

Simulation Trace

`Display simulation trace` — Display velocity trace
`off` (default) | `on`

Select this parameter to display a velocity trace window. Selecting this parameter can slow the simulation time.

Dependencies

Selecting this parameter enables these parameters:

- **Simulation trace update rate, dtTrace**
- **Simulation trace display window, traceWindow**

`Simulation trace update rate, dtTrace` — Trace update rate
`1` (default) | `scalar`

Simulation trace update rate, in s. Set to `0` for continuous sample period. For a discrete period, specify a non-zero rate.

Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Display simulation trace**.

`Simulation trace display window, traceWindow` — Trace window update rate
`10` (default) | `scalar`

Simulation trace window update rate, in s.

Dependencies

To enable this parameter, on the **Fault Tracking** tab, select **Display simulation trace**.

References

[1] Environmental Protection Agency (EPA). *EPA urban dynamometer driving schedule*. 40 CFR 86.115-78, July 1, 2001.

[2] European Union Commission. "Speed trace tolerances". *European Union Commission Regulation*. 32017R1151, Sec 1.2.6.6, June 1, 2017.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
Longitudinal Driver

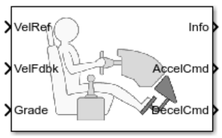
Topics
“Install Drive Cycle Data”
“Track Drive Cycle Errors”
“Time Series Objects and Collections”

Introduced in R2017a

Longitudinal Driver

Longitudinal speed-tracking controller

Library: Powertrain Blockset / Vehicle Scenario Builder
Vehicle Dynamics Blockset / Vehicle Scenarios / Driver



Description

The Longitudinal Driver block implements a longitudinal speed-tracking controller. Based on reference and feedback velocities, the block generates normalized acceleration and braking commands that can vary from 0 through 1. You can use the block to model the dynamic response of a driver or to generate the commands necessary to track a longitudinal drive cycle.

Configurations

External Actions

Use the **External Actions** parameters to create input ports for signals that can disable, hold, or override the closed-loop acceleration or deceleration commands. The block uses this priority order for the input commands: disable (highest), hold, override.

This table summarizes the external action parameters.

Goal	External Action Parameter	Input Ports	Data Type
Override the accelerator command with an input acceleration command.	**Accelerator override**	`EnablAccelOvr`	`Boolean`
		`AccelOvrCmd`	`double`
Hold the acceleration command at the current value.	**Accelerator hold**	`AccelHld`	`Boolean`
Disable the acceleration command.	**Accelerator disable**	`AccelZero`	`Boolean`
Override the decelerator command with an input deceleration command.	**Decelerator override**	`EnablDecelOvr`	`Boolean`
		`DecelOvrCmd`	`double`
Hold the decelerator command at current value.	**Decelerator hold**	`DecelHld`	`Boolean`
Disable the decelerator command.	**Decelerator disable**	`DecelZero`	`Boolean`

Controller

Use the **Control type, cntrlType** parameter to specify one of these control options.

Setting	Block Implementation
`PI`	Proportional-integral (PI) control with tracking windup and feed-forward gains.
`Scheduled PI`	PI control with tracking windup and feed-forward gains that are a function of vehicle velocity.
`Predictive`	Optimal single-point preview (look ahead) control model developed by C. C. MacAdam[1, 2, 3]. The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block: • Represents the dynamics as a linear single track (bicycle) vehicle • Minimizes the previewed error signal at a single point *T** seconds ahead in time • Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms

Shift

Use the **Shift type, shftType** parameter to specify one of these shift options.

Setting	Block Implementation
`None`	No transmission. Block outputs a constant gear of 1. Use this setting to minimize the number of parameters you need to generate acceleration and braking commands to track forward vehicle motion. This setting does not allow reverse vehicle motion.
`Reverse, Neutral, Drive`	Block uses a Stateflow® chart to model reverse, neutral, and drive gear shift scheduling. Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using simple reverse, neutral, and drive gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses the initial gear and time required to shift to shift the vehicle up into drive or down into reverse or neutral. For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.

Setting	Block Implementation
`Scheduled`	Block uses a Stateflow chart to model reverse, neutral, park, and N-speed gear shift scheduling. Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, park, and N-speed gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses these parameters to determine the: • Initial gear • Upshift and downshift accelerator pedal positions • Upshift and downshift velocity • Timing for shifting and engaging forward and reverse from neutral For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.
`External`	Block uses the input gear, vehicle state, and velocity feedback to generate acceleration and braking commands to track forward and reverse vehicle motion. For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.

Gear Signal

Use the **Output gear signal** parameter to create the `GearCmd` output port. The `GearCmd` signal contains the integer value of the commanded vehicle gear.

Gear	Integer
Park	`80`
Reverse	`-1`
Neutral	`0`
Drive	`1`
Gear	`Gear number`

Controller: PI Speed-Tracking

If you set the control type to `PI` or `Scheduled PI`, the block implements proportional-integral (PI) control with tracking windup and feed-forward gains. For the `Scheduled PI` configuration, the block uses feed forward gains that are a function of vehicle velocity.

To calculate the speed control output, the block uses these equations.

Setting	Equation
`PI`	$y = \frac{K_{ff}}{v_{nom}} v_{ref} + \frac{K_p e_{ref}}{v_{nom}} + \int \left(\frac{K_i e_{ref}}{v_{nom}} + K_{aw} e_{out} \right) dt + K_g \theta$

Setting	Equation
`Scheduled PI`	$y = \frac{K_{ff}(v)}{v_{nom}} v_{ref} + \frac{K_p(v)e_{ref}}{v_{nom}} + \int \left(\frac{K_i(v)e_{ref}}{v_{nom}} + K_{aw}e_{out} \right) e_{ref} dt + K_g(v)\theta$

where:

$$e_{ref} = v_{ref} - v$$

$$e_{out} = y_{sat} - y$$

$$y_{sat} = \begin{cases} -1 & y < -1 \\ y & -1 \le y \le 1 \\ 1 & 1 < y \end{cases}$$

The velocity error low-pass filter uses this transfer function.

$$H(s) = \frac{1}{\tau_{err}s + 1} \quad \text{for} \quad \tau_{err} > 0$$

To calculate the acceleration and braking commands, the block uses these equations.

$$y_{acc} = \begin{cases} 0 & y_{sat} < 0 \\ y_{sat} & 0 \le y_{sat} \le 1 \\ 1 & 1 < y_{sat} \end{cases}$$

$$y_{dec} = \begin{cases} 0 & y_{sat} > 0 \\ -y_{sat} & -1 \le y_{sat} \le 0 \\ 1 & y_{sat} < -1 \end{cases}$$

The equations use these variables.

v_{nom}	Nominal vehicle speed
K_p	Proportional gain
K_i	Integral gain
K_{aw}	Anti-windup gain
K_{ff}	Velocity feed-forward gain
K_g	Grade angle feed-forward gain
θ	Grade angle
τ_{err}	Error filter time constant
y	Nominal control output magnitude
y_{sat}	Saturated control output magnitude
e_{ref}	Velocity error
e_{out}	Difference between saturated and nominal control outputs
y_{acc}	Acceleration signal
y_{dec}	Braking signal
v	Velocity feedback signal

v_{ref}	Reference velocity signal

Controller: Predictive Speed-Tracking

If you set the **Control type, cntrlType** parameter to `Predictive`, the block implements an optimal single-point preview (look ahead) control model developed by C. C. MacAdam[1, 2, 3]. The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block:

- Represents the dynamics as a linear single track (bicycle) vehicle
- Minimizes the previewed error signal at a single point T* seconds ahead in time
- Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms

Vehicle Dynamics

For longitudinal motion, the block implements these linear dynamics.

$$x_1 = v$$

$$\dot{x}_1 = x_2 = \frac{K_{pt}}{m} - g\sin(\gamma) + F_r x_1$$

In matrix notation:

$$\dot{x} = Fx + g\bar{u}$$

where:

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

$$F = \begin{bmatrix} 0 & 1 \\ \frac{F_r}{m} & 0 \end{bmatrix}$$

$$g = \begin{bmatrix} 0 \\ \frac{K_{pt}}{m} \end{bmatrix}$$

$$\bar{u} = u - \frac{m^2}{K_{pt}} g\sin(\gamma)$$

The block uses this equation for the rolling resistance.

$$F_r = -\left[\tanh(x_1)\left(\frac{a_r}{x_1} + c_r x_1\right) + b_r\right]$$

The single-point model assumes a minimum previewed error signal at a single point *T** seconds ahead in time. *a** is the driver ability to predict the future vehicle response based on the current steering control input. *b** is the driver ability to predict the future vehicle response based on the current vehicle state. The block uses these equations.

$$a^* = (T^*)m^T\left[I + \sum_{n=1}^{\infty}\frac{F^n(T^*)^n}{(n+1)!}\right]ge$$

$$b^* = m^T\left[I + \sum_{n=1}^{\infty}\frac{F^n(T^*)^n}{n!}\right]$$

where:

$$m^T = [1 \;\; 1]$$

The equations use these variables.

a, b	Forward and rearward tire location, respectively
m	Vehicle mass
I	Vehicle rotational inertia
a^*, $\boldsymbol{b}^*$	Driver prediction scalar and vector gain, respectively
$\boldsymbol{x}$	Predicted vehicle state vector
v	Longitudinal velocity
$\boldsymbol{F}$	System matrix
K_{pt}	Tractive force and brake limit
γ	Grade angle
$\boldsymbol{g}$	Control coefficient vector
g	Gravitational constant
T^*	Preview time window
$f(t+T^*)$	Previewed path input T* seconds ahead
U	Forward vehicle velocity
$\boldsymbol{m^T}$	Constant observer vector; provides vehicle lateral position
F_r	Rolling resistance
a_r	Static rolling and driveline resistance
b_r	Linear rolling and driveline resistance
c_r	Aerodynamic rolling and driveline resistance

Optimization

The single-point model implemented by the block finds the steering command that minimizes a local performance index, J, over the current preview interval, (t, $t+T$).

$$J = \frac{1}{T}\int_{t}^{t+T}[f(\eta) - y(\eta)]^2 d\eta$$

To minimize J with respect to the steering command, this condition must be met.

$$\frac{dJ}{du} = 0$$

You can express the optimal control solution in terms of a current non-optimal and corresponding nonzero preview output error T^* seconds ahead[1, 2, 3].

$$u^o(t) = u(t) + \frac{e(t + T^*)}{a^*}$$

The block uses the preview distance and vehicle longitudinal velocity to determine the preview time window.

$$T^* = \frac{L}{U}$$

The equations use these variables.

T^*	Preview time window
$f(t+T^*)$	Previewed path input T^* sec ahead
$y(t+T^*)$	Previewed plant output T^* sec ahead
$e(t+T^*)$	Previewed error signal T^* sec ahead
$u(t)$, $u^o(t)$	Steer angle and optimal steer angle, respectively
L	Preview distance
J	Performance index
U	Forward (longitudinal) vehicle velocity

Driver Lag

The single-point model implemented by the block introduces a driver lag. The driver lag accounts for the delay when the driver is tracking tasks. Specifically, it is the transport delay deriving from perceptual and neuromuscular mechanisms. To calculate the driver transport delay, the block implements this equation.

$$H(s) = e^{-s\tau}$$

The equations use these variables.

τ	Driver transport delay
$y(t+T^*)$	Previewed plant output T^* sec ahead
$e(t+T^*)$	Previewed error signal T^* sec ahead
$u(t)$, $u^o(t)$	Steer angle and optimal steer angle, respectively
J	Performance index

Ports

Input

`VelRef` — Reference vehicle velocity
`scalar`

Reference velocity, v_{ref}, in m/s.

`EnblAccelOvr` — Enable acceleration command override
`scalar`

Enable acceleration command override.

Dependencies

To enable this port, select **Acceleration override**.

Data Types: `Boolean`

`AccelOvrCmd` — Acceleration override command
`scalar`

Acceleration override command, normalized from 0 through 1.

Dependencies

To enable this port, select **Acceleration override**.

Data Types: `double`

`AccelHld` — Acceleration hold
`scalar`

Boolean signal that holds the acceleration command at the current value.

Dependencies

To enable this port, select **Acceleration hold**.

Data Types: `Boolean`

`AccelZero` — Disable acceleration command
`scalar`

Disable acceleration command.

Dependencies

To enable this port, select **Acceleration disable**.

Data Types: `Boolean`

`EnblDecelOvr` — Enable deceleration command override
`scalar`

Enable deceleration command override.

Dependencies

To enable this port, select **Deceleration override**.

Data Types: `Boolean`

`DecelOvrCmd` — Deceleration override command
`scalar`

Deceleration override command, normalized from 0 through 1.

Dependencies

To enable this port, select **Deceleration override**.

Data Types: `double`

DecelHld — Deceleration hold
scalar

Boolean signal that holds the deceleration command at the current value.

Dependencies

To enable this port, select **Deceleration hold**.

Data Types: Boolean

DecelZero — Disable deceleration command
scalar

Disable deceleration command.

Dependencies

To enable this port, select **Deceleration disable**.

Data Types: Boolean

ExtGear — Gear
scalar

Gear	Integer
Park	80
Reverse	-1
Neutral	0
Drive	1
Gear	Gear number

Dependencies

To enable this port, set **Shift type, shftType** to External.

VelFdbk — Longitudinal vehicle velocity
scalar

Longitudinal vehicle velocity, U, in the vehicle-fixed frame, in m/s.

Grade — Road grade angle
scalar

Road grade angle, θ or γ, in deg.

Output

Info — Bus signal
bus

Bus signal containing these block calculations.

<table>
<tr><th colspan="2">Signal</th><th>Variable</th><th>Description</th></tr>
<tr><td colspan="2"><code>Accel</code></td><td>y_{acc}</td><td>Commanded vehicle acceleration, normalized from 0 through 1</td></tr>
<tr><td colspan="2"><code>Decel</code></td><td>y_{dec}</td><td>Commanded vehicle deceleration, normalized from 0 through 1</td></tr>
<tr><td colspan="3"><code>Gear</code></td><td>Integer value of commanded gear</td></tr>
<tr><td colspan="3"><code>Clutch</code></td><td>Clutch command</td></tr>
<tr><td colspan="2"><code>Err</code></td><td>e_{ref}</td><td>Difference in reference vehicle speed and vehicle speed</td></tr>
<tr><td colspan="2"><code>ErrSqrSum</code></td><td>$\int_0^t e_{ref}{}^2 dt$</td><td>Integrated square of error</td></tr>
<tr><td colspan="2"><code>ErrMax</code></td><td>$\max(e_{ref}(t))$</td><td>Maximum error during simulation</td></tr>
<tr><td colspan="2"><code>ErrMin</code></td><td>$\min(e_{ref}(t))$</td><td>Minimum error during simulation</td></tr>
<tr><td rowspan="8"><code>ExtActions</code></td><td colspan="2"><code>EnblAccelOvr</code></td><td>Override the accelerator command with an input acceleration command</td></tr>
<tr><td colspan="2"><code>AccelOvrCmd</code></td><td>Input accelerator override command</td></tr>
<tr><td colspan="2"><code>AccelHld</code></td><td>Hold the acceleration command at the current value</td></tr>
<tr><td colspan="2"><code>AccelZero</code></td><td>Disable the acceleration command</td></tr>
<tr><td colspan="2"><code>EnblDecelOvr</code></td><td>Override the decelerator command with an input deceleration command</td></tr>
<tr><td colspan="2"><code>DecelOvrCmd</code></td><td>Input deceleration override command</td></tr>
<tr><td colspan="2"><code>DecelHld</code></td><td>Hold the decelerator command at current value</td></tr>
<tr><td colspan="2"><code>DecelZero</code></td><td>Disable the decelerator command</td></tr>
</table>

`AccelCmd` — Commanded vehicle acceleration
`scalar`

Commanded vehicle acceleration, y_{acc}, normalized from 0 through 1.

`DecelCmd` — Commanded vehicle deceleration
`scalar`

Commanded vehicle deceleration, y_{dec}, normalized from 0 through 1.

`GearCmd` — Commanded vehicle gear
`scalar`

Integer value of commanded vehicle gear.

Gear	Integer
Park	`80`
Reverse	`-1`

Gear	Integer
Neutral	0
Drive	1
Gear	Gear number

Dependencies

To enable this port, select **Output gear signal**.

Parameters

External Actions

Accelerator override — Override acceleration command
off (default) | on

Select to override the acceleration command with an input acceleration command.

Dependencies

Selecting this parameter creates the EnblAccelOvr and AccelOvrCmd input ports.

Accelerator hold — Hold acceleration command
off (default) | on

Select to hold the acceleration command.

Dependencies

Selecting this parameter creates the AccelHld input port.

Accelerator disable — Disable acceleration command
off (default) | on

Select to disable the acceleration command.

Dependencies

Selecting this parameter creates the AccelZero input port.

Decelerator override — Override deceleration command
off (default) | on

Select to override the deceleration command with an input deceleration command.

Dependencies

Selecting this parameter creates the EnblDecelOvr and DecelOvrCmd input ports.

Decelerator hold — Hold deceleration command
off (default) | on

Select to hold the deceleration command.

Dependencies

Selecting this parameter creates the `DecelHld` input port.

`Decelerator disable` — Disable deceleration command

`off` (default) | `on`

Select to disable the deceleration command.

Dependencies

Selecting this parameter creates the `DecelZero` input port.

Configuration

`Control type, cntrlType` — Longitudinal control

`PI` (default) | `Scheduled PI` | `Predictive`

Type of longitudinal control.

Setting	Block Implementation
`PI`	Proportional-integral (PI) control with tracking windup and feed-forward gains.
`Scheduled PI`	PI control with tracking windup and feed-forward gains that are a function of vehicle velocity.
`Predictive`	Optimal single-point preview (look ahead) control model developed by C. C. MacAdam[1, 2, 3]. The model represents driver steering control behavior during path-following and obstacle avoidance maneuvers. Drivers preview (look ahead) to follow a predefined path. To implement the MacAdam model, the block: • Represents the dynamics as a linear single track (bicycle) vehicle • Minimizes the previewed error signal at a single point *T** seconds ahead in time • Accounts for the driver lag deriving from perceptual and neuromuscular mechanisms

`Shift type, shftType` — Shift type

`None` (default) | `Reverse, Neutral, Drive` | `Scheduled` | `External`

Shift type.

Setting	Block Implementation
`None`	No transmission. Block outputs a constant gear of 1. Use this setting to minimize the number of parameters you need to generate acceleration and braking commands to track forward vehicle motion. This setting does not allow reverse vehicle motion.

Setting	Block Implementation
`Reverse, Neutral, Drive`	Block uses a Stateflow chart to model reverse, neutral, and drive gear shift scheduling. Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using simple reverse, neutral, and drive gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses the initial gear and time required to shift to shift the vehicle up into drive or down into reverse or neutral. For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.
`Scheduled`	Block uses a Stateflow chart to model reverse, neutral, park, and N-speed gear shift scheduling. Use this setting to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, park, and N-speed gear shift scheduling. Depending on the vehicle state and vehicle velocity feedback, the block uses these parameters to determine the: • Initial gear • Upshift and downshift accelerator pedal positions • Upshift and downshift velocity • Timing for shifting and engaging forward and reverse from neutral For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.
`External`	Block uses the input gear, vehicle state, and velocity feedback to generate acceleration and braking commands to track forward and reverse vehicle motion. For neutral gears, the block uses braking commands to control the vehicle speed. For reverse gears, the block uses an acceleration command to generate torque and a brake command to reduce vehicle speed.

`Reference and feedback units, velUnits` — Velocity units

m/s (default)

Vehicle velocity reference and feedback units.

Dependencies

If you set **Control type, cntrlType** control type to `Scheduled` or `Scheduled PI`, the block uses the **Reference and feedback units, velUnits** for the **Nominal speed, vnom** parameter dimension.

If you set **Shift Type, shftType** to `Scheduled`, the block uses the **Longitudinal velocity units, velUnits** for these parameter dimensions:

- **Upshift velocity data table, upShftTbl**

- **Downshift velocity data table, dwnShftTbl**

`Output gear signal` — Create `GearCmd` output port

`off` (default) | `on`

Specify to create output port `GearCmd`.

Control

Longitudinal

`Proportional gain, Kp` — Gain

`10` (default) | `scalar`

Proportional gain, K_p, dimensionless.

Dependencies

To create this parameter, set **Control type** to `PI`.

`Integral gain, Ki` — Gain

`5` (default) | `scalar`

Proportional gain, K_i, dimensionless.

Dependencies

To create this parameter, set **Control type** to `PI`.

`Velocity feed-forward, Kff` — Gain

`.1` (default) | `scalar`

Velocity feed-forward gain, K_{ff}, dimensionless.

Dependencies

To create this parameter, set **Control type** to `PI`.

`Grade angle feed-forward, Kg` — Gain

`0` (default) | `scalar`

Grade angle feed-forward gain, K_g, in 1/deg.

Dependencies

To create this parameter, set **Control type** to `PI`.

`Velocity gain breakpoints, VehVelVec` — Breakpoints

`[0 100]` (default) | `vector`

Velocity gain breakpoints, *VehVelVec*, dimensionless.

Dependencies

To create this parameter, set **Control type** to `Scheduled PI`.

`Velocity feed-forward gain values, KffVec` — Gain

`[.1 .1]` (default) | `vector`

Velocity feed-forward gain values, *KffVec*, as a function of vehicle velocity, dimensionless.

Dependencies

To create this parameter, set **Control type** to `Scheduled PI`.

`Proportional gain values, KpVec` — Gain
`[10 10]` (default) | `vector`

Proportional gain values, *KpVec*, as a function of vehicle velocity, dimensionless.

Dependencies

To create this parameter, set **Control type** to `Scheduled PI`.

`Integral gain values, KiVec` — Gain
`[5 5]` (default) | `vector`

Integral gain values, *KiVec*, as a function of vehicle velocity, dimensionless.

Dependencies

To create this parameter, set **Control type** to `Scheduled PI`.

`Grade angle feed-forward values, KgVec` — Grade gain
`[0 0]` (default) | `vector`

Grade angle feed-forward values, *KgVec*, as a function of vehicle velocity, in 1/deg.

Dependencies

To create this parameter, set **Control type** to `Scheduled PI`.

`Nominal speed, vnom` — Nominal vehicle speed
`5` (default) | `scalar`

Nominal vehicle speed, v_{nom}, in units specified by the **Reference and feedback units, velUnits** parameter. The block uses the nominal speed to normalize the controller gains.

Dependencies

To create this parameter, set **Control type** to `PI` or `Scheduled PI`.

`Anti-windup, Kaw` — Gain
`1` (default) | `scalar`

Anti-windup gain, K_{aw}, dimensionless.

Dependencies

To create this parameter, set **Control type** to `PI` or `Scheduled PI`.

`Error filter time constant, tauerr` — Filter
`.01` (default) | `scalar`

Error filter time constant, τ_{err}, in s. To disable the filter, enter 0.

Dependencies

To create this parameter, set **Control type** to `PI` or `Scheduled PI`.

Predictive

`Vehicle mass, m` — Mass
`1500` (default) | `scalar`

Vehicle mass, *m*, in kg.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to `Predictive`.

`Effective vehicle total tractive force, Kpt` — Tractive force
`3000` (default) | `scalar`

Effective vehicle total tractive force, K_{pt}, in N.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to `Predictive`.

`Driver response time, tau` — Tau
`.1` (default) | `scalar`

Driver response time, τ, in s.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to `Predictive`.

`Preview distance, L` — Distance
`2` (default) | `scalar`

Driver preview distance, *L*, in m.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to `Predictive`.

`Rolling resistance coefficient, aR` — Resistance
`200` (default) | `scalar`

Static rolling and driveline resistance coefficient, a_R, in N. Block uses the parameter to estimate the constant acceleration or braking effort.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to `Predictive`.

`Rolling and driveline resistance coefficient, bR` — Resistance
`2.5` (default) | `scalar`

Rolling and driveline resistance coefficient, b_R, in N·s/m. Block uses the parameter to estimate the linear velocity-dependent acceleration or braking effort.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to `Predictive`.

`Aerodynamic drag coefficient, cR` — Drag
`.5` (default) | `scalar`

Aerodynamic drag coefficient, c_R, in N·s^2/m^2. Block uses the parameter to estimate the quadratic velocity-dependent acceleration or braking effort.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to `Predictive`.

`Gravitational constant, g` — Gravitational constant
`9.81` (default) | `scalar`

Gravitational constant, g, in m/s^2.

Dependencies

To create this parameter, set **Longitudinal control type, cntrlType** to `Predictive`.

Shift

Reverse, Neutral, Drive

`Initial gear, GearInit` — Initial gear
`0` (default) | `scalar`

Integer value of the initial gear. The block uses the initial gear to generate acceleration and braking commands to track forward and reverse vehicle motion.

Gear	Integer
Park	`80`
Reverse	`-1`
Neutral	`0`
Drive	`1`
Gear	`Gear number`

Dependencies

To create this parameter, set **Shift type, shftType** to `Reverse, Neutral, Drive` or `Scheduled`. If you specify `Reverse, Neutral, Drive`, the **Initial Gear, GearInit** parameter value can be only `-1`, `0`, or `1`.

`Time required to shift, tShift` — Time
`.1` (default) | `scalar`

Time required to shift, *tShift*, in s. The block uses the time required to shift to generate acceleration and braking commands to track forward and reverse vehicle motion using reverse, neutral, and drive gear shift scheduling.

Dependencies

To create this parameter, set **Shift type, shftType** to `Reverse, Neutral, Drive`.

Scheduled

`Initial gear, GearInit` — Initial gear

`0` (default) | `scalar`

Integer value of the initial gear. The block uses the initial gear to generate acceleration and braking commands to track forward and reverse vehicle motion.

Gear	Integer
Park	`80`
Reverse	`-1`
Neutral	`0`
Drive	`1`
Gear	`Gear number`

Dependencies

To create this parameter, set **Shift type, shftType** to `Reverse, Neutral, Drive` or `Scheduled`. If you specify `Reverse, Neutral, Drive`, the **Initial Gear, GearInit** parameter value can be only `-1`, `0`, or `1`.

`Up and down shift accelerator pedal positions, pdlVec` — Pedal position breakpoints

`[0.1 0.4 0.5 0.9]` (default) | `[1-by-m] vector`

Pedal position breakpoints for lookup tables when calculating upshift and downshift velocities, dimensionless. Vector dimensions are 1 by the number of pedal position breakpoints, `m`.

Dependencies

To create this parameter, set **Shift type, shftType** to `Scheduled`.

`Upshift velocity data table, upShftTbl` — Table

`[m-by-n] array`

Upshift velocity data as a function of pedal position and gear, in units specified by the **Reference and feedback units, velUnits** parameter. Upshift velocities indicate the vehicle velocity at which the gear should increase by 1.

The array dimensions are `m` pedal positions by `n` gears. The first column of data, when `n` equals 1, is the upshift velocity for the neutral gear.

Dependencies

To create this parameter, set **Shift type, shftType** to `Scheduled`.

`Downshift velocity data table, dwnShftTbl` — Table

`[m-by-n] array`

Downshift velocity data as a function of pedal position and gear, in units specified by the **Reference and feedback units, velUnits** parameter. Downshift velocities indicate the vehicle velocity at which the gear should decrease by 1.

The array dimensions are `m` pedal positions by `n` gears. The first column of data, when `n` equals 1, is the downshift velocity for the neutral gear.

Dependencies

To create this parameter, set **Shift type, shftType** to `Scheduled`.

`Time required to shift, tClutch` — Time
`.5` (default) | `scalar`

Time required to shift, t_{Clutch}, in s.

Dependencies

To create this parameter, set **Shift type, shftType** to `Scheduled`.

`Time required to engage reverse from neutral, tRev` — Time
`.5` (default) | `scalar`

Time required to engage reverse from neutral, t_{Rev}, in s.

Dependencies

To create this parameter, set **Shift type, shftType** to `Scheduled`.

`Time required to engage park from neutral, tPark` — Time
`120` (default) | `scalar`

Time required to engage park from neutral, t_{Park}, in s.

Dependencies

To create this parameter, set **Shift type, shftType** to `Scheduled`.

References

[1] MacAdam, C. C. "An Optimal Preview Control for Linear Systems". *Journal of Dynamic Systems, Measurement, and Control*. Vol. 102, Number 3, Sept. 1980.

[2] MacAdam, C. C. "Application of an Optimal Preview Control for Simulation of Closed-Loop Automobile Driving ". *IEEE Transactions on Systems, Man, and Cybernetics*. Vol. 11, Issue 6, June 1981.

[3] MacAdam, C. C. *Development of Driver/Vehicle Steering Interaction Models for Dynamic Analysis*. Final Technical Report UMTRI-88-53. Ann Arbor, Michigan: The University of Michigan Transportation Research Institute, Dec. 1988.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also
Drive Cycle Source | Vehicle Body Total Road Load

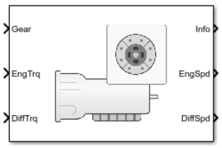
Introduced in R2017a

Transmission Blocks

Automated Manual Transmission

Ideal automated manual transmission

Library: Powertrain Blockset / Transmission / Transmission Systems



Description

The Automated Manual Transmission block implements an ideal automated transmission (AMT). An AMT is a manual transmission with additional actuators and an electronic control unit (ECU) to regulate clutch and gear selection based on commands from a controller. The number of gears is specified via an integer vector with corresponding gear ratios, inertias, viscous damping, and efficiency factors. The clutch and synchronization engagement rates are linear and adjustable.

Use the block for:

- Power and torque capacity sizing
- Determining gear ratio impact on fuel economy and performance

To determine the rotational drive shaft speed and reaction torque, the Automated Manual Transmission block calculates:

- Clutch lock-up and clutch friction
- Locked rotational dynamics
- Unlocked rotational dynamics

To specify the block efficiency calculation, for **Efficiency factors**, select either of these options.

Setting	Block Implementation
`Gear only`	Efficiency determined from a 1D lookup table that is a function of the gear.
`Gear, input torque, input speed, and temperature`	Efficiency determined from a 4D lookup table that is a function of: • Gear • Input torque • Input speed • Oil temperature

Clutch Control

The AMT delivers drive shaft torque continuously by controlling the pressure signals from the clutch. If you select **Control type** parameter `Ideal integrated controller`, the block generates idealized clutch pressure signals. To use your own clutch control signals, select **Control type** parameter `External control`.

Clutch Lock-Up and Clutch Friction

Based on the clutch lock-up condition, the block implements one of these friction models.

If	Clutch Condition	Friction Model
$\omega_i \neq N\omega_d$ or $T_S < \lvert T_f - Nw_i b_i \rvert$	Unlocked	$T_f = T_k$ where, $T_k = F_c R_{eff} \mu_k \tanh\left[4\left(\frac{w_i}{N} - w_d\right)\right]$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o{}^3 - R_i{}^3)}{3(R_o{}^2 - R_i{}^2)}$
$\omega_i = N\omega_t$ and $T_S \geq \lvert T_f - N b_i \omega_i \rvert$	Locked	$T_f = T_s$

The equations use these variables.

ω_t	Output drive shaft speed
ω_i	Input drive shaft speed
ω_d	Drive shaft speed
b_i	Viscous damping
F_c	Applied clutch force
N	Engaged gear
T_f	Frictional torque
T_k	Kinetic frictional torque
T_s	Static frictional torque
R_{eff}	Effective clutch radius
R_o	Annular disk outer radius
R_i	Annular disk inner radius
μ_s	Coefficient of static friction
μ_k	Coefficient of kinetic friction

Locked Rotational Dynamics

To model the rotational dynamics when the clutch is locked, the block implements these equations.

$$\dot{\omega}_d J_N = \eta_N T_d - \frac{\omega_i}{N} b_N + N T_i$$

$$\omega_i = N\omega_d$$

The block determines the input torque, T_i, through differentiation.

The equations use these variables.

ω_i	Input drive shaft speed
ω_d	Drive shaft speed
N	Engaged gear
b_N	Engaged gear viscous damping
J_N	Engaged gear inertia
η_N	Engaged gear efficiency
T_d	Drive shaft torque
T_i	Applied input torque

Unlocked Rotational Dynamics

To model the rotational dynamics when the clutch is unlocked, the block implements this equation.

$$\dot{\omega}_d J_N = NT_f - \omega_d b_N + T_d$$

where:

ω_d	Drive shaft speed
N	Engaged gear
b_N	Engaged gear viscous damping
J_N	Engaged gear inertia
T_d	Drive shaft torque
T_i	Applied input torque

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrEng`	Engine power	P_{eng}	$\omega_i T_i$
		`PwrDiffrntl`	Differential power	P_{diff}	$\omega_d T_d$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrEffLoss`	Mechanical power loss	$P_{effloss}$	$\omega_d T_d(\eta_N - 1)$
		`PwrDampLoss`	Mechanical damping loss	$P_{damploss}$	$-b_N\omega_d^2 - b_{in}\omega_i^2$
		`PwrCltchLoss`	Clutch power loss	P_{mech}	When locked: 0 When unlocked: $-T_k(\omega_i - N\omega_d)$

Bus Signal			Description	Variable	Equations
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredTrans`	Rate change in rotational kinetic energy	P_{str}	When locked: $\dot{\omega}_i \omega_i (J_{in} + \frac{J_N}{N^2})$ When unlocked: $J_{in}\dot{\omega}_i\omega_i + J_N\dot{\omega}_d\omega_d$

The equations use these variables.

b_N	Engaged gear viscous damping
J_N	Engaged gear rotational inertia
J_{in}	Flywheel rotational inertia
η_N	Engaged gear efficiency
N	Engaged gear ratio
T_i	Applied input torque, typically from the engine crankshaft or dual mass flywheel damper
T_d	Applied load torque, typically from the differential or drive shaft
ω_d	Initial input drive shaft rotational velocity
ω_i, $\acute{\omega}_i$	Applied drive shaft angular speed and acceleration

Ports

Input

`Gear` — Gear number to engage
`scalar`

Integer value of gear number to engage.

`CltchCmd` — Clutch command
`scalar`

Clutch pressure command.

Dependencies

To create this port, select **Control type** parameter `External control`.

`EngTrq` — Applied input torque
`scalar`

Applied input torque, T_i, typically from the engine crankshaft or dual mass flywheel damper, in N·m.

`DiffTrq` — Applied load torque
`scalar`

Applied load torque, T_d, typically from the differential or driveshaft, in N·m.

Temp — Oil temperature
scalar

Oil temperature, in K. To determine the efficiency, the block uses a 4D lookup table that is a function of:

- Gear
- Input torque
- Input speed
- Oil temperature

Dependencies

To create this port, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

Output

Info — Bus signal
bus

Bus signal contains these block calculations.

Signal			Description	Variable	Units
Eng	EngTrq		Input applied torque	T_i	N·m
	EngSpd		Input drive shaft speed	ω_i	rad/s
Diff	DiffTrq		Output drive shaft torque	T_t	N·m
	DiffSpd		Output drive shaft speed	ω_t	rad/s
Cltch	CltchForce		Applied clutch force	F_c	N
	CltchLocked		Clutch lock status, Boolean: • Locked — 0 • Unlocked — 1	N/A	N/A
Trans	TransSpdRatio		Speed ratio at time t	$\phi(t)$	N/A
	TransEta		Ratio of output power to input power	η	N/A
	TransGearCmd		Commanded gear	N_{cmd}	N/A
	TransGear		Engaged gear	N	N/A
PwrInfo	PwrTrnsfrd	PwrEng	Engine power	P_{eng}	W
		PwrDiffrntl	Differential power	P_{diff}	W
	PwrNotTrnsfrd	PwrEffLoss	Mechanical power loss	$P_{effloss}$	W

Signal			Description	Variable	Units
		PwrDampLoss	Mechanical damping loss	$P_{damploss}$	W
		PwrCltchLoss	Clutch power loss	P_{mech}	W
	PwrStored	PwrStoredTrans	Rate change in rotational kinetic energy	P_{str}	W

EngSpd — Angular speed
scalar

Applied drive shaft angular speed input, ω_i, in rad/s.

DiffSpd — Angular speed
scalar

Drive shaft angular speed output, ω_d, in rad/s.

Parameters

Control type — Specify control type
Ideal integrated controller (default) | External control

The AMT delivers drive shaft torque continuously by controlling the pressure signals from the clutch. If you select **Control type** parameter Ideal integrated controller, the block generates idealized clutch pressure signals. To use your own clutch control signals, select **Control type** parameter External control.

Dependencies

This table summarizes the port configurations.

Control Mode	Creates Ports
External control	CltchCmd

Efficiency factors — Specify efficiency calculation
Gear only (default) | Gear, input torque, input speed, and temperature

To specify the block efficiency calculation, for **Efficiency factors**, select either of these options.

Setting	Block Implementation
Gear only	Efficiency determined from a 1D lookup table that is a function of the gear.
Gear, input torque, input speed, and temperature	Efficiency determined from a 4D lookup table that is a function of: • Gear • Input torque • Input speed • Oil temperature

Dependencies

Setting Parameter To	Enables
`Gear only`	**Efficiency vector, eta**
`Gear, input torque, input speed, and temperature`	**Efficiency torque breakpoints, Trq_bpts** **Efficiency speed breakpoints, omega_bpts** **Efficiency temperature breakpoints, Temp_bpts** **Efficiency lookup table, eta_tbl**

Transmission

`Input shaft inertia, Jin` — Inertia
`.01` (default) | `scalar`

Input shaft inertia, in kg·m^2.

`Input shaft damping, bin` — Damping
`.001` (default) | `scalar`

Input shaft damping, in N·m·s/rad.

`Initial input velocity, omegain_o` — Angular velocity
`0` (default) | `scalar`

Angular velocity, in rad/s.

`Gear number vector, G` — Specify number of transmission speeds
`[-1, 0, 1, 2, 3, 4, 5]` (default) | `vector`

Vector of integer gear commands used to specify the number of transmission speeds. Neutral gear is `0`. For example, you can set these parameter values.

To Specify	Set Gear number, G To
Four transmission speeds, including neutral	`[0,1,2,3,4]`
Three transmission speeds, including neutral and reverse	`[-1,0,1,2,3]`
Five transmission speeds, including neutral and reverse	`[-1,0,1,2,3,4,5]`

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Transmission damping vector**, and **Efficiency vector** parameters must be equal.

`Efficiency torque breakpoints, Trq_bpts` — Breakpoints
`[25, 50, 75, 100, 150, 200, 250]` (default) | `vector`

Torque breakpoints for efficiency table, in N·m.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

Efficiency speed breakpoints, omega_bpts — Breakpoints
`[52.4 78.5 105 131 157 183 209 262 314 419 524]` (default) | `vector`

Speed breakpoints for efficiency table, rad/s.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

Efficiency temperature breakpoints, Temp_bpts — Breakpoints
`[313 358]` (default) | `vector`

Temperature breakpoints for efficiency table, in K.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

Gear ratio vector, N — Ratio of input speed to output speed
`[-4.47, 1, 4.47, 2.47, 1.47, 1, 0.8]` (default) | `vector`

Vector of gear ratios (that is, input speed to output speed) with indices corresponding to the ratios specified in **Gear number, G**. For neutral, set the gear ratio to `1`. For example, you can set these parameter values.

To Specify Gear Ratios For	Set Gear number, G To	Set Gear ratio, N To
Four transmission speeds, including neutral	`[0,1,2,3,4]`	`[1,4.47,2.47,1.47,1]`
Five transmission speeds, including neutral and reverse	`[-1,0,1,2,3,4,5]`	`[-4.47,1,4.47,2.47,1.47,1,0.8]`

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Transmission damping vector**, and **Efficiency vector** parameters must be equal.

Transmission inertia vector, Jout — Gear rotational inertia
`[0.128 0.01 0.128 0.1 0.062 0.028 0.01]` (default) | `vector`

Vector of gear rotational inertias, with indices corresponding to the inertias specified in **Gear number, G**, in kg·m^2. For example, you can set these parameter values.

To Specify Inertia For	Set Gear number, G To	Set Inertia, J To
Four gears, including neutral	`[0,1,2,3,4]`	`[0.01,2.28,2.04,0.32,0.028]`
Inertia for five gears, including reverse and neutral	`[-1,0,1,2,3,4,5]`	`[2.28,0.01,2.28,2.04,0.32,0.028,0.01]`

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Transmission damping vector**, and **Efficiency vector** parameters must be equal.

Transmission damping vector, bout — Gear viscous damping coefficient
[.003 .001 .003 .0025 .002 .001 .001] (default) | vector

Vector of gear viscous damping coefficients, with indices corresponding to the coefficients specified in **Gear number, G**, in N·m·s/rad. For example, you can set these parameter values.

To Specify Damping For	Set Gear number, G To	Set Damping, b To
Four gears, including neutral	[0,1,2,3,4]	[0.001,0.003,0.0025, 0.002,0.001]
Five gears, including reverse and neutral	[-1,0,1,2,3,4,5]	[0.003,0.001,0.003, 0.0025,0.002,0.001,0.001]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Transmission damping vector**, and **Efficiency vector** parameters must be equal.

Efficiency vector, eta — Gear efficiency
[0.9, 0.9, 0.9, 0.9, 0.9, 0.95, 0.95] (default) | vector

Vector of gear mechanical efficiency, with indices corresponding to the efficiencies specified in **Gear number, G**. For example, you can set these parameter values.

To Specify Efficiency For	Set Gear number, G To	Set Efficiency, eta To
Four gears, including neutral	[0,1,2,3,4]	[0.9,0.9,0.9,0.9,0.95]
Five gears, including reverse and neutral	[-1,0,1,2,3,4,5]	[0.9,0.9,0.9, 0.9,0.9,0.95,0.95]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Transmission damping vector**, and **Efficiency vector** parameters must be equal.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear only`.

Efficiency lookup table, eta_tbl — Gear efficiency
array

Table of gear mechanical efficiency, η_N as a function of gear, input torque, input speed, and temperature.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

Initial output velocity, omegaout_o — Transmission
0 (default) | scalar

Transmission initial output rotational velocity, ω_{to}, in rad/s. If you select **Clutch initially locked**, the block ignores the **Initial output velocity, omega_o** parameter value.

Initial gear, G_o — Engaged gear
0 (default) | scalar

Initial gear to engage, G_o.

Clutch and Synchronizer

`Clutch pressure time constant, tauc` — Time
`.02` (default) | `scalar`

Pressure input filter time constant, τ_c, in s.

`Synchronization time, ts` — Time
`.25` (default) | `scalar`

Time required for gear selection and synchronization, t_s, in s.

`Clutch time, tc` — Time
`.5` (default) | `scalar`

Time required to engage and disengage the clutch during shift events, t_c, in s.

Dependencies

To create this parameter, select **Control type** parameter `Ideal integrated controller`.

`Effective clutch radius, R` — Radius
`.2` (default) | `scalar`

The effective radius, R_{eff}, used with the applied clutch friction force to determine the friction force, in m. The effective radius is defined as:

$$R_{eff} = \frac{2(R_o 3 - R_i 3)}{3(R_o 2 - R_i 2)}$$

The equation uses these variables.

R_o	Annular disk outer radius
R_i	Annular disk inner radius

`Clutch force gain, K_c` — Force
`5e3` (default) | `scalar`

Open loop lock-up clutch gain, K_c, in N.

`Clutch static friction coefficient, mus` — Coefficient
`0.6` (default) | `scalar`

Dimensionless clutch disc coefficient of static friction, μ_s.

`Clutch kinematic friction coefficient, muk` — Coefficient
`0.4` (default) | `scalar`

Dimensionless clutch disc coefficient of kinetic friction, μ_k.

`Clutch initially locked` — Select to initially lock clutch
`off` (default) | `on`

Select to lock clutch initially.

Dependencies

To create this parameter, select **Control type** parameter `Ideal integrated controller`.

`Synchronizer initially locked` — Select to initially lock synchronizer
`off` (default) | `on`

Select to initially lock synchronizer.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

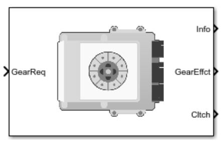
See Also
AMT Controller | Dual Clutch Transmission | Continuously Variable Transmission | Ideal Fixed Gear Transmission

Introduced in R2017a

AMT Controller

Automated manual transmission controller with clutch open, close, and synchronization timing

Library: Powertrain Blockset / Transmission / Transmission Controllers



Description

The AMT Controller block implements an automated manual transmission (AMT) controller. You can specify the clutch open, close, and synchronization timing parameters. The block determines the clutch commands using integrator-based timers and latching logic that is based on the specified timing parameters and gear request.

Ports

Inputs

`GearReq` — Gear number to engage
`scalar`

Gear number request, G_{req}.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Variable
`GearReq`	Gear number request	G_{req}
`GearEngd`	Nominal gear commanded by the controller	G_o
`Cltch`	Clutch pressure command for gears, between `0` and `1`	NA

`GearEffct` — Effective gear for shifting
`scalar`

Effective gear for shifting. The block uses this signal for the smooth application of inertial, efficiency, gear ratio, and damping parameters.

`Cltch` — Command for clutch pressure
`scalar`

Clutch pressure command, between `0` and `1`.

Parameters

`Initial gear, G_o` — Engaged gear
`0` (default) | `scalar`

Initial gear to engage, G_o.

`Clutch actuation time, tc` — Time
`.1` (default) | `scalar`

Time required to engage and disengage the clutch during shift events, t_c, in s.

`Synchronizer time, ts` — Time
`.01` (default) | `scalar`

Time required for gear selection and synchronization, t_s, in s.

`Sample period, dt` — Time
`-1` (default) | `scalar`

Sample period, *dt*, in s.

`Clutch initially locked` — Select to initially lock clutch
`off` (default) | `on`

Selecting this parameter initially locks the clutch.

`Synchronizer initially locked` — Select to initially lock synchronizer
`off` (default) | `on`

Selecting this parameter initially locks the synchronizer.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

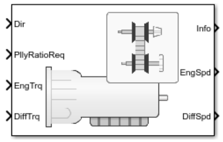
See Also

Automated Manual Transmission

Introduced in R2017a

Continuously Variable Transmission

Push belt continuously variable transmission with independent radii control
Library: Powertrain Blockset / Transmission / Transmission Systems



Description

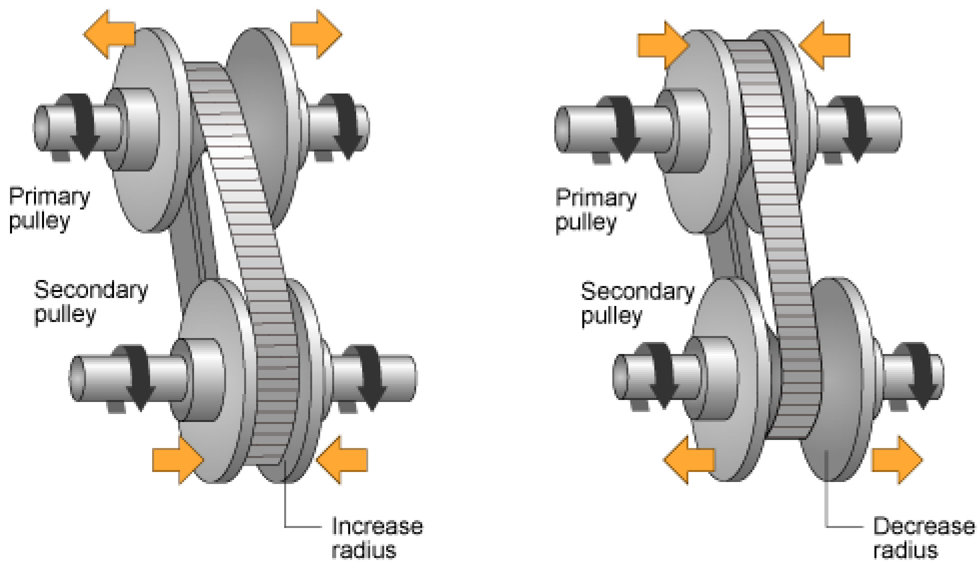
The Continuously Variable Transmission block implements a push belt continuously variable transmission (CVT) with independent radii control. Use the block for control system design, powertrain matching, and fuel economy studies. You can configure the block for internal or external control:

- Internal — Input direction and pulley ratio requests
- External — Input direction and pulley displacement requests

The table summarizes the pulley kinematic, speed reduction, and dynamic calculations made by the Continuously Variable Transmission block.

Calculation	Pulley Kinematics	Reverse and Final Speed Reduction	Dynamics
Final angular speed ratio	✓	✓	✓
Belt torque applied to the secondary and primary pulleys			✓
Torque applied to the secondary and primary pulleys		✓	
Angular velocity of secondary and primary pulleys	✓	✓	✓
Belt and pulley geometry	✓		
Belt linear speed			✓
Wrap angle on secondary and primary pulley	✓		
Primary and secondary pulley radii	✓		

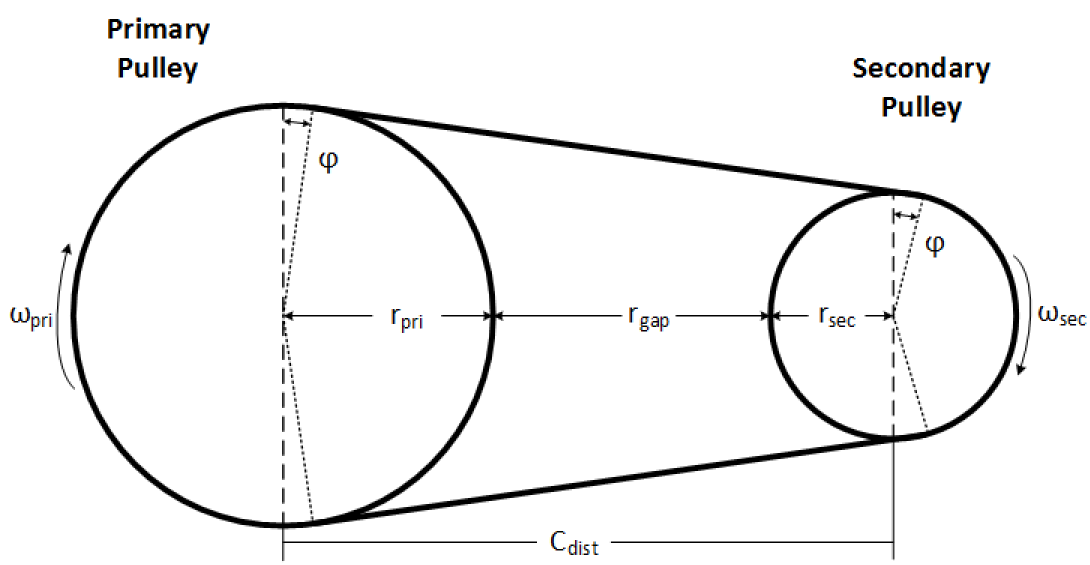
The figure shows the CVT variator with two configurations. In the first configuration, which illustrates speed reduction, the variator is set to decrease the primary pulley radius and increase the secondary pulley radius. In the second configuration, which illustrates overdrive, the variator is set to increase the primary pulley radius and decrease the secondary pulley radius.



Pulley Kinematics

Using the physical dimensions of the system, the block calculates the primary and secondary variator positions that meet the pulley ratio request.

The figure and equations summarize the geometric dependencies.



$$C_{dist} = rp_{max} + r_{gap} + r_{sec\_max}$$
$$L_0 = f(rp_{max}, rs_{max}, rp_{min}, rs_{min}, C_{dist})$$
$$ratio_{command} = f\left(ratio_{request}, ratio_{max}, ratio_{min}\right)$$
$$r_{pri} = f(r_0, ratio_{command}, C_{dist})$$
$$r_{\mathrm{sec}} = f(r_0, ratio_{command}, C_{dist})$$
$$x_{pri} = f\left(r_0, r_{pri}, \theta_{wedge}\right)$$
$$x_{\mathrm{sec}} = f\left(r_0, r_{\mathrm{sec}}, \theta_{wedge}\right)$$

The equations use these variables.

$ratio_{request}$	Pulley gear ratio request
$ratio_{command}$	Pulley gear ratio command, based on request and physical limitations
r_{gap}	Gap distance between variator pulleys
C_{dist}	Distance between variator pulley centers
rp_{max}	Maximum variator primary pulley radius
rs_{max}	Maximum variator secondary pulley radius
rp_{min}	Minimum variator primary pulley radius
rs_{min}	Minimum variator secondary pulley radius
r_o	Initial pulley radii with gear ratio of 1
L_o	Initial belt length, resulting from variator specification
x_{pri}	Variator primary pulley displacement, resulting from controller request
x_{sec}	Variator secondary pulley displacement, resulting from controller request
r_{pri}	Variator primary pulley radius, resulting from controller request
r_{sec}	Variator secondary pulley radius, resulting from controller request
Θ_{wedge}	Variator wedge angle
Φ	Angle of belt to pulley contact point
L	Belt length, resulting from variator position

Reverse and Final Speed Reduction

The CVT input shaft connects to a planetary gear set that drives the primary pulley. The shift direction determines the input gear inertia, efficiency, and gear ratio. The shift direction is the filtered commanded direction:

$$\frac{Dir_{shift}}{Dir}(s) = \frac{1}{\tau_s s + 1}$$

For forward motion ($Dir_{shift} = 1$):

$$N_i = 1$$
$$\eta_i = \eta_{fwd}$$
$$J_i = J_{fwd}$$

For reverse motion ($Dir_{shift} = -1$):

$$N_i = -N_{rev}$$
$$\eta_i = \eta_{rev}$$
$$J_i = J_{rev}$$

The gear ratio and efficiency determine the input drive shaft speed and torque applied to the primary pulley:

$$T_{app\_pri} = \eta_i N_i T_i$$

The block reduces the secondary pulley speed and applied torque using a fixed gear ratio.

$$T_{app\_sec} = \frac{T_o}{\eta_o N_o}$$

$$\omega_o = \frac{\omega_{sec}}{N_o}$$

The final gear ratio, without slip, is given by:

$$N_{final} = \frac{\omega_i}{\omega_o} = N_i N_o \frac{r_{sec}}{r_{pri}}$$

The equations use these variables.

N_i	Input planetary gear ratio
Dir	CVT direction command
Dir_{shift}	Direction used to determine planetary inertia, efficiency, and ratio
τ_s	Direction shift time constant
η_{fwd}, η_{rev}	Forward and reverse gear efficiency, respectively
J_{fwd}, J_{rev}	Forward and reverse gear inertia, respectively
N_{rev}	Reverse gear ratio
T_{app_pri}, T_{app_sec}	Torque applied to primary and secondary pulleys, respectively
T_i	Input drive shaft torque
ω_i, ω_o	Input and output drive shaft speed, respectively
ω_{pri}, ω_{sec}	Primary and secondary pulley speed, respectively
N_{final}	Total no-slip gear ratio

Dynamics

The maximum torque that the CVT can transmit depends on the friction between the pulleys and belt. According to *Prediction of Friction Drive Limit of Metal V-Belt*, the torque friction is defined as:

$$T_{fric}(r_p, \mu) = \frac{2\mu F_{ax} r_p}{\cos(\vartheta_{wedge})}$$

Without macro slip, the tangential acceleration of the pulley is assumed to be equal to the belt acceleration. Once the torque reaches the static friction limit, the belt begins to slip, and the pulley and belt acceleration are independent. During slip, the torque transmitted by the belt is a function of the kinetic friction factor. During the transition from slip to non-slip conditions, the belt and tangential pulley velocities are equal.

The block implements these equations for four different slip conditions.

Condition	Equations
Belt slips on both secondary and primary pulleys	$(J_{pri} + J_i)\dot{\omega}_{pri} = T_{app\_pri} - T_{BoP\_pri} - b_{pri}\omega_{pri}$ $J_{sec}\dot{\omega}_{sec} = T_{app\_sec} - T_{BoP\_sec} - b_{sec}\omega_{sec}$ $m_b\dot{v}_b = \frac{T_{BoP\_pri}}{r_{pri}} + \frac{T_{BoP\_sec}}{r_{sec}} - b_b v_b$ $r_{pri}\omega_{pri} \neq v_b$ $r_{sec}\omega_{sec} \neq v_b$
Belt slips on only the primary pulley	$(J_{pri} + J_i)\dot{\omega}_{pri} = T_{app\_pri} - T_{BoP\_pri} - b_{pri}\omega_{pri}$ $\left(m_b + \frac{J_{sec}}{r^2{}_{sec}}\right)\dot{v}_b = \frac{T_{BoP\_pri}}{r_{pri}} + \frac{T_{BoP\_sec}}{r_{sec}} - \left(b_b + \frac{b_{sec}}{r^2{}_{sec}}\right)v_b$ $\omega_{sec} = \frac{v_b}{r_{sec}}$ $r_{pri}\omega_{pri} \neq v_b$ $T_{BoP\_pri} = \mathrm{sgn}(r_{pri}\omega_{pri} - v_b)T_{fric}(r_{pri}, \mu_{kin})$ $\left\|T_{BoP\_sec}\right\| < T_{fric}(r_{sec}, \mu_{static})$
Belt slips on only the secondary pulley	$(m_b + \frac{J_{pri} + J_i}{r^2{}_{pri}})\dot{v}_b = \frac{T_{app\_pri}}{r_{pri}} + \frac{T_{BoP\_sec}}{r_{sec}} - \left(b_b + \frac{b_{pri}}{r^2{}_{pri}}\right)v_b$ $J_{sec}\dot{\omega}_b = T_{app\_sec} + T_{BoP\_sec} - b_{sec}\omega_{sec}$ $\omega_{pri} = \frac{v_b}{r_{pri}}$ $r_{sec}\omega_{sec} \neq v_b$ $T_{BoP\_sec} = \mathrm{sgn}(r_{sec}\omega_{sec} - v_b)T_{fric}(r_{sec}, \mu_{kin})$ $\left\|T_{BoP\_pri}\right\| < T_{fric}(r_{pri}, \mu_{static})$
Belt does not slip	$\left(m_b + \frac{J_{sec}}{r^2{}_{sec}} + \frac{J_{pri} + J_i}{r^2{}_{pri}}\right)\dot{v}_b = \frac{T_{app\_pri}}{r_{pri}} + \frac{T_{app\_sec}}{r_{sec}} - \left(b_b + \frac{b_{sec}}{r^2{}_{sec}} + \frac{b_{pri}}{r^2{}_{pri}}\right)v_b$ $\omega_{pri} = \frac{v_b}{r_{pri}}$ $\omega_{sec} = \frac{v_b}{r_{sec}}$ $\left\|T_{BoP\_pri}\right\| < T_{fric}(r_{pri}, \mu_{static})$ $\left\|T_{BoP\_sec}\right\| < T_{fric}(r_{sec}, \mu_{static})$

Condition	Equations
Slip direction	$PriSlipDir = \begin{cases} 0 & r_{pri}\omega_{pri} = v_b \\ 1 & r_{pri}\omega_{pri} > v_b \\ -1 & r_{pri}\omega_{pri} < v_b \end{cases}$ $SecSlipDir = \begin{cases} 0 & r_{sec}\omega_{sec} = v_b \\ 1 & r_{sec}\omega_{sec} > v_b \\ -1 & r_{sec}\omega_{sec} < v_b \end{cases}$

The equations use these variables.

T_{BoP_pri}, T_{BoP_sec}	Belt torque acting on the primary and secondary pulleys, respectively
T_{app_pri}, T_{app_sec}	Torque applied to primary and secondary pulleys, respectively
J_{pri}, J_{sec}	Primary and secondary pulley rotational inertias, respectively
b_{pri}, b_{sec}	Primary and secondary pulley rotational viscous damping, respectively
F_{ax}	Pulley clamp force
μ	Coefficient of friction
μ_{kin}, μ_{static}	Coefficient of kinetic and static friction
v_b, a_b	Linear speed and acceleration of the belt, respectively
m_b	Total belt mass
r_{pri}, r_{sec}	Radii of the primary and secondary pulleys, respectively
Φ_{wrap}	Wrap angle of belt to pulley contact point
Φ_{wrap_pri}, Φ_{wrap_sec}	Primary and secondary pulley wrap angles, respectively

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrEng`	Engine power	P_{eng}	$\omega_i T_i$
		`PwrDiffrntl`	Differential power	P_{diff}	$\omega_o T_o$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrBltLoss`	Belt slip power loss	$P_{bltloss}$	$\left(J_{in} + J_{pri}\right)\dot{\omega}_{pri}\omega_{pri} + J_{sec}\dot{\omega}_{sec}\omega_{sec} + m_b\dot{v}_b v_b + b_{pri}\omega_{pri}^2 + b_{sec}\omega_{sec}^2 + b_b v_b^2 - T_{app_{pri}}\omega_{pri} - T_{app_{sec}}\omega_{sec}$

Bus Signal			Description	Variable	Equations
		PwrGearInLoss	Input planetary gear mechanical power loss	$P_{grinloss}$	$-\lvert\omega_i T_i - T_{app\_pri}\omega_{pri}\rvert$
		PwrGearOutLoss	Output gear reduction mechanical power loss	$P_{groutloss}$	$-\lvert\omega_o T_o - T_{app\_sec}\omega_{sec}\rvert$
		PwrDampLoss	Mechanical damping loss	$P_{damploss}$	$-b_{pri}\omega_{pri}^2 - b_{sec}\omega_{sec}^2 - b_b v_b^2$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredTrans	Rate change in rotational kinetic energy	P_{str}	$(J_{in} + J_{pri})\dot{\omega}_{pri}\omega_{pri} + J_{sec}\dot{\omega}_{sec}\omega_{sec} + m_b\dot{v}_b v_b$

The equations use these variables.

T_{app_pri}, T_{app_sec}	Torque applied to primary and secondary pulleys, respectively
T_i, T_o	Input and output drive shaft torque, respectively
J_{pri}, J_{sec}	Primary and secondary pulley rotational inertias, respectively
b_{pri}, b_{sec}	Primary and secondary pulley rotational viscous damping, respectively
ω_{pri}, ω_{sec}	Primary and secondary pulley speed, respectively
ω_i, ω_o	Input and output drive shaft speed, respectively
v_b, a_b	Linear speed and acceleration of the belt, respectively
r_{pri}, r_{sec}	Radii of the primary and secondary pulleys, respectively

Ports

Inputs

`Dir` — Direction request
`scalar`

Direction request, Dir_{req}, controlling the direction. The block filters the request to determine the direction, forward or reverse. Dir equals `1` for forward motion. Dir equals `-1` for reverse.

$$Dir = \begin{cases} 1 & \text{when } Dir_{req} \geq 0 \\ -1 & \text{when } Dir_{req} < 0 \end{cases}$$

`PllyRatioReq` — Pulley ratio request
`scalar`

CVT pulley ratio request, $ratio_{request}$.

Dependencies

To create this port, for the **Control mode** parameter, select `Ideal integrated controller`.

`PriDisp` — Primary pulley displacement
`scalar`

Variator primary pulley displacement, x_{pri}, in m.

Dependencies

To create this port, for the **Control mode** parameter, select `External control`.

`SecDisp` — Secondary pulley displacement
`scalar`

Variator secondary pulley displacement, x_{sec}, in m.

Dependencies

To create this port, for the **Control mode** parameter, select `External control`.

`EngTrq` — Input drive shaft torque
`scalar`

External torque applied to the input drive shaft, T_i, in N·m.

`DiffTrq` — Output drive shaft torque
`scalar`

External torque applied to the output drive shaft, T_o, in N·m.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Variable	Units
`EngTrq`	Input shaft torque	T_i	N·m
`DiffTrq`	Output shaft torque	T_o	N·m
`EngSpd`	Input shaft speed	ω_i	rad/s
`DiffSpd`	Output shaft speed	ω_o	rad/s
`PriRadius`	Primary pulley radius	r_{pri}	m
`PriPhi`	Primary pulley wrap angle	Φ_{pri}	rad
`SecRadius`	Secondary pulley radius	r_{sec}	m
`SecPhi`	Secondary pulley wrap angle	Φ_{sec}	rad
`BltLngthDelta`	Change in belt length	ΔL	m
`BltLngth`	Belt length	L	m
`BltLngthInit`	Initial belt length	L_o	m

Signal			Description	Variable	Units
`BltOnPriTrq`			Belt torque acting on the primary pulley	T_{BoP_pri}	N·m
`BltOnSecTrq`			Belt torque acting on the secondary pulley	T_{BoP_sec}	N·m
`BltVel`			Linear speed of the belt	v_b	m/s
`PriAngVel`			Primary pulley speed	ω_{pri}	rad/s
`SecAngVel`			Secondary pulley speed	ω_{sec}	rad/s
`PriSlipDir`			Primary pulley slip direction indicator	*PriSlipDir*	N/A
`SecSlipDir`			Secondary pulley slip direction indicator	*SecSlipDir*	N/A
`TransSpdRatio`			Total no-slip gear ratio	N_{final}	N/A
`PwrInfo`	`PwrTrnsfrd`	`PwrEng`	Engine power	P_{eng}	W
		`PwrDiffrntl`	Differential power	P_{diff}	W
	`PwrNotTrnsfrd`	`PwrBltLoss`	Belt slip power loss	$P_{bltloss}$	W
		`PwrGearInLoss`	Input planetary gear mechanical power loss	$P_{grinloss}$	W
		`PwrGearOutLoss`	Output gear reduction mechanical power loss	$P_{groutloss}$	W
		`PwrDampLoss`	Mechanical damping loss	$P_{damploss}$	W
	`PwrStored`	`PwrStoredTrans`	Rate change in rotational kinetic energy	P_{str}	W

EngSpd — Input drive shaft speed
`scalar`

Input drive shaft angular speed, ω_i, in rad/sec.

`DiffSpd` — Output drive shaft speed
`scalar`

Output drive shaft angular speed, ω_o, in rad/sec.

Parameters

`Control mode` — External or internal
`Ideal integrated controller` (default) | `External control`

Specify the control method, either internal or external.

Dependencies

This table summarizes the port and input model configurations.

Control Mode	Creates Ports
Ideal integrated controller	PllyRatioReq
External control	PriDisp SecDisp

Kinematics

Maximum variator primary pulley radius, rp_max — Radius
.08 (default) | scalar

Maximum variator primary pulley radius, rp_{max}, in m.

Maximum variator secondary pulley radius, rs_max — Radius
.07 (default) | scalar

Maximum variator secondary pulley radius, rs_{max}, in m.

Minimum variator primary pulley radius, rp_min — Radius
.03 (default) | scalar

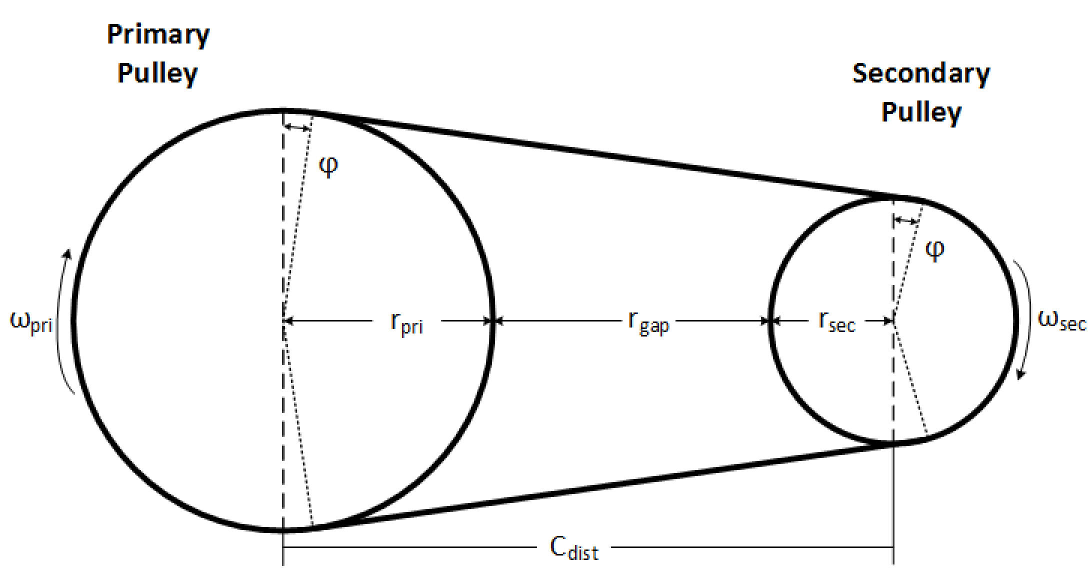
Minimum variator primary pulley radius, rp_{min}, in m.

Minimum variator secondary pulley radius, rs_min — Radius
.03 (default) | scalar

Minimum variator secondary pulley radius, rs_{min}, in m.

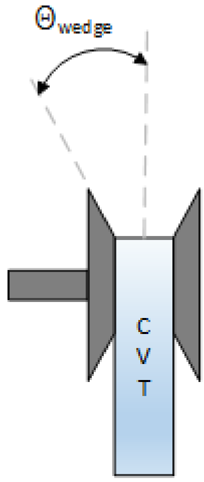
Gap distance between variator pulleys, rgap — Specify crown wheel connection
.025 (default) | scalar

The gap between the secondary and primary pulleys, r_{gap}, in m. The figure shows the pulley geometry.



Variator wedge angle, thetawedge — Specify crown wheel connection
11 (default) | scalar

Variator wedge angle, Θ_{wedge}, in deg.



Dynamics

Primary pulley inertia, J_pri — Inertia
0.1 (default) | scalar

Primary pulley inertia, J_{pri}, in kg·m^2.

Secondary pulley inertia, J_sec — Inertia
0.1 (default) | scalar

Secondary pulley inertia, J_{sec}, in kg·m^2.

Primary pulley damping coefficient, b_pri — Damping
0.001 (default) | scalar

Primary pulley damping coefficient, b_{pri}, in N·m·s/rad.

Secondary pulley damping coefficient, b_sec — Damping
0.001 (default) | scalar

Secondary pulley damping coefficient, b_{sec}, in N·m·s/rad.

Belt damping coefficient, b_b — Damping
0.0025 (default) | scalar

Belt damping coefficient, b_b, in kg/s.

Static friction coefficient, mu_static — Friction
0.3 (default) | scalar

Static friction coefficient between the belt and primary pulley, μ_{static}, dimensionless.

Kinetic friction coefficient, mu_kin — Friction
0.2 (default) | scalar

Kinetic friction coefficient between the belt and primary pulley, μ_{kin}, dimensionless.

Belt mass, m_b — Mass
3 (default) | scalar

Belt mass, m_b, in kg.

Pulley clamp force, F_ax — Pulley clamp force
5000 (default) | scalar

Pulley clamp force, F_{ax}, in N.

Reverse and Output Ratio

Forward inertia, J_fwd — Inertia
0.1 (default) | scalar

Forward inertia, J_{fwd}, in kg·m^2.

Reverse inertia, J_rev — Inertia
0.1 (default) | scalar

Reverse inertia, J_{rev}, in kg·m^2.

Forward efficiency, eta_fwd — Efficiency
0.95 (default) | scalar

Forward efficiency, η_{fwd}, dimensionless.

Reverse efficiency, eta_rev — Efficiency
0.95 (default) | scalar

Reverse efficiency, η_{rev}, dimensionless.

Reverse gear ratio, N_rev — Ratio
2 (default) | scalar

Reverse gear ratio, N_{rev}, dimensionless.

Shift time constant, tau_s — Constant
.01 (default) | scalar

Shift time constant, τ_s, in s.

Output gear ratio, N_o — Ratio
2 (default) | scalar

Output gear ratio, N_o, dimensionless.

Output gear efficiency, eta_o — Efficiency
0.98 (default) | scalar

Output gear efficiency, η_o, dimensionless.

References

[1] Ambekar, Ashok G. *Mechanism and Machine Theory*. New Delhi: Prentice-Hall of India, 2007.

[2] Bonsen, B. *Efficiency optimization of the push-belt CVT by variator slip control*. Ph.D. Thesis. Eindhoven University of Technology, 2006.

[3] *CVT How Does It Work*. CVT New Zealand 2010 Ltd, 10 Feb. 2011. Web. 25 Apr. 2016.

[4] Klaassen, T. W. G. L. *The Empact CVT: Dynamics and Control of an Electromechanically Actuated CVT*. Ph.D. Thesis. Eindhoven University of Technology, 2007.

[5] Sakagami, K. *Prediction of Friction Drive Limit of Metal V-Belt*. Warrendale, PA: SAE International Journal of Engines 8(3):1408-1416, 2015.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

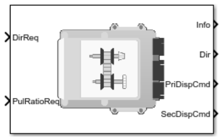
CVT Controller

Introduced in R2017a

CVT Controller

Continuously variable transmission controller

Library: Powertrain Blockset / Transmission / Transmission Controllers



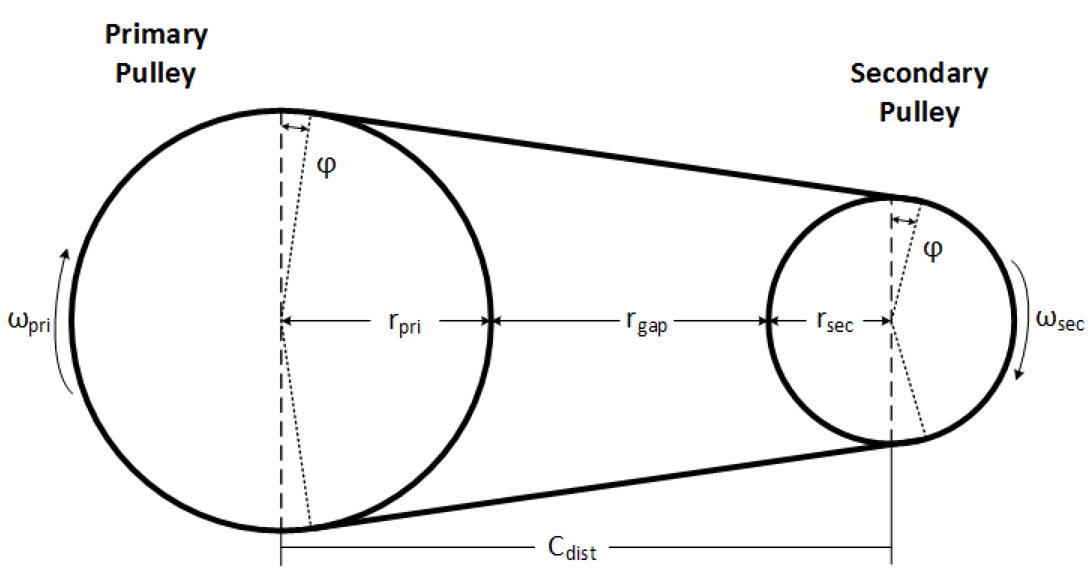
Description

The CVT Controller block implements a push belt continuously variable transmission (CVT) controller. The block uses standard pulley and geometric equations to calculate the kinematic setpoints for the CVT variator. You can use the block to control a CVT.

Pulley Kinematics

Using the physical dimensions of the system, the block calculates the primary and secondary variator positions that meet the pulley ratio request.

The figure and equations summarize the geometric dependencies.



$$C_{dist} = rp_{max} + r_{gap} + r_{sec\_max}$$
$$L_0 = f(rp_{max}, rs_{max}, rp_{min}, rs_{min}, C_{dist})$$
$$ratio_{command} = f\left(ratio_{request}, ratio_{max}, ratio_{min}\right)$$
$$r_{pri} = f(r_0, ratio_{command}, C_{dist})$$
$$r_{\mathrm{sec}} = f(r_0, ratio_{command}, C_{dist})$$
$$x_{pri} = f\left(r_0, r_{pri}, \theta_{wedge}\right)$$
$$x_{\mathrm{sec}} = f\left(r_0, r_{\mathrm{sec}}, \theta_{wedge}\right)$$

The equations use these variables.

$ratio_{request}$	Pulley gear ratio request
$ratio_{command}$	Pulley gear ratio command, based on request and physical limitations
r_{gap}	Gap distance between variator pulleys
C_{dist}	Distance between variator pulley centers
rp_{max}	Maximum variator primary pulley radius
rs_{max}	Maximum variator secondary pulley radius
rp_{min}	Minimum variator primary pulley radius
rs_{min}	Minimum variator secondary pulley radius
r_o	Initial pulley radii with gear ratio of 1
L_o	Initial belt length, resulting from variator specification
x_{pri}	Variator primary pulley displacement, resulting from controller request
x_{sec}	Variator secondary pulley displacement, resulting from controller request
r_{pri}	Variator primary pulley radius, resulting from controller request
r_{sec}	Variator secondary pulley radius, resulting from controller request
Θ_{wedge}	Variator wedge angle
Φ	Angle of belt to pulley contact point
L	Belt length, resulting from variator position

Ports

Inputs

`DirReq` — Direction request

`scalar`

Direction request, Dir_{req}, controlling the direction, either forward or reverse. Dir equals `1` for forward motion. Dir equals `-1` for reverse.

$$Dir = \begin{cases} 1 & \text{when } Dir_{req} \geq 0 \\ -1 & \text{when } Dir_{req} < 0 \end{cases}$$

`PllyRatioReq` — Pulley ratio request

`scalar`

CVT pulley ratio request, $ratio_{request}$.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal		Description	Variable	Units
`Radius`	`PriRadius`	Variator primary pulley radius, resulting from controller request	r_{pri}	m
	`SecRadius`	Variator secondary pulley radius, resulting from controller request	r_{sec}	m
	`InitPllyRadius`	Initial pulley radii with gear ratio of 1	r_o	m
`RatioAdj`		Pulley gear ratio command, based on request and physical limitations	$ratio_{command}$	N/A
`RatioMax`		Maximum pulley ratio	$ratio_{max}$	N/A
`RatioMin`		Minimum pulley ratio	$ratio_{min}$	N/A
`PriDispCmd`		Variator primary pulley displacement, resulting from controller request	x_{pri}	m
`SecDispCmd`		Variator secondary pulley displacement, resulting from controller request	x_{sec}	m

`Dir` — Direction request
`scalar`

Direction request, Dir_{req}, controlling the direction, either forward or reverse. *Dir* equals `1` for forward motion. *Dir* equals `-1` for reverse.

$$Dir = \begin{cases} 1 & \text{when } Dir_{req} \geq 0 \\ -1 & \text{when } Dir_{req} < 0 \end{cases}$$

`PriDispCmd` — Primary pulley displacement
`scalar`

Variator primary pulley displacement, x_{pri}, in m.

`SecDispCmd` — Secondary pulley displacement
`scalar`

Variator secondary pulley displacement, x_{sec}, in m.

Parameters

Kinematics

`Maximum variator primary pulley radius, rp_max` — Radius
`.08` (default) | `scalar`

Maximum variator primary pulley radius, rp_{max}, in m.

`Maximum variator secondary pulley radius, rs_max` — Radius
`.07` (default) | `scalar`

Maximum variator secondary pulley radius, rs_{max}, in m.

`Minimum variator primary pulley radius, rp_min` — Radius
`.03` (default) | `scalar`

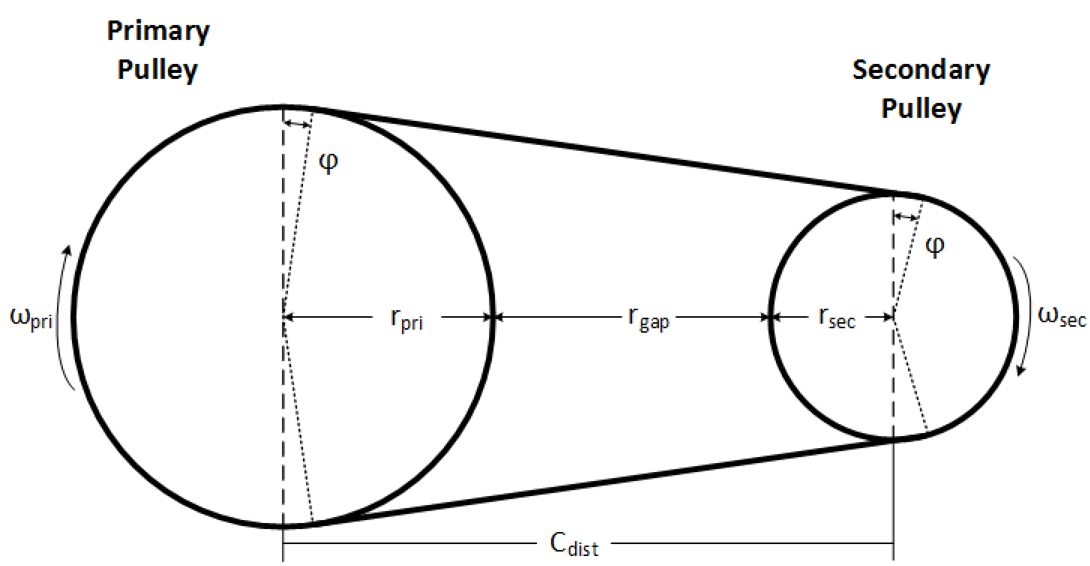
Minimum variator primary pulley radius, rp_{min}, in m.

`Minimum variator secondary pulley radius, rs_min` — Radius
`.03` (default) | `scalar`

Minimum variator secondary pulley radius, rs_{min}, in m.

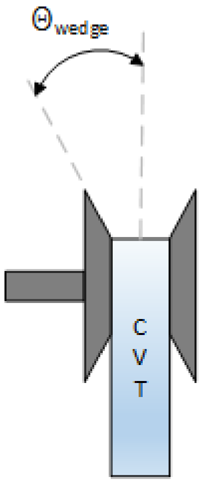
`Gap distance between variator pulleys, rgap` — Specify crown wheel connection
`.025` (default) | `scalar`

The gap between the secondary and primary pulleys, r_{gap}, in m. The figure shows the pulley geometry.



`Variator wedge angle, thetawedge` — Specify crown wheel connection
`11` (default) | `scalar`

Variator wedge angle, Θ_{wedge}, in deg.



References

[1] Ambekar, Ashok G. *Mechanism and Machine Theory*. New Delhi: Prentice-Hall of India, 2007.

[2] Bonsen, B. *Efficiency optimization of the push-belt CVT by variator slip control*. Ph.D. Thesis. Eindhoven University of Technology, 2006.

[3] *CVT How Does It Work*. CVT New Zealand 2010 Ltd. February 10, 2011. Accessed April 25, 2016.

[4] Klaassen, T. W. G. L. *The Empact CVT: Dynamics and Control of an Electromechanically Actuated CVT*. Ph.D. Thesis. Eindhoven University of Technology, 2007.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

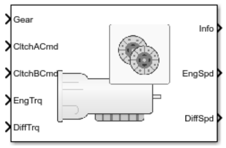
See Also

Continuously Variable Transmission

Introduced in R2017a

Dual Clutch Transmission

Dual clutch transmission that applies torque to the drive shaft
Library: Powertrain Blockset / Transmission / Transmission Systems



Description

The Dual Clutch Transmission block implements a dual clutch transmission (DCT). In a DCT, two clutches apply mechanical torque to the drive shaft. Odd gears engage one clutch, while even gears engage the secondary clutch. The number of gears is specified via an integer vector with corresponding gear ratios, inertias, viscous damping, and efficiency factors. The clutch and synchronization engagement rates are linear and adjustable. You can provide external clutch signals or configure the block to generate idealized internal clutch signals. The block implements the transmission model with minimal parameterization or computational cost.

Use the block to model a simplified automated manual transmission (AMT) for:

- Power and torque capacity sizing
- Determining gear ratio impact on fuel economy and performance

To determine the rotational drive shaft speed and reaction torque, the Dual Clutch Transmission block calculates:

- Clutch lock-up and clutch friction
- Locked rotational dynamics
- Unlocked rotational dynamics

To specify the block efficiency calculation, for **Efficiency factors**, select either of these options.

Setting	Block Implementation
`Gear only`	Efficiency determined from a 1D lookup table that is a function of the gear.
`Gear, input torque, input speed, and temperature`	Efficiency determined from a 4D lookup table that is a function of: • Gear • Input torque • Input speed • Oil temperature

Clutch Control

The DCT delivers drive shaft torque continuously by controlling the pressure signals from both clutches. If you select **Control mode** parameter `Ideal integrated controller`, the block generates idealized clutch pressure signals. The block uses the maximum pressure from each clutch to approximate the single-clutch commands that result in equivalent drive shaft torque. To use your own clutch control signals, select **Control mode** parameter `External control`.

Clutch Lock-Up and Clutch Friction

Based on the clutch lock-up condition, the block implements one of these friction models.

If	Clutch Condition	Friction Model
$\omega_i \neq N\omega_d$ or $T_S < \lvert T_f - Nw_i b_i \rvert$	Unlocked	$T_f = T_k$ where, $T_k = F_c R_{eff} \mu_k \tanh\left[4\left(\frac{w_i}{N} - w_d\right)\right]$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o{}^3 - R_i{}^3)}{3(R_o{}^2 - R_i{}^2)}$
$\omega_i = N\omega_t$ and $T_S \geq \lvert T_f - Nb_i\omega_i \rvert$	Locked	$T_f = T_s$

The equations use these variables.

ω_t	Output drive shaft speed
ω_i	Input drive shaft speed
ω_d	Drive shaft speed
b_i	Viscous damping
F_c	Applied clutch force
N	Engaged gear
T_f	Frictional torque
T_k	Kinetic frictional torque
T_s	Static frictional torque
R_{eff}	Effective clutch radius
R_o	Annular disk outer radius
R_i	Annular disk inner radius
μ_s	Coefficient of static friction
μ_k	Coefficient of kinetic friction

Locked Rotational Dynamics

To model the rotational dynamics when the clutch is locked, the block implements these equations.

$$\dot{\omega}_d J_N = \eta_N T_d - \frac{\omega_i}{N} b_N + NT_i$$

$$\omega_i = N\omega_d$$

The block determines the input torque, T_i, through differentiation.

The equations use these variables.

ω_i	Input drive shaft speed
ω_d	Drive shaft speed
N	Engaged gear
b_N	Engaged gear viscous damping
J_N	Engaged gear inertia
η_N	Engaged gear efficiency
T_d	Drive shaft torque
T_i	Applied input torque

Unlocked Rotational Dynamics

To model the rotational dynamics when the clutch is unlocked, the block implements this equation.

$$\dot{\omega}_d J_N = NT_f - \omega_d b_N + T_d$$

where:

ω_d	Drive shaft speed
N	Engaged gear
b_N	Engaged gear viscous damping
J_N	Engaged gear inertia
T_d	Drive shaft torque
T_i	Applied input torque

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrEng`	Engine power	P_{eng}	$\omega_i T_i$
		`PwrDiffrntl`	Differential power	P_{diff}	$\omega_d T_d$
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input	`PwrEffLoss`	Mechanical power loss	$P_{effloss}$	$\omega_d T_d(\eta_N - 1)$
		`PwrDampLoss`	Mechanical damping loss	$P_{damploss}$	$-b_N\omega_d^2 \ - b_{in}\omega_i^2$

Bus Signal			Description	Variable	Equations
	• Negative signals indicate a loss	`PwrCltchLoss`	Clutch power loss	P_{mech}	When locked: 0 When unlocked: $-T_k(\omega_i - N\omega_d)$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredTrans`	Rate change in rotational kinetic energy	P_{str}	When locked: $\dot{\omega}_i\omega_i(J_{in} + \frac{J_N}{N^2})$ When unlocked: $J_{in}\dot{\omega}_i\omega_i + J_N\dot{\omega}_d\omega_d$

The equations use these variables.

b_N	Engaged gear viscous damping
J_N	Engaged gear rotational inertia
J_{in}	Flywheel rotational inertia
η_N	Engaged gear efficiency
N	Engaged gear ratio
T_i	Applied input torque, typically from the engine crankshaft or dual mass flywheel damper
T_d	Applied load torque, typically from the differential or drive shaft
ω_d	Initial input drive shaft rotational velocity
ω_i, $\dot{\omega}_i$	Applied drive shaft angular speed and acceleration

Ports

Inputs

`Gear` — Gear number to engage

`scalar`

Integer value of gear number to engage.

`CltchACmd` — Command for odd-numbered gears

`scalar`

Clutch pressure command for odd-numbered gears, between `0` and `1`.

Dependencies

To create this port, select **Control mode** parameter `External control`.

`CltchBCmd` — Command for even-numbered gears

`scalar`

Clutch pressure command for even-numbered gears, between `0` and `1`.

Dependencies

To create this port, select **Control mode** parameter `External control`.

`EngTrq` — Applied torque

`scalar`

Applied input torque, T_i, typically from the engine crankshaft or dual mass flywheel damper, in N·m.

`DiffTrq` — Applied torque

`scalar`

Applied load torque, T_d, typically from the drive shaft, in N·m.

`Temp` — Oil temperature

`scalar`

Oil temperature, in K. To determine the efficiency, the block uses a 4D lookup table that is a function of:

- Gear
- Input torque
- Input speed
- Oil temperature

Dependencies

To create this port, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

Output

`Info` — Bus signal

bus

Bus signal containing these block calculations.

Signal		Description	Variable	Units
`Eng`	`EngTrq`	Applied input torque, typically from the engine crankshaft or dual mass flywheel damper	T_i	N·m
	`EngSpd`	Applied drive shaft angular speed input	ω_i	rad/s
`Diff`	`DiffTrq`	Applied load torque, typically from the differential	T_d	N·m
	`DiffSpd`	Drive shaft angular speed output	ω_d	rad/s
`Cltch`	`CltchForce`	Applied clutch force	F_c	N
	`CltchLocked`	Clutch state	NA	NA

Signal			Description	Variable	Units
Trans	TransSpd Ratio		Input to output speed ratio at time t	$\Phi(t)$	NA
	TransEta		Ratio of output power to input power	η_N	NA
	TransGearCmd		Commanded gear	N_{cmd}	NA
	TransGear		Engaged gear	N	NA
PwrInfo	PwrTrnsfrd	PwrEng	Engine power	P_{eng}	W
		PwrDiffrntl	Differential power	P_{diff}	W
	PwrNotTrnsfrd	PwrEffLoss	Mechanical power loss	$P_{effloss}$	W
		PwrDampLoss	Mechanical damping loss	$P_{damploss}$	W
		PwrCltchLoss	Clutch power loss	P_{mech}	W
	PwrStored	PwrStoredTrans	Rate change in rotational kinetic energy	P_{str}	W

EngSpd — Angular speed
`scalar`

Drive shaft angular speed, ω_d, in rad/s.

`DiffSpd` — Angular speed
`scalar`

Drive shaft angular speed, ω_d, in rad/s.

Parameters

`Control mode` — Specify control mode
`External control` (default) | `Ideal integrated controller`

The DCT delivers drive shaft torque continuously by controlling the pressure signals from both clutches. If you select **Control mode** parameter `Ideal integrated controller`, the block generates idealized clutch pressure signals. The block uses the maximum pressure from each clutch to approximate the single-clutch commands that result in equivalent drive shaft torque. To use your own clutch control signals, select **Control mode** parameter `External control`.

Dependencies

This table summarizes the port configurations.

Control Mode	Creates Ports
External control	CltchACmd
	CltchBCmd

Efficiency factors — Specify efficiency calculation
Gear only (default) | Gear, input torque, input speed, and temperature

To specify the block efficiency calculation, for **Efficiency factors**, select either of these options.

Setting	Block Implementation
Gear only	Efficiency determined from a 1D lookup table that is a function of the gear.
Gear, input torque, input speed, and temperature	Efficiency determined from a 4D lookup table that is a function of: • Gear • Input torque • Input speed • Oil temperature

Dependencies

Setting Parameter To	Enables
Gear only	**Efficiency vector, eta**
Gear, input torque, input speed, and temperature	**Efficiency torque breakpoints, Trq_bpts** **Efficiency speed breakpoints, omega_bpts** **Efficiency temperature breakpoints, Temp_bpts** **Efficiency lookup table, eta_tbl**

Transmission

Input shaft inertia, Jin — Inertia
0.1 (default) | scalar

Input shaft inertia, in kg·m^2.

Input shaft damping, bin — Damping
0.001 (default) | scalar

Input shaft damping, in N·m·s/rad.

Initial input velocity, omegain_o — Angular velocity
0 (default) | scalar

Angular velocity, in rad/s.

Efficiency torque breakpoints, Trq_bpts — Breakpoints
[25 50 75 100 150 200 250] (default) | vector

Torque breakpoints for efficiency table, in N·m.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

`Efficiency speed breakpoints, omega_bpts` — Breakpoints
`[52.4 78.5 105 131 157 183 209 262 314 419 524]` (default) | `vector`

Speed breakpoints for efficiency table, in rad/s.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

`Efficiency temperature breakpoints, Temp_bpts` — Breakpoints
`[313 358]` (default) | `vector`

Temperature breakpoints for efficiency table, in K.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

`Gear number vector, G` — Specify number of transmission speeds
`[-1, 0, 1, 2, 3, 4, 5, 6, 7, 8]` (default) | `vector`

Vector of integers used to specify the number of transmission speeds. Neutral gear is `0`. For example, you can set these parameter values.

To Specify	Set Gear number, G to
Four transmission speeds, including neutral	`[0,1,2,3,4]`
Three transmission speeds, including neutral and reverse	`[-1,0,1,2,3]`
Five transmission speeds, including neutral and reverse	`[-1,0,1,2,3,4,5]`

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

`Gear ratio vector, N` — Ratio of input speed to output speed
`[-4.70, 4.70, 4.700, 3.130,2.100, 1.670,1.290, 1.000,0.840, 0.670]` (default) | `vector`

Vector of gear ratios (that is, input speed to output speed) with indices corresponding to the ratios specified in **Gear number, G**. For neutral, set the gear ratio to `1`. For example, you can set these parameter values.

To Specify Gear Ratios for	Set Gear number, G to	Set Gear ratio, N to
Four transmission speeds, including neutral	`[0,1,2,3,4]`	`[1,4.47,2.47,1.47,1]`

To Specify Gear Ratios for	Set Gear number, G to	Set Gear ratio, N to
Five transmission speeds, including neutral and reverse	[-1,0,1,2,3,4,5]	[-4.47,1,4.47,2.47,1.47,1,0.8]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

Transmission inertia vector, Jout — Gear rotational inertia

[0.08 0.08 0.08 0.04 0.02 0.01 0.01 0.01 0.01 0.01] (default) | vector

Vector of gear rotational inertias, with indices corresponding to the inertias specified in **Gear number, G**, in kg·m^2. For example, you can set these parameter values.

To Specify Inertia for	Set Gear number, G to	Set Inertia, J to
Four gears, including neutral	[0,1,2,3,4]	[0.01,2.28,2.04,0.32,0.028]
Inertia for five gears, including reverse and neutral	[-1,0,1,2,3,4,5]	[2.28,0.01,2.28,2.04,0.32,0.028,0.01]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

Damping vector, bout — Gear viscous damping coefficient

[.003 .001 .003 .0025 .002 .001 .001 .001 .001 .001] (default) | vector

Vector of gear viscous damping coefficients, with indices corresponding to the coefficients specified in **Gear number, G**, in N·m·s/rad. For example, you can set these parameter values.

To Specify Damping for	Set Gear number, G to	Set Damping, b to
Four gears, including neutral	[0,1,2,3,4]	[0.001,0.003,0.0025, 0.002,0.001]
Five gears, including reverse and neutral	[-1,0,1,2,3,4,5]	[0.003,0.001,0.003,0.0025, 0.002,0.001,0.001]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

Efficiency vector, eta — Gear efficiency

[0.930, 0.930, 0.930, 0.940,0.947, 0.948,0.946, 0.943,0.940, 0.935] (default) | vector

Vector of gear mechanical efficiency, with indices corresponding to the efficiencies specified in **Gear number, G**. For example, you can set these parameter values.

To Specify Efficiency for	Set Gear number, G to	Set Efficiency, eta to
Four gears, including neutral	[0,1,2,3,4]	[0.9,0.9,0.9,0.9,0.95]
Five gears, including reverse and neutral	[-1,0,1,2,3,4,5]	[0.9,0.9,0.9, 0.9,0.9,0.95,0.95]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Transmission inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear only`.

`Efficiency lookup table, eta_tbl` — Gear efficiency
`array`

Table of gear mechanical efficiency, η_N as a function of gear, input torque, input speed, and temperature.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

`Initial output velocity, omegaout_o` — Transmission
`0` (default) | `scalar`

Transmission initial output rotational velocity, ω_{to}, in rad/s. If you select **Clutch initially locked**, the block ignores the **Initial output velocity, omega_o** parameter value.

`Initial gear, G_o` — Engaged gear
`0` (default) | `scalar`

Initial gear to engage, G_o.

Clutch and Synchronizer

`Clutch pressure time constant, tauc` — Time
`.02` (default) | `scalar`

Time required to engage and disengage the clutch during shift events, t_c, in s.

`Synchronization time, ts` — Time
`.2` (default) | `scalar`

Time required for gear selection and synchronization, t_s, in s.

`Clutch time, tc` — Time
`.5` (default) | `scalar`

Time required to engage clutch, t_c, in s.

Dependencies

To create this parameter, select **Control mode** parameter `Ideal integrated controller`.

`Effective clutch radius, R` — Radius
`.25` (default) | `scalar`

The effective radius, R_{eff}, used with the applied clutch friction force to determine the friction force, in m. The effective radius is defined as:

$$R_{eff} = \frac{2(R_o3 - R_i3)}{3(R_o2 - R_i2)}$$

The equation uses these variables.

R_o	Annular disk outer radius
R_i	Annular disk inner radius

Clutch force gain, K_c — Force
5e4 (default) | scalar

Open loop lock-up clutch gain, K_c, in N.

Clutch static friction coefficient, mus — Coefficient
0.3 (default) | scalar

Dimensionless clutch disc coefficient of static friction, μ_s.

Clutch kinematic friction coefficient, muk — Coefficient
0.25 (default) | scalar

Dimensionless clutch disc coefficient of kinetic friction, μ_k.

Clutch initially locked — Select to initially lock clutch
off (default) | on

Selecting this parameter initially locks the clutch.

Dependencies

To create this parameter, select **Control mode** parameter `Ideal integrated controller`.

Synchronizer initially locked — Select to initially lock synchronizer
off (default) | on

Selecting this parameter initially locks the synchronizer.

Extended Capabilities

C/C++ Code Generation

Generate C and C++ code using Simulink® Coder™.

See Also

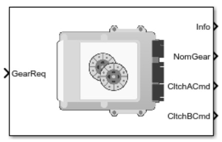
DCT Controller | Automated Manual Transmission

Introduced in R2017a

DCT Controller

Dual clutch transmission controller

Library: Powertrain Blockset / Transmission / Transmission Controllers



Description

The DCT Controller block implements a dual clutch transmission (DCT) controller. You can specify the clutch open, close, and synchronization timing parameters. The block determines the clutch commands using integrator-based timers and latching logic that is based on the specified timing parameters and gear request.

Ports

Inputs

`GearReq` — Gear number to engage
`scalar`

Gear number request, G_{req}.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Variable
`GearReq`	Gear number request	G_{req}
`GearEngd`	Nominal gear commanded by the controller	G_o
`GearEffct`	Effective gear	NA
`CltchACmd`	Clutch pressure command for odd-numbered gears, between `0` and `1`	NA
`CltchBCmd`	Clutch pressure command for even-numbered gears, between `0` and `1`	NA

`NomGear` — Nominal gear for shifting
`scalar`

Nominal gear for shifting. The Dual Clutch Transmission block uses this signal for the smooth application of inertial, efficiency, gear ratio, and damping parameters.

`CltchACmd` — Command for odd-numbered gears
`scalar`

Clutch pressure command for odd-numbered gears, between `0` and `1`.

`CltchBCmd` — Command for even-numbered gears
`scalar`

Clutch pressure command for even-numbered gears, between `0` and `1`.

Parameters

`Initial gear, G_o` — Engaged gear
`0` (default) | `scalar`

Initial gear to engage, G_o.

`Clutch actuation time, tc` — Time
`.1` (default) | `scalar`

Time required to engage and disengage the clutch during shift events, t_c, in s.

`Synchronizer time, ts` — Time
`.01` (default) | `scalar`

Time required for gear selection and synchronization, t_s, in s.

`Sample period, dt` — Time
`-1` (default) | `scalar`

Sample period, *dt*, in s.

`Clutch initially locked` — Select to initially lock clutch
`off` (default) | `on`

Selecting this parameter initially locks the clutch.

`Synchronizer initially locked` — Select to initially lock synchronizer
`off` (default) | `on`

Selecting this parameter initially locks the synchronizer.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

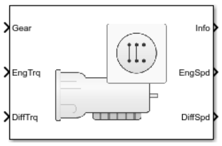
See Also
Dual Clutch Transmission | AMT Controller

Introduced in R2017a

Ideal Fixed Gear Transmission

Ideal fixed gear transmission without clutch or synchronization

Library: Powertrain Blockset / Transmission / Transmission Systems
Vehicle Dynamics Blockset / Powertrain / Transmission



Description

The Ideal Fixed Gear Transmission implements an idealized fixed-gear transmission without a clutch or synchronization. Use the block to model the overall gear ratio and power loss when you do not need a detailed transmission model, for example, in component-sizing, fuel economy, and emission studies. The block implements a transmission model with minimal parameterization or computational cost.

To specify the block efficiency calculation, for **Efficiency factors**, select either of these options.

Setting	Block Implementation
`Gear only`	Efficiency determined from a 1D lookup table that is a function of the gear.
`Gear, input torque, input speed, and temperature`	Efficiency determined from a 4D lookup table that is a function of: • Gear • Input torque • Input speed • Oil temperature

The block uses this equation to determine the transmission dynamics:

$$\dot{\omega}_i \frac{J_N}{N^2} = \eta_N\left(\frac{T_o}{N} + T_i\right) - \frac{\omega_i}{N^2} b_N$$

$$\omega_i = N\omega_o$$

The block filters the gear command signal:

$$\frac{G}{G_{cmd}}(s) = \frac{1}{\tau_s s + 1}$$

Neutral Gear

When **Initial gear number, G_o** is equal to `0`, the initial gear is neutral. The block uses these parameters to decouple the input flywheel from the downstream gearing.

- **Initial input velocity, omega_o**
- **Initial neutral input velocity, omegainN_o**

The block uses these equations for the neutral gear speed and flywheel.

$$\dot{\omega}_{neutral}\frac{J_N}{N^2} = \eta_N\frac{T_o}{N} - \frac{\omega_{neutral}}{N^2}b_N$$

$$\omega_{neutral} = N\omega_o$$

$$\dot{\omega}_1 J_F = \eta_{@N\,=\,0}T_i - b_{@N\,=\,0}\omega_i$$

$$J_F = J_{@N\,=\,1} - J_{@N\,=\,0}$$

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
PwrInfo	PwrTrnsfrd — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	PwrEng	Engine power	P_{eng}	$\omega_i T_i$
		PwrDiffrntl	Differential power	P_{diff}	$\omega_o T_o$
	PwrNotTrnsfrd — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	PwrEffLoss	Mechanical power loss	$P_{effloss}$	$\omega_o T_o(\eta_N - 1)$
		PwrDampLoss	Mechanical damping loss	$P_{damploss}$	For G=0: $-\frac{b_N\omega_i^2}{\lvert N^2\rvert}$ For G ≠ 0: $-b_N\omega_i^2 - \frac{b_N\omega_{neutral}^2}{\lvert N^2\rvert}$
	PwrStored — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	PwrStoredTrans	Rate change in rotational kinetic energy	P_{str}	For G=0: $\frac{J_N}{N^2}\dot{\omega}_i\omega_i$ For G ≠ 0: $J_F\dot{\omega}_i\omega_i + \frac{J_N}{N^2}\dot{\omega}_{neutral}\omega_{neutral}$

The equations use these variables.

b_N	Engaged gear viscous damping
J_N	Engaged gear rotational inertia
J_F	Flywheel rotational inertia
η_N	Engaged gear efficiency
G	Engaged gear number
G_{cmd}	Gear number to engage
N	Engaged gear ratio

T_i	Applied input torque, typically from the engine crankshaft or dual mass flywheel damper
T_o	Applied load torque, typically from the differential or drive shaft
ω_o	Initial input drive shaft rotational velocity
ω_i, $\acute{\omega}_i$	Applied drive shaft angular speed and acceleration
ω_{No}	Initial neutral gear input rotational velocity
$\omega_{neutral}$	Neutral gear drive shaft rotational velocity
τ_s	Shift time constant

Ports

Inputs

`Gear` — Gear number to engage
`scalar`

Integer value of gear number to engage, G_{cmd}.

`EngTrq` — Applied input torque
`scalar`

Applied input torque, T_i, typically from the engine crankshaft or dual mass flywheel damper, in N·m.

`DiffTrq` — Applied load torque
`scalar`

Applied load torque, T_o, typically from the differential, in N·m.

`Temp` — Oil temperature
`scalar`

Oil temperature, in K. To determine the efficiency, the block uses a 4D lookup table that is a function of:

- Gear
- Input torque
- Input speed
- Oil temperature

Dependencies

To enable this port, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal			Description	Variable	Units
Eng	EngTrq		Applied input torque, typically from the engine crankshaft or dual mass flywheel damper	T_i	N·m
	EngSpd		Applied drive shaft angular speed input	ω_i	rad/s
Diff	DiffTrq		Applied load torque, typically from the differential	T_o	N·m
	DiffSpd		Drive shaft angular speed output	ω_o	rad/s
Trans	TransSpdRatio		Input to output speed ratio at time t	$\Phi(t)$	N/A
	TransEta		Ratio of output power to input power	η_N	N/A
	TransGearCmd		Commanded gear	N_{cmd}	N/A
	TransGear		Engaged gear	N	N/A
PwrInfo	PwrTrnsfrd	PwrEng	Engine power	P_{eng}	W
		PwrDiffrntl	Differential power	P_{diff}	W
	PwrNotTrnsfrd	PwrEffLoss	Mechanical power loss	$P_{effloss}$	W
		PwrDampLoss	Mechanical damping loss	$P_{damploss}$	W
	PwrStored	PwrStoredTrans	Rate change in rotational kinetic energy	P_{str}	W

EngSpd — Angular speed
scalar

Applied drive shaft angular speed input, ω_i, in rad/s.

DiffSpd — Angular speed
scalar

Drive shaft angular speed output, ω_o, in rad/s.

Parameters

`Efficiency factors` — Specify efficiency calculation

`Gear only` (default) | `Gear, input torque, input speed, and temperature`

To specify the block efficiency calculation, for **Efficiency factors**, select either of these options.

Setting	Block Implementation
`Gear only`	Efficiency determined from a 1D lookup table that is a function of the gear.
`Gear, input torque, input speed, and temperature`	Efficiency determined from a 4D lookup table that is a function of: • Gear • Input torque • Input speed • Oil temperature

Dependencies

Setting Parameter To	Enables
`Gear only`	**Efficiency vector, eta**
`Gear, input torque, input speed, and temperature`	**Efficiency torque breakpoints, Trq_bpts** **Efficiency speed breakpoints, omega_bpts** **Efficiency temperature breakpoints, Temp_bpts** **Efficiency lookup table, eta_tbl**

`Gear property interpolation method` — Interpolation

`Nearest` (default) | `Linear` | `Flat` | `Cubic spline`

Method that the block uses to switch the gear ratio during gear shifting.

Transmission

`Gear number vector, G` — Specify number of transmission speeds

`[-1,0,1,2,3,4,5]` (default) | `vector`

Vector of integer gear commands used to specify the number of transmission speeds. Neutral gear is `0`. For example, you can set these parameter values.

To Specify	Set Gear number, G To
Four transmission speeds, including neutral	`[0,1,2,3,4]`
Three transmission speeds, including neutral and reverse	`[-1,0,1,2,3]`
Five transmission speeds, including neutral and reverse	`[-1,0,1,2,3,4,5]`

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

`Efficiency torque breakpoints, Trq_bpts` — Breakpoints

`[25,50,75,100,150,200,250]` (default) | `vector`

Torque breakpoints for efficiency table.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

`Efficiency speed breakpoints, omega_bpts` — Breakpoints

`[52.4 78.5 105 131 157 183 209 262 314 419 524]` (default) | `vector`

Speed breakpoints for efficiency table.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

`Efficiency temperature breakpoints, Temp_bpts` — Breakpoints

`[313 358]` (default) | `vector`

Temperature breakpoints for efficiency table.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

`Gear ratio vector, N` — Ratio of input speed to output speed

`[-4.47,4.47,4.47,2.47,1.47,1,0.8]` (default) | `vector`

Vector of gear ratios (that is, input speed to output speed) with indices corresponding to the ratios specified in **Gear number, G**. For neutral, set the gear ratio to `1`. For example, you can set these parameter values.

To Specify Gear Ratios For	Set Gear number, G To	Set Gear ratio, N To
Four transmission speeds, including neutral	`[0,1,2,3,4]`	`[1,4.47,2.47,1.47,1]`
Five transmission speeds, including neutral and reverse	`[-1,0,1,2,3,4,5]`	`[-4.47,1,4.47,2.47, 1.47,1,0.8]`

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

`Inertia vector, Jout` — Gear rotational inertia

`[0.128 0.01 0.128 0.1 0.062 0.028 0.01]` (default) | `vector`

Vector of gear rotational inertias, J_N, with indices corresponding to the inertias specified in **Gear number, G**, in kg*m^2. For example, you can set these parameter values.

To Specify Inertia For	Set Gear number, G To	Set Inertia, J To
Four gears, including neutral	[0,1,2,3,4]	[0.01,2.28,2.04, 0.32,0.028]
Inertia for five gears, including reverse and neutral	[-1,0,1,2,3,4,5]	[2.28,0.01,2.28, 2.04,0.32,0.028,0.01]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

`Damping vector, bout` — Gear viscous damping coefficient

`[.003 .001 .003 .0025 .002 .001 .001]` (default) | `vector`

Vector of gear viscous damping coefficients, b_N, with indices corresponding to the coefficients specified in **Gear number, G**, in N·m·s/rad. For example, you can set these parameter values.

To Specify Damping For	Set Gear number, G To	Set Damping, b To
Four gears, including neutral	[0,1,2,3,4]	[0.001,0.003, 0.0025,0.002,0.001]
Five gears, including reverse and neutral	[-1,0,1,2,3,4,5]	[0.003,0.001, 0.003,0.0025, 0.002,0.001,0.001]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

`Efficiency vector, eta` — Gear efficiency

`[0.9,0.9,0.9,0.9,0.9,0.95,0.95]` (default) | `vector`

Vector of gear mechanical efficiency, η_N, with indices corresponding to the efficiencies specified in **Gear number, G**. For example, you can set these parameter values.

To Specify Efficiency For	Set Gear number, G To	Set Efficiency, eta To
Four gears, including neutral	[0,1,2,3,4]	[0.9,0.9,0.9,0.9,0.95]
Five gears, including reverse and neutral	[-1,0,1,2,3,4,5]	[0.9,0.9,0.9, 0.9,0.9,0.95,0.95]

Vector dimensions for the **Gear number vector**, **Gear ratio vector**, **Inertia vector**, **Damping vector**, and **Efficiency vector** parameters must be equal.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear only`.

`Efficiency lookup table, eta_tbl` — Gear efficiency

`array`

Table of gear mechanical efficiency, η_N as a function of gear, input torque, input speed, and temperature.

Dependencies

To enable this parameter, set **Efficiency factors** to `Gear, input torque, input speed, and temperature`.

Initial gear number, G_o — Gear
0 (default) | scalar

Initial gear number, G_o, dimensionless.

Initial output velocity, omega_o — Output speed
0 (default) | scalar

Transmission initial output rotational velocity, ω_o, in rad/s.

Initial neutral input velocity, omegainN_o — Neutral gear input speed
0 (default) | scalar

Initial neutral gear input rotational velocity, ω_{No}, in rad/s.

Shift time constant, tau_s — Time
.01 (default) | scalar

Shift time constant, τ_s, in s.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

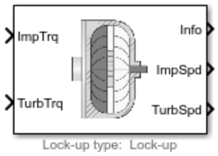
See Also

Automated Manual Transmission | Dual Clutch Transmission | Continuously Variable Transmission

Introduced in R2017a

Torque Converter

Three-part torque converter consisting of an impeller, turbine, and stator
Library: Powertrain Blockset / Transmission / Torque Converters



Description

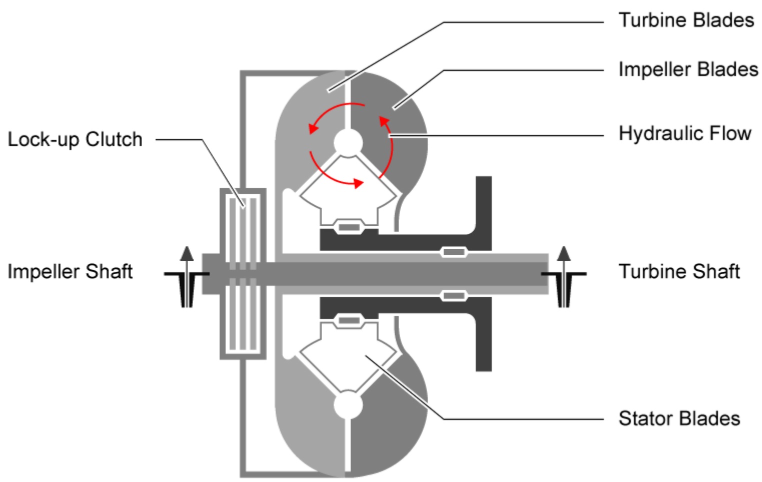
The Torque Converter block implements a three-part torque converter consisting of an impeller, turbine, and stator with an optional clutch lock-up capability. The block can simulate driving (power flowing from impeller to turbine) and coasting (power from turbine dissipated in torque converter hydraulic fluid).

You can specify torque converter characteristics:

- Speed ratio — Ratio of turbine angular speed to impeller angular speed
- Torque ratio — Ratio of turbine torque to impeller torque
- Capacity factor parameterization — Function of input speed or input torque

Optional clutch lock-up configurations include:

- No lock-up — Model fluid-coupling only
- Lock-up — Model automatic clutch engagement
- External lock-up — Model clutch pressure as input from an external signal



Dynamics

Clutch Lock-Up Condition and Clutch Friction

Based on the clutch lock-up condition, the block implements these friction models.

If	Clutch Condition	Friction Model
$\omega_i \neq \omega_t$ or $T_S < \left\| \frac{J_t}{(J_i + J_t)}[T_i + T_f - \omega_i(b_t + b_i)] \right\|$	Unlocked	$T_f = T_k$ where: $T_k = F_c R_{eff} m_k \tanh[4(\omega_i - \omega_t)]$ $T_s = F_c R_{eff} m_s$ $R_{eff} = \frac{2(R_o 3 - R_i 3)}{3(R_o 2 - R_i 2)}$
$\omega_i = \omega_t$ and $T_S \geq \left\| \frac{J_t}{(J_i + J_t)}[T_i + T_f - w_t(b_t + b_i) + w_t b_t] \right\|$	Locked	$T_f = T_s$

Locked Rotational Dynamics

To model the rotational dynamics if the clutch is locked, the block implements equations.

$$\dot{\omega}(J_i + J_t) = T_i - \omega(b_i + b_t) + T_{ext}$$
$$\omega = \omega_i = \omega_t$$

The rotational velocity represents both the impeller and turbine rotational velocities.

Unlocked Rotational Dynamics

To model the rotational dynamics if the clutch is unlocked, the block implements equations.

$$\dot{\omega}_i J_i = \mathrm{T}_i - \omega_i b_i - T_f - T_p$$
$$\dot{\omega}_t J_t = \mathrm{T}_{ext} - \omega_t b_t + T_f + T_t$$

$$T_p = \ \omega_i 2\psi(\phi)$$
$$T_t = \ T_p \zeta(\phi)$$

To approximate the torque multiplication lag between the impeller and turbine, you can specify the parameter **Fluid torque response time constant (set to 0 to disable), tauc [s]**.

Power Accounting

For the power accounting, the block implements these equations.

Bus Signal			Description	Variable	Equations
`PwrInfo`	`PwrTrnsfrd` — Power transferred between blocks • Positive signals indicate flow into block • Negative signals indicate flow out of block	`PwrImp`	Applied impeller power	P_{imp}	$\omega_i T_i$
		`PwrTurb`	Applied turbine output power	P_{turb}	$\omega_t T_t$

Bus Signal			Description	Variable	Equations
	`PwrNotTrnsfrd` — Power crossing the block boundary, but not transferred • Positive signals indicate an input • Negative signals indicate a loss	`PwrDampLoss`	Mechanical damping loss	$P_{damploss}$	$-b_t\omega_t^2 - b_i\omega_i^2$
		`PwrFluidCplingLoss`	Heat loss to transmission fluid	P_{flloss}	$-\left(T_p\omega_i - T_{hyd}\omega_t\right)$
		`PwrCltchLoss`	Clutch slip power loss	$P_{cltloss}$	$-T_k(\omega_i - \omega_t)$
	`PwrStored` — Stored energy rate of change • Positive signals indicate an increase • Negative signals indicate a decrease	`PwrStoredImp`	Rate change in impeller rotational kinetic energy	P_{strimp}	$\dot{\omega}_i\omega_i J_i$
		`PwrStoredTurb`	Rate change in turbine rotational kinetic energy	$P_{strturb}$	$\dot{\omega}_t\omega_t J_t$

The block implements equations that use these variables.

T_f	Frictional torque
T_k	Kinetic frictional torque
T_s	Static frictional torque
T_i	Applied input torque
T_p	Impeller reaction torque
T_{ext}	Externally applied turbine torque
$\psi(\phi)$	Torque conversion capacity factor
$\zeta(\phi)$	Torque ratio
ω_i	Impeller rotational shaft speed
ω_t	Turbine rotational shaft speed
J_i	Impeller rotational inertia
J_t	Turbine rotational inertia
b_i	Impeller rotational viscous damping
b_t	Turbine rotational viscous damping
R_{eff}	Effective clutch radius
R_o	Annular disk outer radius
R_i	Annular disk inner radius

Ports

Inputs

`ImpTrq` — Applied impeller torque

`scalar`

Applied input torque, typically from the engine crankshaft or dual mass flywheel, in N·m.

`TurbTrq` — Applied turbine torque

`scalar`

Applied turbine torque, typically from the transmission, in N·m.

`Clutch Force` — Applied clutch force

`scalar`

Applied clutch force, typically from a hydraulic actuator, in N.

Dependencies

To create this port, select `External lock-up input` for the **Lock-up clutch configuration** parameter.

Output

`Info` — Bus signal

bus

Bus signal containing these block calculations.

Signal			Description	Units
`Imp`	`ImpTrq`		Applied input torque	N·m
	`ImpSpd`		Impeller rotational shaft speed	rad/s
`Turb`	`TurbTrq`		Applied turbine torque	N·m
	`TurbSpd`		Turbine rotational shaft speed	rad/s
`Cltch`	`CltchForce`		Applied clutch force	N
	`CltchLocked`		Clutch locked or unlocked state	N/A
`TrqConv`	`TrqConvSpdRatio`		Turbine to impeller speed ratio	N/A
	`TrqConvEta`		Torque conversion efficiency	N/A
`PwrInfo`	`PwrTrnsfrd`	`PwrImp`	Applied impeller power	W
		`PwrTurb`	Applied turbine output power	W
	`PwrNotTrnsfrd`	`PwrDampLoss`	Mechanical damping loss	W
		`PwrFluidCplingLoss`	Heat loss to transmission fluid	W
		`PwrCltchLoss`	Clutch slip power loss	W
	`PwrStored`	`PwrStoredImp`	Rate change in impeller rotational kinetic energy	W
		`PwrStoredTurb`	Rate change in turbine rotational kinetic energy	W

`ImpSpd` — Impeller speed

`scalar`

Impeller rotational shaft speed, ω_i, in rad/s.

`TrbSpd` — Turbine speed
`scalar`

Turbine rotational shaft speed, ω_t, in rad/s.

Parameters

Configuration

`Lock-up clutch configuration` — Select lock-up clutch configuration
`Lock-up` (default) | `No lock-up` | `External lock-up input`

To Model	Select
Fluid-coupling only	`No lock-up`
Automatic clutch engagement	`Lock-up`
Clutch pressure as input from an external signal	`External lock-up input`

Dependencies

To enable the **Clutch** parameters, select `Lock-up` or `External lock-up input` for the **Lock-up clutch configuration** parameter.

Torque Converter

`Impeller shaft inertia, Ji` — Inertia
`.1` (default) | `scalar`

Impeller shaft inertia, in kg·m^2.

`Impeller shaft viscous damping, bi` — Viscous damping coefficient
`.001` (default) | `scalar`

Impeller shaft viscous damping, in N·m·s/rad.

`Turbine shaft inertia, Jt` — Inertia
`.1` (default) | `scalar`

Turbine shaft inertia, in kg·m^2.

`Turbine shaft viscous damping, bt` — Viscous damping coefficient
`.001` (default) | `scalar`

Turbine shaft viscous damping, in N·m·s/rad.

`Initial impeller shaft velocity, omegai_o` — Angular velocity
`0` (default) | `scalar`

Initial impeller shaft velocity, in rad/s.

`Initial turbine shaft velocity, omegat_o` — Angular velocity
`0` (default) | `scalar`

Initial turbine shaft velocity, in rad/s.

`Speed ratio vector, phi` — Ratio
`[ 0 0.50 0.60 0.70 0.80 0.87 0.92 0.94 0.96 0.97]` (default) | `vector`

Vector of turbine speed to impeller speed ratios. Breakpoints for the capacity and torque multiplication vectors.

`Capacity factor parameterization` — Select factor ratio type
`Input speed / sqrt(input torque)` (default) | `Absorbed torque / input speed^2`

To Set Factor Ratio to	Select
Impeller angular velocity to square root impeller torque	`Input speed / sqrt(input torque)`
Impeller absorbed torque to square of impeller angular velocity	`Absorbed torque / input speed^2`

`Capacity vector, psi` — Vector
`[12.2938 12.8588 13.1452 13.6285 14.6163 16.2675 19.3503 22.1046 29.9986 50.00]` (default) | `vector`

Capacity factor parameterization Setting	Capacity Vector Units
`Input speed / sqrt(input torque)`	(rad/s)/(N·m)^0.5
`Absorbed torque / input speed^2`	N·m/(rad/s)^2

`Torque ratio vector, zeta` — Vector
`[2.2320 1.5462 1.4058 1.2746 1.1528 1.0732 1.0192 0.9983 0.9983 0.9983]` (default) | `vector`

Vector of turbine torque to impeller speed ratios.

`Fluid torque response time constant (set to 0 to disable), tauTC` — Time constant
`.02` (default) | `scalar`

To account for the delay in torque calculations due to changing input torque, specify the fluid torque transfer time constant, in s.

`Interpolation method` — Select interpolation method
`Linear` (default) | `Flat` | `Nearest`

Interpolates the torque ratio and capacity factor functions between the discrete relative velocity values.

Clutch

`Clutch force equivalent net radius, Reff` — Effective radius
`.3` (default) | `scalar`

The effective radius, R_{eff}, used with the applied clutch friction force to determine the friction force, in m. The effective radius is defined as:

$$R_{eff} = \frac{2(R_o 3 - R_i 3)}{3(R_o 2 - R_i 2)}$$

The equation uses these variables.

R_o	Annular disk outer radius
R_i	Annular disk inner radius

Dependencies

To enable the **Clutch** parameters, select `Lock-up` or `External lock-up input` for the **Lock-up clutch configuration** parameter.

`Static friction coefficient, mus` — Coefficient
`1.2` (default) | `scalar`

Dimensionless clutch disc coefficient of static friction.

Dependencies

To enable the **Clutch** parameters, select `Lock-up` or `External lock-up input` for the **Lock-up clutch configuration** parameter.

`Kinetic friction coefficient, muk` — Coefficient
`1` (default) | `scalar`

Dimensionless clutch disc coefficient of kinetic friction.

To enable the **Clutch** parameters, select `Lock-up` or `External lock-up input` for the **Lock-up clutch configuration** parameter.

`Initially lock clutch` — Select to initially lock clutch
`off` (default) | `on`

Dependencies

To enable this parameter, select `Lock-up` or `External lock-up input` for the **Lock-up clutch configuration** parameter.

`Lock-up speed ratio threshold, philu` — Threshold
`.85` (default) | `scalar`

Set speed ratio threshold that engages clutch lock-up.

Dependencies

To enable this parameter, select `Lock-up` for the **Lock-up clutch configuration** parameter.

`Minimum lock-up engagement speed, omegal` — Angular velocity
`900*pi/30` (default) | `scalar`

Set the minimum impeller speed that engages clutch lock-up, in rad/s.

Dependencies

To enable this parameter, select `Lock-up` for the **Lock-up clutch configuration** parameter.

`Lock-up disengagement speed, omegau` — Angular velocity
`800*pi/30` (default) | `scalar`

Set the minimum impeller speed that disengages clutch lock-up, in rad/s.

Dependencies

To enable this parameter, select `Lock-up` for the **Lock-up clutch configuration** parameter.

`Lock-up clutch force gain, K_c` — Gain

`5000` (default) | `scalar`

Open loop clutch lock-up force gain, in N.

Dependencies

To enable this parameter, select `Lock-up` for the **Lock-up clutch configuration** parameter.

`Lock-up clutch time constant, tauC` — Time constant

`.0500` (default) | `scalar`

Open loop clutch lock-up time constant, in s.

Dependencies

To enable this parameter, select `Lock-up` for the **Lock-up clutch configuration** parameter.

Extended Capabilities

C/C++ Code Generation
Generate C and C++ code using Simulink® Coder™.

See Also

CI Core Engine | SI Core Engine

Introduced in R2017a

8

Functions

mdf

Access information contained in MDF-file

Syntax

`mdfObj = mdf(mdfFileName)`

Description

The `mdf` function creates an object for accessing a measurement data format (MDF) file. See “Measurement Data Format (MDF)” on page 8-4.

`mdfObj = mdf(mdfFileName)` identifies a measurement data format (MDF) file and returns an MDF-file object, which you can use to access information and data contained in the file. You can specify a full or partial path to the file.

Examples

Create an MDF-File Object for a Specified MDF-File

Create an MDF object for a given file, and view the object display.

```
mdfObj = mdf([matlabroot,'/examples/vnt/data/Logging_MDF.mf4'])
```

```
mdfObj = 

  MDF with properties:

   File Details
                Name: 'Logging_MDF.mf4'
                Path: 'C:\Program Files\MATLAB\R2021b\examples\vnt\data\Logging_MDF.mf4'
              Author: ''
          Department: ''
             Project: ''
             Subject: ''
             Comment: ''
             Version: '4.10'
            DataSize: 1542223
    InitialTimestamp: 2020-06-25 20:41:13.133000000

   Creator Details
    ProgramIdentifier: 'MDF4Lib'
             Creator: [1×1 struct]

   File Contents
          Attachment: [5×1 struct]
        ChannelNames: {62×1 cell}
        ChannelGroup: [1×62 struct]
```

```
   Options
          Conversion: Numeric
```

Input Arguments

`mdfFileName` — MDF-file name
char vector | string

MDF-file name, specified as a character vector or string, including the necessary full or relative path.

Example: `'MDFFile.mf4'`

Data Types: `char` | `string`

Output Arguments

`mdfObj` — MDF-file
MDF-file object

MDF-file, returned as an MDF-file object. The object provides access to the MDF-file information contained in the following properties.

Property	Description
`Name`	Name of the MDF-file, including extension
`Path`	Full path to the MDF-file, including file name
`Author`	Author who originated the MDF-file
`Department`	Department that originated the MDF-file
`Project`	Project that originated the MDF-file
`Subject`	Subject matter in the MDF-file
`Comment`	Open comment field from the MDF-file
`Version`	MDF standard version of the file
`DataSize`	Total size of the data in the MDF-file, in bytes
`InitialTimestamp`	Time when file data acquisition began in UTC or local time
`ProgramIdentifier`	Originating program of the MDF-file
`Creator`	Structure containing details about creator of the MDF-file, with these fields: `VendorName`, `ToolName`, `ToolVersion`, `UserName`, and `Comment`
`Attachment`	Structure of information about attachments contained within the MDF-file, with these fields: `Name`, `Path`, `Comment`, `Type`, `MIMEType`, `Size`, `EmbeddedSize`, and `MD5CheckSum`
`ChannelNames`	Cell array of the channel names in each channel group
`ChannelGroup`	Structure of information about channel groups contained within the MDF-file, with these fields: `AcquisitionName`, `Comment`, `NumSamples`, `DataSize`, `Sorted`, `SourceInfo`, and `Channel`

Property	Description
`Conversion`	Conversion option for data in the MDF-file. Supported values are: • `'Numeric'` (default) — Apply only numeric conversion rules (CC_Type 1-6). Data with non-numeric conversion rules is imported as raw, unconverted values. • `'None'` — Do not apply any conversion rules. All data is imported as raw data. • `'All'` — Apply all numeric and text conversion rules (CC_Type 1-10).

More About

Measurement Data Format (MDF)

Measurement data format (MDF) files are binary format files for storing measurement data. The format standard is defined by the Association for Standardization of Automation and Measuring Systems (ASAM), which you can read about at ASAM MDF.

Vehicle Network Toolbox™ and Powertrain Blockset provide access to MDF-files through an object you create with the `mdf` function.

See Also

Functions
`saveAttachment` | `read`

Introduced in R2016b

read

Read channel data from MDF-file

Syntax

```
data = read(mdfObj)
data = read(mdfObj,chanList)
data = read(mdfObj,chanGroupIndex)
data = read(mdfObj,chanGroupIndex,chanName)
data = read(mdfObj,chanGroupIndex,chanName,startPosition)
data = read(mdfObj,chanGroupIndex,chanName,startPosition,endPosition)
data = read( ___ ,Name=Value)
[data,time] = read( ___ ,OutputFormat="Vector")
```

Description

`data = read(mdfObj)` reads all data for all channels from the MDF-file identified by the MDF-file object `mdfObj`, and assigns the output to `data`. If the file data is one channel group, the output is a timetable; multiple channel groups are returned as a cell array of timetables, where the cell array index corresponds to the channel group number.

`data = read(mdfObj,chanList)` reads data for all channels specified in the channel list table `chanList`.

`data = read(mdfObj,chanGroupIndex)` reads data for all channels in the specified channel group.

`data = read(mdfObj,chanGroupIndex,chanName)` reads data for the specified channels.

`data = read(mdfObj,chanGroupIndex,chanName,startPosition)` reads data from the position specified by `startPosition`.

`data = read(mdfObj,chanGroupIndex,chanName,startPosition,endPosition)` reads data for the range specified from `startPosition` to `endPosition`.

`data = read( ___ ,Name=Value)` specifies certain function behaviors using optional name-value pairs.

`[data,time] = read( ___ ,OutputFormat="Vector")` returns two vectors: one vector of channel data and a corresponding vector of timestamps. This form of syntax with two output arguments is supported only when `OutputFormat="Vector"`.

Examples

Read All Data from MDF-File

Read all available data from the MDF-file.

```
mdfObj = mdf("MDFFile.mf4");
data = read(mdfObj);
```

Read Raw Data

Read raw data from a specified channel in the first channel group, without applying any conversion rules.

```
mdfObj = mdf("MDFFile.mf4");
data = read(mdfObj,1,"Unsigned_UInt32_LE_Primary_Offset_0",Conversion="None");
data(1:4,:)
```

```
ans =

  4×1 timetable

    Time     Unsigned_UInt32_LE_Primary_Offset_0
    _____    ___________________________________

    0 sec                    0
    1 sec                    1
    2 sec                    2
    3 sec                    3
```

Read All Data from Specified Channel List

Read all available data from the MDF-file for channels specified as part of a channel list.

```
mdfObj = mdf("MDFFile.mf4");
chanList = channelList(mdfObj) % Channel table
data = read(mdfObj,chanList(1:3,:)); % First 3 channels
```

Read All Data from Multiple Channels

Read all available data from the MDF-file for specified channels.

```
mdfObj = mdf("MDFFile.mf4");
data = read(mdfObj,1,["Channel1","Channel2"]);
```

Read Range of Data from Specified Index Values

Read a range of data from the MDF-file using indexing for `startPosition` and `endPosition` to specify the data range.

```
mdfObj = mdf("MDFFile.mf4");
data = read(mdfObj,1,["Channel1","Channel2"],1,10);
```

Read Range of Data from Specified Time Values

Read a range of data from the MDF-file using time values for `startPosition` and `endPosition` to specify the data range.

```
mdfObj = mdf("MDFFile.mf4");
data = read(mdfObj,1,["Channel1","Channel2"],seconds(5.5),seconds(7.3));
```

Read All Data in Vector Format

Read all available data from the MDF-file, returning data and time vectors.

```
mdfObj = mdf("MDFFile.mf4");
[data,time] = read(mdfObj,1,"Channel1",OutputFormat="Vector");
```

Read All Data in Time Series Format

Read all available data from the MDF-file, returning time series data.

```
mdfObj = mdf("MDFFile.mf4");
data = read(mdfObj,1,"Channel1",OutputFormat="TimeSeries");
```

Read Data from Channel List Entry

Read data from a channel identified by the `channelList` function.

Get list of channels and display their names and group numbers.

```
mdfObj = mdf("File05.mf4");
chlist = channelList(mdfObj);
chlist(1:2,1:2) % Partial listing
```

```
  2×2 table

              ChannelName               ChannelGroupNumber
    ________________________________    __________________

    "Float_32_LE_Offset_64"                     2
    "Float_64_LE_Primary_Offset_0"              2
```

Read data from the first channel in the list.

```
data = read(mdfObj,chlist{1,2},chlist{1,1});
data(1:5,:)
```

```
  5×1 timetable

      Time       Float_32_LE_Offset_64
    ________     _____________________

    0 sec                  5
    0.01 sec             5.1
    0.02 sec             5.2
```

```
    0.03 sec              5.3
    0.04 sec              5.4
```

Read Data and Metadata

Read data from an MDFfile into a timetable along with channel group and channel metadata.

Read from channel group 1 into a timetable.

```
mdfObj = mdf("File05.mf4");
TTout = read(mdfObj,1,IncludeMetata=true);
TTout.Properties.CustomProperties
```

```
ans = 

CustomProperties with properties:

    ChannelGroupAcquisitionName: ""
            ChannelGroupComment: "Integer Types"
         ChannelGroupSourceInfo: [1×1 struct]
             ChannelDisplayName: [""    ""]
                 ChannelComment: [""    ""]
                    ChannelUnit: [""    ""]
                    ChannelType: [FixedLength    FixedLength]
                ChannelDataType: [IntegerSignedLittleEndian    IntegerUnsignedLittleEndian]
                 ChannelNumBits: [16 32]
           ChannelComponentType: [None    None]
         ChannelCompositionType: [None    None]
              ChannelSourceInfo: [1×2 struct]
              ChannelReadOption: [Numeric    Numeric]
```

Input Arguments

mdfObj — MDF-file

MDF-file object

MDF-file, specified as an MDF-file object.

Example: `mdf("MDFFile.mf4")`

chanList — List of channels

table

List of channels, specified as a table in the format returned by the `channelList` function.

Example: `channelList()`

Data Types: `table`

chanGroupIndex — Index of the channel group

numeric value

Index of channel group, specified as a numeric value that identifies the channel group from which to read.

Example: 1

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

chanName — Name of channel

string | char vector

Name of channel, specified as a string, character vector, or array. `chanName` identifies the name of a channel in the channel group. Use a cell array of character vectors or array of strings to identify multiple channels.

Example: `"Channel1"`

Data Types: `char` | `string` | `cell`

`startPosition` — First position of channel data
numeric value | duration

First position of channel data, specified as a numeric value or duration. The `startPosition` option specifies the first position from which to read channel data. Provide a numeric value to specify an index position; use a duration to specify a time position. If only `startPosition` is provided without the `endPosition` option, the data value at that location is returned. When used with `endPosition` to specify a range, the function returns data from the `startPosition` (inclusive) to the `endPosition` (noninclusive).

Example: 1

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `duration`

`endPosition` — Last position of channel data range
numeric value | duration

Last position of channel data range, specified as a numeric value or duration. The `endPosition` option specifies the last position for reading a range of channel data. Provide both the `startPosition` and `endPosition` to specify retrieval of a range of data. The function returns up to but not including `endPosition` when reading a range. Provide a numeric value to specify an index position; use a duration to specify a time position.

Example: 1000

Data Types: `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64` | `duration`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` *in quotes.*

Example: `Conversion="Numeric"`

`OutputFormat` — Format for output data
`"Timetable"` (default) | `"Vector"` | `"TimeSeries"`

Format for output data, specified as a string or character vector. This option formats the output according to the following table.

OutputFormat	Description
"Timetable"	Return a timetable from one or more channels into one output variable. This is the only format allowed when reading from multiple channels at the same time. (Default.) Note: The timetable format includes variables for the MDF channels. Because the variable titles must be valid MATLAB identifiers, they might not be exactly the same as those values in the MDF object `ChannelNames` property. The variable headers are derived from the property using the function `matlab.lang.makeValidName`. The original channel names are available in the `VariableDescriptions` property of the `timetable` object.
"Vector"	Return a vector of numeric data values, and optionally a vector of time values from one channel. Use one output variable to return only data, or two output variables to return vectors for both data and time stamps.
"TimeSeries"	Return a time series of data from one channel.

Example: "Vector"

Data Types: char | string

Conversion — Conversion option for MDF-file data
"Numeric" (default) | "All" | "None"

Conversion option for MDF-file data, specified as "Numeric", "All", or "None". The default uses the value specified in the `Conversion` property of the `mdf` object. This option overrides that setting.

- "Numeric" — Apply only numeric conversion rules (CC_Type 1-6). Data with non-numeric conversion rules are imported as raw, unconverted values.
- "None" — Do not apply any conversion rules. All data are imported as raw data.
- "All" — Apply all numeric and text conversion rules (CC_Type 1-10).

Example: Conversion="All"

Data Types: char | string

IncludeMetadata — Read metadata with data
false (default) | true

Read channel group and channel metadata from the MDF-file along with its data. The default value is `false`. Metadata can only be included when the `OutputFormat` is specified as "Timetable". The timetable cannot be empty. You can access the metadata in `data.Properties.CustomProperties`.

Specifying `IncludeMetadata=true` might impact function performance when reading data from a channel group with many channels.

Example: IncludeMetadata=true

Data Types: logical

Output Arguments

`data` — Channel data
timetable (default) | double | time series | cell array

Channel data, returned as a timetable, cell array of timetables, vector of doubles, or a time series according to the `OutputFormat` option value and the number of channel groups.

`time` — Channel data times
double

Channel data times, returned as a vector of double elements. The time vector is returned only when `OutputFormat="Vector"`.

See Also

Functions
`mdf` | `saveAttachment` | `channelList` | `mdfWrite` | `mdfAddChannelGroupMetadata`

Topics
"Time Series"
"Represent Dates and Times in MATLAB"
"Tables"

Introduced in R2016b

saveAttachment

Save attachment from MDF-file

Syntax

```
saveAttachment(mdfObj,AttachmentName)
saveAttachment(mdfObj,AttachmentName,DestFile)
```

Description

`saveAttachment(mdfObj,AttachmentName)` saves the specified attachment from the MDF-file to the current MATLAB working folder. The attachment is saved with its existing name.

`saveAttachment(mdfObj,AttachmentName,DestFile)` saves the specified attachment from the MDF-file to the given destination. You can specify relative or absolute paths to place the attachment in a specific folder.

Examples

Save Attachment with Original Name

Save an MDF-file attachment with its original name in the current folder.

```
mdfObj = mdf('MDFFile.mf4');
saveAttachment(mdfObj,'AttachmentName.ext')
```

Save Attachment with New Name

Save an MDF-file attachment with a new name in the current folder.

```
mdfObj = mdf('MDFFile.mf4');
saveAttachment(mdfObj,'AttachmentName.ext','MyFile.ext')
```

Save Attachment in Parent Folder

Save an MDF-file attachment in a folder specified with a relative path name, in this case in the parent of the current folder.

```
mdfObj = mdf('MDFFile.mf4');
saveAttachment(mdfObj,'AttachmentName.ext','..\MyFile.ext')
```

Save Attachment in Specified Folder

This example saves an MDF-file attachment using an absolute path name.

```
mdfObj = mdf('MDFFile.mf4');
saveAttachment(mdfObj,'AttachmentName.ext','C:\MyDir\MyFile.ext')
```

Input Arguments

`mdfObj` — MDF-file

MDF-file object

MDF-file, specified as an MDF-file object.

Example: `mdf('MDFFile.mf4')`

`AttachmentName` — MDF-file attachment name

char vector | string

MDF-file attachment name, specified as a character vector or string. The name of the attachment is available in the `Name` field of the MDF-file object `Attachment` property.

Example: `'file1.dbc'`

Data Types: `char` | `string`

`DestFile` — Destination file name for the saved attachment

existing attachment name (default) | char vector | string

Destination file name for the saved attachment, specified as a character vector or string. The specified destination can include an absolute or relative path, otherwise the attachment is saved in the current folder.

Example: `'MyFile.ext'`

Data Types: `char` | `string`

See Also

Functions
`mdf` | `read`

Introduced in R2016b

mdfDatastore

Datastore for collection of MDF-files

Description

Use the MDF datastore object to access data from a collection of MDF-files.

Creation

Syntax

```
mdfds = mdfDatastore(location)
mdfds = mdfDatastore(__,'Name1',Value1,'Name2',Value2,...)
```

Description

`mdfds = mdfDatastore(location)` creates an MDFDatastore based on an MDF-file or a collection of files in the folder specified by `location`. All files in the folder with extensions `.mdf`, `.dat`, or `.mf4` are included.

`mdfds = mdfDatastore(__,'Name1',Value1,'Name2',Value2,...)` specifies function options and properties of `mdfds` using optional name-value pairs.

Input Arguments

`location` — Location of MDF datastore files
character vector | cell array | `DsFileSet` object

Location of MDF datastore files, specified as a character vector, cell array of character vectors, or `matlab.io.datastore.DsFileSet` object identifying either files or folders. The path can be relative or absolute, and can contain the wildcard character `*`. If `location` specifies a folder, by default the datastore includes all files in that folder with the extensions `.mdf`, `.dat`, or `.mf4`.

Example: `'CANape.MF4'`

Data Types: `char` | `cell` | `DsFileSet`

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments to set file information or object “Properties” on page 8-15. Allowed options are `IncludeSubfolders`, `FileExtensions`, and the properties `ReadSize`, `SelectedChannelGroupNumber`, and `SelectedChannelNames`.

Example: `'SelectedChannelNames','Counter_B4'`

`IncludeSubfolders` — Include files in subfolders
`false` (default) | `true`

Include files in subfolders, specified as a logical. Specify `true` to include files in each folder and recursively in subfolders.

Example: `'IncludeSubfolders',true`

Data Types: `logical`

`FileExtensions` — Custom extensions for filenames to include in MDF datastore
`{'.mdf','.dat','.mf4'}` (default) | char | cell

Custom extensions for filenames to include in the MDF datastore, specified as a character vector or cell array of character vectors. By default, the supported extensions include `.mdf`, `.dat`, and `.mf4`. If your files have custom or nonstandard extensions, use this Name-Value setting to include files with those extensions.

Example: `'FileExtensions',{'.myformat1','.myformat2'}`

Data Types: `char` | `cell`

Properties

`ChannelGroups` — All channel groups present in first MDF-file
table

This property is read-only.

All channel groups present in first MDF-file, returned as a table.

Data Types: `table`

`Channels` — All channels present in first MDF-file
table

This property is read-only.

All channels present in first MDF-file, returned as a table.

Those channels targeted for reading must have the same name and belong to the same channel group in each file of the MDF datastore.

Data Types: `table`

`Files` — Files included in datastore
char | string | cell

Files included in the datastore, specified as a character vector, string, or cell array.

Example: `{'file1.mf4','file2.mf4'}`

Data Types: `char` | `string` | `cell`

`ReadSize` — Size of data returned by `read`
`'file'` (default) | numeric | duration

Size of data returned by the `read` function, specified as `'file'`, a numeric value, or a duration. A character vector value of `'file'` causes the entire file to be read; a numeric double value specifies the number of records to read; and a duration value specifies a time range to read.

If you later change the `ReadSize` property value type, the datastore resets.

Example: `50`

Data Types: double | char | duration

SelectedChannelGroupNumber — Channel group to read
numeric scalar

Channel group to read, specified as a numeric scalar value.

Example: 1

Data Types: single | double | int8 | int16 | int32 | int64 | uint8 | uint16 | uint32 | uint64

SelectedChannelNames — Names of channels to read
char | string | cell

Names of channels to read, specified as a character vector, string, or cell array.

Those channels targeted for reading must have the same name and belong to the same channel group in each file of the MDF datastore.

Example: 'Counter_B4'

Data Types: char | string | cell

Conversion — Conversion option for MDF-file data
'Numeric' (default) | 'All' | 'None'

Conversion option for MDF-file data, specified as 'Numeric', 'All', or 'None'.

- 'Numeric' (default) — Apply only numeric conversion rules (CC_Type 1-6). Data with non-numeric conversion rules is imported as raw, unconverted values.
- 'None' — Do not apply any conversion rules. All data is imported as raw data.
- 'All' — Apply all numeric and text conversion rules (CC_Type 1-10).

Example: 'All'

Data Types: char | string

Object Functions

read	Read data in MDF datastore
readall	Read all data in MDF datastore
preview	Subset of data from MDF datastore
reset	Reset MDF datastore to initial state
hasdata	Determine if data is available to read from MDF datastore
partition	Partition MDF datastore
numpartitions	Number of partitions for MDF datastore
combine (MATLAB)	Combine data from multiple datastores
transform (MATLAB)	Transform datastore
isPartitionable (MATLAB)	Determine whether datastore is partitionable
isShuffleable (MATLAB)	Determine whether datastore is shuffleable

Examples

Create an MDF Datastore

Create an MDF datastore from the sample file `CANape.MF4`, and read it into a timetable.

```
mdfds = mdfDatastore(fullfile(matlabroot,'examples','vnt','data','CANape.MF4'));
while hasdata(mdfds)
    m = read(mdfds);
end
```

See Also

Introduced in R2017b

hasdata

Package: `matlab.io.datastore`

Determine if data is available to read from MDF datastore

Syntax

`tf = hasdata(mdfds)`

Description

`tf = hasdata(mdfds)` returns logical `1` (`true`) if there is data available to read from the MDF datastore specified by `mdfds`. Otherwise, it returns logical `0` (`false`).

Examples

Check MDF Datastore for Readable Data

Use `hasdata` in a loop to control read iterations.

```
mdfds = mdfDatastore(fullfile(matlabroot,'examples','vnt','data','CANape.MF4'));
while hasdata(mdfds)
    m = read(mdfds);
end
```

Input Arguments

`mdfds` — MDF datastore
MDF datastore object

MDF datastore, specified as an MDF datastore object.

Example: `mdfds = mdfDatastore('CANape.MF4')`

Output Arguments

`tf` — Indicator of data to read
`1` | `0`

Indicator of data to read, returned as a logical `1` (`true`) or `0` (`false`).

See Also

Functions
`mdfDatastore` | `read` | `readall` | `reset`

Introduced in R2017b

numpartitions

Package: `matlab.io.datastore`

Number of partitions for MDF datastore

Syntax

```
N = numpartitions(mdfds)
N = numpartitions(mdfds,pool)
```

Description

`N = numpartitions(mdfds)` returns the recommended number of partitions for the MDF datastore `mdfds`. Use the result as an input to the `partition` function.

`N = numpartitions(mdfds,pool)` returns a reasonable number of partitions to parallelize `mdfds` over the parallel pool, `pool`, based on the number of files in the datastore and the number of workers in the pool.

Examples

Find Recommended Number of Partitions for MDF Datastore

Determine the number of partitions you should use for your MDF datastore.

```
mdfds = mdfDatastore(fullfile(matlabroot,'examples','vnt','data','CANape.MF4'));
N = numpartitions(mdfds);
```

Input Arguments

`mdfds` — MDF datastore
MDF datastore object

MDF datastore, specified as an MDF datastore object.

Example: `mdfds = mdfDatastore('CANape.MF4')`

`pool` — Parallel pool
parallel pool object

Parallel pool specified as a parallel pool object.

Example: `gcp`

Output Arguments

`N` — Number of partitions
double

Number of partitions, returned as a double. This number is the calculated recommendation for the number of partitions for your MDF datastore. Use this when partitioning your datastore with the `partition` function.

See Also

Functions
`mdfDatastore` | `read` | `reset` | `partition`

Introduced in R2017b

partition

Package: `matlab.io.datastore`

Partition MDF datastore

Syntax

```
subds = partition(mdfds,N,index)

subds = partition(mdfds,'Files',index)
subds = partition(mdfds,'Files',filename)
```

Description

`subds = partition(mdfds,N,index)` partitions the MDF datastore `mdfds` into the number of parts specified by `N`, and returns the partition corresponding to the index `index`.

`subds = partition(mdfds,'Files',index)` partitions the MDF datastore by files and returns the partition corresponding to the file of index `index` in the `Files` property.

`subds = partition(mdfds,'Files',filename)` partitions the datastore by files and returns the partition corresponding to the specified `filename`.

Examples

Partition an MDF Datastore into Default Parts

Partition an MDF datastore from the sample file `CANape.MF4`, and return the first part.

```
mdfds = mdfDatastore(fullfile(matlabroot,'examples','vnt','data','CANape.MF4'));
N = numpartitions(mdfds);
subds1 = partition(mdfds,N,1);
```

Partition an MDF Datastore by Its Files

Partition an MDF datastore according to its files, and return partitions by index and file name.

```
cd c:\temp
mdfds = mdfDatastore({'CANape1.MF4','CANape2.MF4','CANape3.MF4'});
mdfds.Files
```

```
ans =
  3×1 cell array
    'c:\temp\CANape1.MF4'
    'c:\temp\CANape2.MF4'
    'c:\temp\CANape3.MF4'
```

```
subds2 = partition(mdfds,'files',2);
subds3 = partition(mdfds,'files','c:\temp\CANape3.MF4');
```

Input Arguments

mdfds — MDF datastore

MDF datastore object

MDF datastore, specified as an MDF datastore object.

Example: `mdfds = mdfDatastore('CANape.MF4')`

N — Number of partitions

positive integer

Number of partitions, specified as a double of positive integer value. Use the `numpartitions` function for the recommended number or partitions.

Example: `numpartitions(mdfds)`

Data Types: `double`

index — Index

positive integer

Index, specified as a double of positive integer value. When using the `'files'` partition scheme, this value corresponds to the index of the MDF datastore object `Files` property.

Example: `1`

Data Types: `double`

filename — File name

character vector

File name, specified as a character vector. The argument can specify a relative or absolute path.

Example: `'CANape.MF4'`

Data Types: `char`

Output Arguments

subds — MDF datastore partition

MDF datastore object

MDF datastore partition, returned as an MDF datastore object. This output datastore is of the same type as the input datastore `mdfds`.

See Also

Functions

`mdfDatastore` | `read` | `reset` | `numpartitions`

Introduced in R2017b

preview

Package: `matlab.io.datastore`

Subset of data from MDF datastore

Syntax

`data = preview(mdfds)`

Description

`data = preview(mdfds)` returns a subset of data from MDF datastore `mdfds` without changing the current position in the datastore.

Examples

Examine Preview of MDF Datastore

```
mdfds = mdfDatastore(fullfile(matlabroot,'examples','vnt','data','CANape.MF4'));
data = preview(mdfds)
```

```
data2 =

  10×74 timetable

        Time         Counter_B4    Counter_B5    Counter_B6    Counter_B7    PWM
    ______________   __________    __________    __________    __________    ___

    0.00082554 sec   0             0             1             0             100
      0.010826 sec   0             0             1             0             100
      0.020826 sec   0             0             1             0             100
      0.030826 sec   0             0             1             0             100
      0.040826 sec   0             0             1             0             100
      0.050826 sec   0             0             1             0             100
      0.060826 sec   0             0             1             0             100
      0.070826 sec   0             0             1             0             100
```

Input Arguments

`mdfds` — MDF datastore
MDF datastore object

MDF datastore, specified as an MDF datastore object.

Example: `mdfds = mdfDatastore('CANape.MF4')`

Output Arguments

`data` — Subset of data
timetable

Subset of data, returned as a timetable of MDF records.

See Also

Functions
`mdfDatastore` | `read` | `hasdata`

Introduced in R2017b

read

Package: `matlab.io.datastore`

Read data in MDF datastore

Syntax

```
data = read(mdfds)
[data,info] = read(mdfds)
```

Description

`data = read(mdfds)` reads data from the MDF datastore specified by `mdfds`, and returns a timetable.

The `read` function returns a subset of data from the datastore. The size of the subset is determined by the `ReadSize` property of the datastore object. On the first call, `read` starts reading from the beginning of the datastore, and subsequent calls continue reading from the endpoint of the previous call. Use `reset` to read from the beginning again.

`[data,info] = read(mdfds)` also returns to the output argument `info` information, including metadata, about the extracted data.

Examples

Read Datastore by Files

Read data from an MDF datastore one file at a time.

```
mdfds = mdfDatastore({'CANape1.MF4','CANape2.MF4','CANape3.MF4'});
mdfds.ReadSize = 'file';
data = read(mdfds);
```

Read the second file and view information about the data.

```
[data2,info2] = read(mdfds);
info2
```

```
  struct with fields:

              Filename: 'CANape2.MF4'
              FileSize: 57592
    MDFFileProperties: [1×1 struct]
```

Input Arguments

`mdfds` — MDF datastore
MDF datastore object

MDF datastore, specified as an MDF datastore object.

Example: `mdfds = mdfDatastore('CANape.MF4')`

Output Arguments

`data` — Output data
timetable

Output data, returned as a timetable of MDF records.

`info` — Information about data
structure array

Information about data, returned as a structure array with the following fields:

```
Filename
FileSize
MDFFileProperties
```

See Also

Functions
`mdfDatastore` | `readall` | `preview` | `reset` | `hasdata`

Introduced in R2017b

readall

Package: `matlab.io.datastore`

Read all data in MDF datastore

Syntax

```
data = readall(mdfds)
data = readall(mdfds,"UseParallel",true)
```

Description

`data = readall(mdfds)` reads all the data in the MDF datastore specified by `mdfds`, and returns a timetable.

After the `readall` function returns all the data, it resets `mdfds` to point to the beginning of the datastore.

If all the data in the datastore does not fit in memory, then `readall` returns an error.

`data = readall(mdfds,"UseParallel",true)` specifies to use a parallel pool to read all of the data. By default, the `"UseParallel"` option is `false`. The choice of pool depends on the following conditions:

- If you already have a parallel pool running, that pool is used.
- If your parallel preference settings allow a pool to automatically start, this syntax will start one, using the default cluster.
- If no pool is running and one cannot automatically start, this syntax does not use parallel functionality.

Examples

Read All Data in Datastore

Read all the data from a multiple file MDF datastore into a timetable.

```
mdfds = mdfDatastore({'CANape1.MF4','CANape2.MF4','CANape3.MF4'});
data = readall(mdfds);
```

Read All Data in Datastore

Use a parallel pool to read all the data from the datastore into a timetable.

```
mdfds = mdfDatastore({'CANape1.MF4','CANape2.MF4','CANape3.MF4'});
data = readall(mdfds,"UseParallel",true);
```

Input Arguments

`mdfds` — MDF datastore

MDF datastore object

MDF datastore, specified as an MDF datastore object.

Example: `mdfds = mdfDatastore('CANape.MF4')`

Output Arguments

`data` — Output data

timetable

Output data, returned as a timetable of MDF records.

See Also

Functions

`mdfDatastore` | `read` | `preview` | `reset` | `hasdata`

Introduced in R2017b

reset

Package: `matlab.io.datastore`

Reset MDF datastore to initial state

Syntax

`reset(mdfds)`

Description

`reset(mdfds)` resets the MDF datastore specified by `mdfds` to its initial read state, where no data has been read from it. Resetting allows you to reread from the same datastore.

Examples

Reset MDF Datastore

Reset an MDF datastore so that you can read from it again.

```
mdfds = mdfDatastore(fullfile(matlabroot,'examples','vnt','data','CANape.MF4'));
data = read(mdfds);
reset(mdfds);
data = read(mdfds);
```

Input Arguments

`mdfds` — MDF datastore
MDF datastore object

MDF datastore, specified as an MDF datastore object.

Example: `mdfds = mdfDatastore('CANape.MF4')`

See Also

Functions
`mdfDatastore` | `read` | `hasdata`

Introduced in R2017b

channelList

Information on available MDF groups and channels

Syntax

```
chans = channelList(mdfobj)
channelList(mdfObj,chanName)
channelList(mdfObj,chanName,'ExactMatch',true)
```

Description

`chans = channelList(mdfobj)` returns a table of information about channels and groups in the specified MDF-file.

`channelList(mdfObj,chanName)` searches the MDF-file to generate a list of channels matching the specified channel name. The search by default is case-insensitive and identifies partial matches. A table is returned containing information about the matched channels and the containing channel groups. If no matches are found, an empty table is returned.

`channelList(mdfObj,chanName,'ExactMatch',true)` searches the channels for an exact match, including case sensitivity. This is useful if a channel name is a substring of other channel names.

Examples

View Available MDF Channels

View all available MDF channels.

```
mdfObj = mdf('File01.mf4');
chans = channelList(mdfObj)
```

```
chans = 

  4×9 table

               ChannelName                 ChannelGroupNumber    ChannelGroupNumSamples
    ___________________________________    __________________    ______________________

    "Float_32_LE_Offset_64"                        2                     10000         
    "Float_64_LE_Primary_Offset_0"                 2                     10000         
    "Signed_Int16_LE_Offset_32"                    1                     10000         
    "Unsigned_UInt32_LE_Primary_Offset_0"          1                     10000         
```

View Specific MDF Channels

Filter on channel names.

```
chans = channelList(mdfObj,'Float')
```

```
chans = 
```

```
  2×9 table

           ChannelName             ChannelGroupNumber    ChannelGroupNumSamples
    ___________________________    __________________    ______________________

    "Float_32_LE_Offset_64"                2                     10000
    "Float_64_LE_Primary_Offset_0"         2                     10000
```

```
chans = channelList(mdfObj,'Float','ExactMatch',true)
```

```
chans =

  0×9 empty table
```

Input Arguments

`mdfObj` — MDF-file
MDF-file object

MDF-file, specified as an MDF-file object.

Example: `mdf('File01.mf4')`

`chanName` — Name of channel
char vector | string

Name of channel, specified as a character vector or string. By default, case-insensitive and partial matches are returned.

Example: `'Channel1'`

Data Types: `char` | `string`

Output Arguments

`chans` — Information on available MDF channels
table

Information on available MDF channels, returned as a table. To access specific elements, you can index into the table.

See Also

Functions
`mdf`

Introduced in R2018b

mdfVisualize

View channel data from MDF-file

Syntax

```
mdfVisualize(mdfFileName)
```

Description

`mdfVisualize(mdfFileName)` opens an MDF-file in the Simulation Data Inspector for viewing and interacting with channel data. `mdfFileName` is the name of the MDF-file, specified as a full or partial path.

Note `mdfVisualize` supports only integer and floating point data types in MDF-file channels.

Examples

View MDF Data

View the data from a specified MDF-file in the Simulation Data Inspector.

```
mdfVisualize('File01.mf4')
```

Input Arguments

`mdfFileName` — MDF-file name
char vector | string

MDF-file name, specified as a character vector or string, including the necessary full or relative path.

Example: `'MDFFile.mf4'`

Data Types: `char` | `string`

See Also

Functions
`mdf` | `read`

Topics
"View and Analyze Simulation Results"

Introduced in R2019a

autoblks.pwr.PlantInfo

Analyze powertrain power and energy

Description

To assess powertrain efficiencies, use the `autoblks.pwr.PlantInfo` object to evaluate and report power and energy for component-level blocks and system-level reference applications.

Creation

Syntax

`VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName)`

Description

MATLAB creates an `autoblks.pwr.PlantInfo` object for the system that you specify. `VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName)` where `SysName` is the name of the model or subsystem that you want to analyze.

Input Arguments

`SysName` — Model name
character vector

Model that you want to analyze.

Example: `'SiCiPtReferenceApplication'`

Data Types: `char`

Properties

`AvgEff` — Average efficiency
`double`

This property is read-only.

Average efficiency, dimensionless.

`Eff` — Time series of efficiency
`time series`

This property is read-only.

Efficiency, η, dimensionless. To calculate the efficiency, the `Eff` property implements this equation.

$$\eta = \left| \frac{\sum P_{output} - \sum P_{store}(P_{store} > 0)}{\sum P_{input} - \sum P_{store}(P_{store} < 0)} \right|$$

The equation uses these variables.

P_{store}	Stored power
P_{input}, P_{output}	Input and output power logged by Power Accounting Bus Creator block

`EnrgyBalanceAbsTol` — Energy balance absolute tolerance
`0.0100` (default)

Energy balance absolute tolerance, $EnrgyBal_{AbsTol}$.

To determine if the system conserves energy, the `isEnrgyBalanced` method checks the energy conservation at each time step.

$$E_{Err} = \sum E_{trans} + \sum E_{nottrans} - \sum E_{store}$$

Blocks change the input energy plus released stored energy to output energy plus stored energy. For example, a mapped engine block uses fuel (not transferred energy) to produce torque (transferred energy) and heat loss (not transferred energy). The total modified energy represents the average between the input fuel energy and the energy exiting the system (torque and heat loss). To calculate the total energy modified by the block, the method uses the integral of the average transferred, not transferred, and stored power.

$$E_{total} = \frac{1}{2}\left(\int_0^{t_{end}} \left(\sum |P_{trans}| + \sum |P_{nottrans}| + \sum |P_{store}| \right) dt \right) \Bigg|_{t = t_{end}}$$

If the energy conservation error is within an error tolerance, the method returns true. Specifically, if either condition is met, the method returns true.

Condition		
$\frac{\lvert E_{Err} \rvert}{E_{total}} < EnrgyBal_{RelTol}$	or	$E_{total} < EnrgyBal_{AbsTol}$

The equations use these variables.

E_{Err}	Energy conservation error
E_{total}	Total energy modified by block
$EnrgyBal_{RelTol}$, $EnrgyBal_{AbsTol}$	Energy balance relative and absolute tolerance, respectively
P_{trans}, E_{trans}	Transferred power and energy, respectively
$P_{nottrans}$, $E_{nottrans}$	Not transferred power and energy, respectively

P_{store}, E_{store}	Stored power and energy, respectively
P_{input}, P_{output}	Input and output power logged by Power Accounting Bus Creator block

Data Types: `double`

`EnrgyBalanceRelTol` — Energy balance relative tolerance
`0.0100` (default)

Energy balance relative tolerance, $EnrgyBal_{RelTol}$.

To determine if the system conserves energy, the `isEnrgyBalanced` method checks the energy conservation at each time step.

$$E_{Err} = \sum E_{trans} + \sum E_{nottrans} - \sum E_{store}$$

Blocks change the input energy plus released stored energy to output energy plus stored energy. For example, a mapped engine block uses fuel (not transferred energy) to produce torque (transferred energy) and heat loss (not transferred energy). The total modified energy represents the average between the input fuel energy and the energy exiting the system (torque and heat loss). To calculate the total energy modified by the block, the method uses the integral of the average transferred, not transferred, and stored power.

$$E_{total} = \frac{1}{2}\left(\int_0^{t_{end}} \left(\sum |P_{trans}| + \sum |P_{nottrans}| + \sum |P_{store}|\right) dt\right)\Bigg|_{t = t_{end}}$$

If the energy conservation error is within an error tolerance, the method returns true. Specifically, if either condition is met, the method returns true.

Condition		
$\frac{\lvert E_{Err}\rvert}{E_{total}} < EnrgyBal_{RelTol}$	or	$E_{total} < EnrgyBal_{AbsTol}$

The equations use these variables.

E_{Err}	Energy conservation error
E_{total}	Total energy modified by block
$EnrgyBal_{RelTol}$, $EnrgyBal_{AbsTol}$	Energy balance relative and absolute tolerance, respectively
P_{trans}, E_{trans}	Transferred power and energy, respectively
$P_{nottrans}$, $E_{nottrans}$	Not transferred power and energy, respectively
P_{store}, E_{store}	Stored power and energy, respectively
P_{input}, P_{output}	Input and output power logged by Power Accounting Bus Creator block

Data Types: `double`

EnrgyUnits — Energy units
MJ (default) | J

Energy units.

Example: VehPwrAnalysis.EnrgyUnits = 'MJ';

Data Types: char

PwrUnits — Power units
kW (default) | W

Power units.

Example: VehPwrAnalysis.PwrUnits = 'kW';

Data Types: char

Object Methods

addLoggedData	Add logged data
dispSignalSummary	Display powertrain subsystem energy analysis
dispSysSummary	Display powertrain system efficiency
findChildSys	Powertrain subsystem energy analysis
histogramEff	Display powertrain subsystem efficiency histogram
isEnrgyBalanced	Logical flag for energy conservation
loggingOff	Turn signal logging off
loggingOn	Turn signal logging on
run	Run powertrain energy and power analysis
sdiSummary	Display Simulation Data Inspector plots of powertrain energy and power
xlsSysSummary	Write powertrain energy analysis to spreadsheet

Examples

Create PlantInfo Object for Powertrain Energy Analysis

Analyze the power and energy in the conventional vehicle reference application. To create a PlantInfo object, see "step 2" on page 8-36.

1. Open the conventional vehicle reference application. By default, the application has a mapped 1.5 L spark-ignition (SI) engine and a dual clutch transmission. Project files open in a writable location.

   ```
   autoblkConVehStart
   ```
2. Set the system name to SiCiPtReferenceApplication.

   Create the autoblks.pwr.PlantInfo object.

   Use the PwrUnits and EnrgyUnits properties to specify the units.

   ```
   SysName = 'SiCiPtReferenceApplication';
   VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName);
   VehPwrAnalysis.PwrUnits = 'kW';
   VehPwrAnalysis.EnrgyUnits = 'MJ';
   ```
3. Use the run method to turn on logging, run simulation, and add logged data to the object.

```
run(VehPwrAnalysis);
```

4. Use the `dispSysSummary` method to display the results.

```
dispSysSummary(VehPwrAnalysis);
```

5. Use the `xlsSysSummary` method to write the results to a spreadsheet.

```
xlsSysSummary(VehPwrAnalysis,'EnergySummary.xlsx');
```

6. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Engine subsystem.

   To display the results, use the `dispSignalSummary` method.

   Use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency.

```
EngSysName = 'SiCiPtReferenceApplication/Passenger Car/Engine';
EngPwrAnalysis = findChildSys(VehPwrAnalysis,EngSysName);
dispSignalSummary(EngPwrAnalysis);
histogramEff(EngPwrAnalysis);
```

7. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Drivetrain subsystem.

   To display the results, use the `dispSignalSummary` method.

```
DrvtrnSysName = 'SiCiPtReferenceApplication/Passenger Car/Drivetrain';
DrvtrnPwrAnalysis = findChildSys(VehPwrAnalysis,DrvtrnSysName);
dispSignalSummary(DrvtrnPwrAnalysis);
```

8. To plot the results, use the `sdiSummary` method.

```
sdiSummary(VehPwrAnalysis,{EngSysName,DrvtrnSysName})
```

See Also

Power Accounting Bus Creator

Topics

"Conventional Vehicle Powertrain Efficiency"
"Analyze Power and Energy"

Introduced in R2019a

dispSignalSummary

Display powertrain subsystem energy analysis

Syntax

`dispSignalSummary(SubSystem)`

Description

The `dispSignalSummary(SubSystem)` method displays the subsystem energy for the `autoblks.pwr.PlantInfo` object. Use the `autoblks.pwr.PlantInfo` object to evaluate and report power an energy for component-level blocks and system-level models.

After you use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the subsystem that you want to analyze, use the `dispSignalSummary(SubSystem)` method to display the results.

Examples

Use `dispSignalSummary` Method to Display Subsystem Results

Analyze the power and energy in the conventional vehicle reference application. To use the `dispSignalSummary` method to display the engine and drivetrain subsystem results, see “step 6” on page 8-38 and “step 7” on page 8-39.

1. Open the conventional vehicle reference application. By default, the application has a mapped 1.5 L spark-ignition (SI) engine and a dual clutch transmission. Project files open in a writable location.

   ```
   autoblkConVehStart
   ```
2. Set the system name to `SiCiPtReferenceApplication`.

   Create the `autoblks.pwr.PlantInfo` object.

   Use the `PwrUnits` and `EnrgyUnits` properties to specify the units.

   ```
   SysName = 'SiCiPtReferenceApplication';
   VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName);
   VehPwrAnalysis.PwrUnits = 'kW';
   VehPwrAnalysis.EnrgyUnits = 'MJ';
   ```
3. Use the `run` method to turn on logging, run simulation, and add logged data to the object.

   ```
   run(VehPwrAnalysis);
   ```
4. Use the `dispSysSummary` method to display the results.

   ```
   dispSysSummary(VehPwrAnalysis);
   ```
5. Use the `xlsSysSummary` method to write the results to a spreadsheet.

   ```
   xlsSysSummary(VehPwrAnalysis,'EnergySummary.xlsx');
   ```
6. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Engine subsystem.

To display the results, use the `dispSignalSummary` method.

Use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency.

```
EngSysName = 'SiCiPtReferenceApplication/Passenger Car/Engine';
EngPwrAnalysis = findChildSys(VehPwrAnalysis,EngSysName);
dispSignalSummary(EngPwrAnalysis);
histogramEff(EngPwrAnalysis);
```

7. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Drivetrain subsystem.

   To display the results, use the `dispSignalSummary` method.

```
DrvtrnSysName = 'SiCiPtReferenceApplication/Passenger Car/Drivetrain';
DrvtrnPwrAnalysis = findChildSys(VehPwrAnalysis,DrvtrnSysName);
dispSignalSummary(DrvtrnPwrAnalysis);
```

8. To plot the results, use the `sdiSummary` method.

```
sdiSummary(VehPwrAnalysis,{EngSysName,DrvtrnSysName})
```

Input Arguments

`SubSystem` — Subsystem name

character vector

Subsystem that you want to analyze.

Example: `'SiCiPtReferenceApplication/Passenger Car/Engine'`

Example: `'SiCiPtReferenceApplication/Passenger Car/Drivetrain'`

Data Types: `char`

See Also

`autoblks.pwr.PlantInfo`

Topics

"Analyze Power and Energy"

Introduced in R2019a

dispSysSummary

Display powertrain system efficiency

Syntax

```
dispSysSummary(PlantInfoObj)
```

Description

After you use the `run` method to analyze the powertrain power and energy, use the `dispSysSummary(PlantInfoObj)` method to display the system efficiency for the `autoblks.pwr.PlantInfo` object.

Use instances of the `autoblks.pwr.PlantInfo` object to evaluate and report power an energy for component-level blocks and system-level models.

Examples

Use `dispSysSummary` Method to Display Energy Analysis Results

Analyze the power and energy in the conventional vehicle reference application. To use the `dispSysSummary` method to display the results, see “step 4” on page 8-40.

1. Open the conventional vehicle reference application. By default, the application has a mapped 1.5 L spark-ignition (SI) engine and a dual clutch transmission. Project files open in a writable location.

   ```
   autoblkConVehStart
   ```
2. Set the system name to `SiCiPtReferenceApplication`.

   Create the `autoblks.pwr.PlantInfo` object.

   Use the `PwrUnits` and `EnrgyUnits` properties to specify the units.

   ```
   SysName = 'SiCiPtReferenceApplication';
   VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName);
   VehPwrAnalysis.PwrUnits = 'kW';
   VehPwrAnalysis.EnrgyUnits = 'MJ';
   ```
3. Use the `run` method to turn on logging, run simulation, and add logged data to the object.

   ```
   run(VehPwrAnalysis);
   ```
4. Use the `dispSysSummary` method to display the results.

   ```
   dispSysSummary(VehPwrAnalysis);
   ```
5. Use the `xlsSysSummary` method to write the results to a spreadsheet.

   ```
   xlsSysSummary(VehPwrAnalysis,'EnergySummary.xlsx');
   ```
6. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Engine subsystem.

   To display the results, use the `dispSignalSummary` method.

Use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency.

```
EngSysName = 'SiCiPtReferenceApplication/Passenger Car/Engine';
EngPwrAnalysis = findChildSys(VehPwrAnalysis,EngSysName);
dispSignalSummary(EngPwrAnalysis);
histogramEff(EngPwrAnalysis);
```

7 Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Drivetrain subsystem.

   To display the results, use the `dispSignalSummary` method.

```
DrvtrnSysName = 'SiCiPtReferenceApplication/Passenger Car/Drivetrain';
DrvtrnPwrAnalysis = findChildSys(VehPwrAnalysis,DrvtrnSysName);
dispSignalSummary(DrvtrnPwrAnalysis);
```

8 To plot the results, use the `sdiSummary` method.

```
sdiSummary(VehPwrAnalysis,{EngSysName,DrvtrnSysName})
```

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object

`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

See Also

`autoblks.pwr.PlantInfo`

Topics

"Analyze Power and Energy"

Introduced in R2019a

findChildSys

Powertrain subsystem energy analysis

Syntax

findChildSys(PlantInfoObj,SubSystem)

Description

The findChildSys(PlantInfoObj,SubSystem) method finds and returns an autoblks.pwr.PlantInfo object for the subsystem. Use the autoblks.pwr.PlantInfo object to evaluate and report power an energy for component-level blocks and system-level reference applications.

After you use the run method to analyze the powertrain power and energy, use the findChildSys method to evaluate specific subsystems.

Examples

Use findChildSys Method to Analyze Subsystems

Analyze the power and energy in the conventional vehicle reference application. To use the findChildSys method to analyze the engine and drivetrain subsystems, see “step 6” on page 8-42 and “step 7” on page 8-43.

1. Open the conventional vehicle reference application. By default, the application has a mapped 1.5 L spark-ignition (SI) engine and a dual clutch transmission. Project files open in a writable location.

```
autoblkConVehStart
```

2. Set the system name to SiCiPtReferenceApplication.

   Create the autoblks.pwr.PlantInfo object.

   Use the PwrUnits and EnrgyUnits properties to specify the units.

```
SysName = 'SiCiPtReferenceApplication';
VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName);
VehPwrAnalysis.PwrUnits = 'kW';
VehPwrAnalysis.EnrgyUnits = 'MJ';
```

3. Use the run method to turn on logging, run simulation, and add logged data to the object.

```
run(VehPwrAnalysis);
```

4. Use the dispSysSummary method to display the results.

```
dispSysSummary(VehPwrAnalysis);
```

5. Use the xlsSysSummary method to write the results to a spreadsheet.

```
xlsSysSummary(VehPwrAnalysis,'EnergySummary.xlsx');
```

6. Use the findChildSys method to retrieve the autoblks.pwr.PlantInfo object for the Engine subsystem.

To display the results, use the `dispSignalSummary` method.

Use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency.

```
EngSysName = 'SiCiPtReferenceApplication/Passenger Car/Engine';
EngPwrAnalysis = findChildSys(VehPwrAnalysis,EngSysName);
dispSignalSummary(EngPwrAnalysis);
histogramEff(EngPwrAnalysis);
```

7. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Drivetrain subsystem.

   To display the results, use the `dispSignalSummary` method.

```
DrvtrnSysName = 'SiCiPtReferenceApplication/Passenger Car/Drivetrain';
DrvtrnPwrAnalysis = findChildSys(VehPwrAnalysis,DrvtrnSysName);
dispSignalSummary(DrvtrnPwrAnalysis);
```

8. To plot the results, use the `sdiSummary` method.

```
sdiSummary(VehPwrAnalysis,{EngSysName,DrvtrnSysName})
```

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object

`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

`SubSystem` — Subsystem name

character vector

Subsystem that you want to analyze.

Example: `'SiCiPtReferenceApplication/Passenger Car/Engine'`

Example: `'SiCiPtReferenceApplication/Passenger Car/Drivetrain'`

Data Types: `char`

See Also

`autoblks.pwr.PlantInfo`

Topics

"Analyze Power and Energy"

Introduced in R2019a

histogramEff

Display powertrain subsystem efficiency histogram

Syntax

`histogramEff(SubSystem)`

Description

The `histogramEff(SubSystem)` method displays a histogram of the powertrain subsystem efficiency for the `autoblks.pwr.PlantInfo` object. Use instances of the `autoblks.pwr.PlantInfo` object to evaluate and report power an energy for component-level blocks and system-level models.

After you use the `findChildSys` method to analyze the powertrain subsystem power and energy, use the `histogramEff` method to display a histogram of the efficiency.

Examples

Use `histogramEff` Method to Display Results

Analyze the power and energy in the conventional vehicle reference application. To use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency, see “step 6” on page 8-44.

1. Open the conventional vehicle reference application. By default, the application has a mapped 1.5 L spark-ignition (SI) engine and a dual clutch transmission. Project files open in a writable location.

   ```
   autoblkConVehStart
   ```
2. Set the system name to `SiCiPtReferenceApplication`.

   Create the `autoblks.pwr.PlantInfo` object.

   Use the `PwrUnits` and `EnrgyUnits` properties to specify the units.

   ```
   SysName = 'SiCiPtReferenceApplication';
   VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName);
   VehPwrAnalysis.PwrUnits = 'kW';
   VehPwrAnalysis.EnrgyUnits = 'MJ';
   ```
3. Use the `run` method to turn on logging, run simulation, and add logged data to the object.

   ```
   run(VehPwrAnalysis);
   ```
4. Use the `dispSysSummary` method to display the results.

   ```
   dispSysSummary(VehPwrAnalysis);
   ```
5. Use the `xlsSysSummary` method to write the results to a spreadsheet.

   ```
   xlsSysSummary(VehPwrAnalysis,'EnergySummary.xlsx');
   ```
6. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Engine subsystem.

To display the results, use the `dispSignalSummary` method.

Use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency.

```
EngSysName = 'SiCiPtReferenceApplication/Passenger Car/Engine';
EngPwrAnalysis = findChildSys(VehPwrAnalysis,EngSysName);
dispSignalSummary(EngPwrAnalysis);
histogramEff(EngPwrAnalysis);
```

7. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Drivetrain subsystem.

   To display the results, use the `dispSignalSummary` method.

```
DrvtrnSysName = 'SiCiPtReferenceApplication/Passenger Car/Drivetrain';
DrvtrnPwrAnalysis = findChildSys(VehPwrAnalysis,DrvtrnSysName);
dispSignalSummary(DrvtrnPwrAnalysis);
```

8. To plot the results, use the `sdiSummary` method.

```
sdiSummary(VehPwrAnalysis,{EngSysName,DrvtrnSysName})
```

Input Arguments

`SubSystem` — Subsystem name

character vector

Subsystem that you want to analyze.

Example: `'SiCiPtReferenceApplication/Passenger Car/Engine'`

Example: `'SiCiPtReferenceApplication/Passenger Car/Drivetrain'`

Data Types: `char`

See Also

`autoblks.pwr.PlantInfo`

Topics

"Analyze Power and Energy"

Introduced in R2019a

run

Run powertrain energy and power analysis

Syntax

`run(PlantInfoObj)`

Description

Use the `run(PlantInfoObj)` method to turn signal logging on, run a powertrain energy and power analysis, and add data to the `autoblks.pwr.PlantInfo` object. Use instances of the `autoblks.pwr.PlantInfo` object to evaluate and report power an energy for component-level blocks and system-level models.

Examples

Use `run` Method for Powertrain Energy Analysis

Analyze the power and energy in the conventional vehicle reference application. To use the `run` method for the analysis, see "step 3" on page 8-46.

1. Open the conventional vehicle reference application. By default, the application has a mapped 1.5 L spark-ignition (SI) engine and a dual clutch transmission. Project files open in a writable location.

   ```
   autoblkConVehStart
   ```
2. Set the system name to `SiCiPtReferenceApplication`.

   Create the `autoblks.pwr.PlantInfo` object.

   Use the `PwrUnits` and `EnrgyUnits` properties to specify the units.

   ```
   SysName = 'SiCiPtReferenceApplication';
   VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName);
   VehPwrAnalysis.PwrUnits = 'kW';
   VehPwrAnalysis.EnrgyUnits = 'MJ';
   ```
3. Use the `run` method to turn on logging, run simulation, and add logged data to the object.

   ```
   run(VehPwrAnalysis);
   ```
4. Use the `dispSysSummary` method to display the results.

   ```
   dispSysSummary(VehPwrAnalysis);
   ```
5. Use the `xlsSysSummary` method to write the results to a spreadsheet.

   ```
   xlsSysSummary(VehPwrAnalysis,'EnergySummary.xlsx');
   ```
6. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Engine subsystem.

   To display the results, use the `dispSignalSummary` method.

   Use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency.

```
EngSysName = 'SiCiPtReferenceApplication/Passenger Car/Engine';
EngPwrAnalysis = findChildSys(VehPwrAnalysis,EngSysName);
dispSignalSummary(EngPwrAnalysis);
histogramEff(EngPwrAnalysis);
```

7. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Drivetrain subsystem.

   To display the results, use the `dispSignalSummary` method.

```
DrvtrnSysName = 'SiCiPtReferenceApplication/Passenger Car/Drivetrain';
DrvtrnPwrAnalysis = findChildSys(VehPwrAnalysis,DrvtrnSysName);
dispSignalSummary(DrvtrnPwrAnalysis);
```

8. To plot the results, use the `sdiSummary` method.

```
sdiSummary(VehPwrAnalysis,{EngSysName,DrvtrnSysName})
```

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object

`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

See Also

`autoblks.pwr.PlantInfo`

Topics

"Analyze Power and Energy"

Introduced in R2019a

sdiSummary

Display Simulation Data Inspector plots of powertrain energy and power

Syntax

```
sdiSummary(PlantInfoObj,blocknames)
```

Description

The `sdiSummary(PlantInfoObj,blocknames)` method plots the powertrain energy and power analysis results for the `autoblks.pwr.PlantInfo` object.

Use instances of the `autoblks.pwr.PlantInfo` object to evaluate and report power an energy for component-level blocks and system-level models.

Examples

Use sdiSummary Method to Plot Results

Analyze the power and energy in the conventional vehicle reference application. To use the `sdiSummary` method to display the Simulation Data Inspector plots of the engine and drivetrain results, see “step 8” on page 8-49.

1. Open the conventional vehicle reference application. By default, the application has a mapped 1.5 L spark-ignition (SI) engine and a dual clutch transmission. Project files open in a writable location.

   ```
   autoblkConVehStart
   ```
2. Set the system name to `SiCiPtReferenceApplication`.

   Create the `autoblks.pwr.PlantInfo` object.

   Use the `PwrUnits` and `EnrgyUnits` properties to specify the units.

   ```
   SysName = 'SiCiPtReferenceApplication';
   VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName);
   VehPwrAnalysis.PwrUnits = 'kW';
   VehPwrAnalysis.EnrgyUnits = 'MJ';
   ```
3. Use the `run` method to turn on logging, run simulation, and add logged data to the object.

   ```
   run(VehPwrAnalysis);
   ```
4. Use the `dispSysSummary` method to display the results.

   ```
   dispSysSummary(VehPwrAnalysis);
   ```
5. Use the `xlsSysSummary` method to write the results to a spreadsheet.

   ```
   xlsSysSummary(VehPwrAnalysis,'EnergySummary.xlsx');
   ```
6. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Engine subsystem.

   To display the results, use the `dispSignalSummary` method.

Use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency.

```
EngSysName = 'SiCiPtReferenceApplication/Passenger Car/Engine';
EngPwrAnalysis = findChildSys(VehPwrAnalysis,EngSysName);
dispSignalSummary(EngPwrAnalysis);
histogramEff(EngPwrAnalysis);
```

7. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Drivetrain subsystem.

   To display the results, use the `dispSignalSummary` method.

```
DrvtrnSysName = 'SiCiPtReferenceApplication/Passenger Car/Drivetrain';
DrvtrnPwrAnalysis = findChildSys(VehPwrAnalysis,DrvtrnSysName);
dispSignalSummary(DrvtrnPwrAnalysis);
```

8. To plot the results, use the `sdiSummary` method.

```
sdiSummary(VehPwrAnalysis,{EngSysName,DrvtrnSysName})
```

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object

`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

`blocknames` — Block or name

character vector | string | 'all'

Block or subsystem names, specified as a character vector or a string, separated by a comma.

Example: `'SiCiPtReferenceApplication/Passenger Car/Engine'`

Example: `'SiCiPtReferenceApplication/Passenger Car/Engine','SiCiPtReferenceApplication/Passenger Car/Drivetrain'`

Data Types: `char` | `string`

See Also

`autoblks.pwr.PlantInfo`

Topics

"Analyze Power and Energy"
Simulation Data Inspector

Introduced in R2019a

xlsSysSummary

Write powertrain energy analysis to spreadsheet

Syntax

```
xlsSysSummary(PlantInfoObj,filename,sheet)
```

Description

The `xlsSysSummary(PlantInfoObj,filename,sheet)` method exports the system energy and efficiency for the `autoblks.pwr.PlantInfo` object. Use the `autoblks.pwr.PlantInfo` object to evaluate and report power an energy for component-level blocks and system-level models.

After you use the `run` method to analyze the powertrain power and energy, use the `xlsSysSummary` method to write the results to a spreadsheet.

Examples

Use `xlsSysSummary` Method to Write Results to Spreadsheet

Analyze the power and energy in the conventional vehicle reference application. To use the `xlsSysSummary` method to write the results to a spreadsheet, see “step 5” on page 8-50.

1. Open the conventional vehicle reference application. By default, the application has a mapped 1.5 L spark-ignition (SI) engine and a dual clutch transmission. Project files open in a writable location.

   ```
   autoblkConVehStart
   ```
2. Set the system name to `SiCiPtReferenceApplication`.

   Create the `autoblks.pwr.PlantInfo` object.

   Use the `PwrUnits` and `EnrgyUnits` properties to specify the units.

   ```
   SysName = 'SiCiPtReferenceApplication';
   VehPwrAnalysis = autoblks.pwr.PlantInfo(SysName);
   VehPwrAnalysis.PwrUnits = 'kW';
   VehPwrAnalysis.EnrgyUnits = 'MJ';
   ```
3. Use the `run` method to turn on logging, run simulation, and add logged data to the object.

   ```
   run(VehPwrAnalysis);
   ```
4. Use the `dispSysSummary` method to display the results.

   ```
   dispSysSummary(VehPwrAnalysis);
   ```
5. Use the `xlsSysSummary` method to write the results to a spreadsheet.

   ```
   xlsSysSummary(VehPwrAnalysis,'EnergySummary.xlsx');
   ```
6. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Engine subsystem.

   To display the results, use the `dispSignalSummary` method.

Use the `histogramEff` method to display a histogram of the time spent at each engine plant efficiency.

```
EngSysName = 'SiCiPtReferenceApplication/Passenger Car/Engine';
EngPwrAnalysis = findChildSys(VehPwrAnalysis,EngSysName);
dispSignalSummary(EngPwrAnalysis);
histogramEff(EngPwrAnalysis);
```

7. Use the `findChildSys` method to retrieve the `autoblks.pwr.PlantInfo` object for the Drivetrain subsystem.

   To display the results, use the `dispSignalSummary` method.

```
DrvtrnSysName = 'SiCiPtReferenceApplication/Passenger Car/Drivetrain';
DrvtrnPwrAnalysis = findChildSys(VehPwrAnalysis,DrvtrnSysName);
dispSignalSummary(DrvtrnPwrAnalysis);
```

8. To plot the results, use the `sdiSummary` method.

```
sdiSummary(VehPwrAnalysis,{EngSysName,DrvtrnSysName})
```

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object

`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

`filename` — File name

character vector | string

File name, specified as a character vector or a string.

If `filename` does not exist, `xlsSysSummary` creates a file, determining the format based on the specified extension. To create a file compatible with Excel® 97-2003 software, specify an extension of `.xls`. To create files in Excel 2007 formats, specify an extension of `.xlsx`, `.xlsb`, or `.xlsm`. If you do not specify an extension, `xlsSysSummary` uses the default, `.xls`.

Example: `'myFile.xlsx'` or `"myFile.xlsx"`

Example: `'C:\myFolder\myFile.xlsx'`

Example: `'myFile.csv'`

Data Types: `char` | `string`

`sheet` — Worksheet name

character vector | string | positive integer

Worksheet name, specified as one of the following:

- Character vector or string that contains the worksheet name. The name cannot contain a colon (`:`). To determine the names of the sheets in a spreadsheet file, use `xlsfinfo`.
- Positive integer that indicates the worksheet index.

If `sheet` does not exist, `xlswrite` adds a sheet at the end of the worksheet collection. If `sheet` is an index larger than the number of worksheets, `xlswrite` appends empty sheets until the number of worksheets in the workbook equals `sheet`. In either case, `xlswrite` generates a warning indicating that it has added a worksheet.

Data Types: `char` | `string` | `single` | `double` | `int8` | `int16` | `int32` | `int64` | `uint8` | `uint16` | `uint32` | `uint64`

See Also

`autoblks.pwr.PlantInfo` | `xlswrite`

Topics

"Analyze Power and Energy"

Introduced in R2019a

addLoggedData

Add logged data

Syntax

`addLoggedData(PlantInfoObj,logsout)`

Description

`addLoggedData(PlantInfoObj,logsout)` adds logged signal data to the `autoblks.pwr.PlantInfo` object specified by the `Simulink.SimulationData.Dataset` signal data object.

If the data logged for the system does not conserve energy, the method returns a warning.

If the `Simulink.SimulationData.Dataset` object does not include data for the Power Accounting Bus Creator blocks in the system, the method returns an error.

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object
`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

`logsout` — Dataset object for signals
`Simulink.SimulationData.Dataset` object

`Simulink.SimulationData.Dataset` object for signals that you want to log.

See Also

Power Accounting Bus Creator | `autoblks.pwr.PlantInfo`

Topics
"Analyze Power and Energy"

Introduced in R2019a

isEnrgyBalanced

Logical flag for energy conservation

Syntax

`flag=isEnrgyBalanced(PlantInfoObj)`

Description

`flag=isEnrgyBalanced(PlantInfoObj)` returns logical `1` (`true`) if the system conserves energy. Otherwise, it returns logical `0` (`false`).

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object
`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

Output Arguments

`flag` — Indicator of energy conservation
`1` (`true`) | `0` (`false`)

Indicator of energy conservation, returned as a logical `1` (`true`) or `0` (`false`).

Data Types: `logical`

Algorithms

To determine if the system conserves energy, the `isEnrgyBalanced` method checks the energy conservation at each time step.

$$E_{Err} = \sum E_{trans} + \sum E_{nottrans} - \sum E_{store}$$

Blocks change the input energy plus released stored energy to output energy plus stored energy. For example, a mapped engine block uses fuel (not transferred energy) to produce torque (transferred energy) and heat loss (not transferred energy). The total modified energy represents the average between the input fuel energy and the energy exiting the system (torque and heat loss). To calculate the total energy modified by the block, the method uses the integral of the average transferred, not transferred, and stored power.

$$E_{total} = \frac{1}{2}\left.\left(\int_0^{t_{end}} \left(\sum |P_{trans}| + \sum |P_{nottrans}| + \sum |P_{store}|\right)dt\right)\right|_{t = t_{end}}$$

If the energy conservation error is within an error tolerance, the method returns true. Specifically, if either condition is met, the method returns true.

Condition		
$\frac{\lvert E_{Err} \rvert}{E_{total}} < EnrgyBal_{RelTol}$	or	$E_{total} < EnrgyBal_{AbsTol}$

The equations use these variables.

E_{Err}	Energy conservation error
E_{total}	Total energy modified by block
$EnrgyBal_{RelTol}$, $EnrgyBal_{AbsTol}$	Energy balance relative and absolute tolerance, respectively
P_{trans}, E_{trans}	Transferred power and energy, respectively
$P_{nottrans}$, $E_{nottrans}$	Not transferred power and energy, respectively
P_{store}, E_{store}	Stored power and energy, respectively
P_{input}, P_{output}	Input and output power logged by Power Accounting Bus Creator block

See Also

Power Accounting Bus Creator | `autoblks.pwr.PlantInfo`

Topics

"Analyze Power and Energy"

Introduced in R2019a

loggingOff

Turn signal logging off

Syntax

```
loggingOff(PlantInfoObj)
```

Description

`loggingOff(PlantInfoObj)` turns signal logging off for all Power Accounting Bus Creator blocks in the `autoblks.pwr.PlantInfo` system object.

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object
`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

See Also

Power Accounting Bus Creator | `autoblks.pwr.PlantInfo`

Topics
"Analyze Power and Energy"

Introduced in R2019a

loggingOn

Turn signal logging on

Syntax

`loggingOn(PlantInfoObj)`

Description

`loggingOn(PlantInfoObj)` turns signal logging on for all Power Accounting Bus Creator blocks in the `autoblks.pwr.PlantInfo` system object.

Input Arguments

`PlantInfoObj` — Instance of `PlantInfo` object
`autoblks.pwr.PlantInfo` object

`autoblks.pwr.PlantInfo` object for the system that you want to analyze.

See Also

Power Accounting Bus Creator | `autoblks.pwr.PlantInfo`

Topics

"Analyze Power and Energy"

Introduced in R2019a

Battery.PulseSequence

Define a single pulse sequence

Description

Use the Battery.PulseSequence object to define a single experimental pulse sequence at a specific temperature and pulse current magnitude.

You can place multiple experimental pulse sequences into an array of Battery.PulseSequence objects. To do so, create a Battery.PulseSequence object for each experimental pulse sequence instance.

To use the Battery.PulseSequence object and methods, you need these products:

- Powertrain Blockset
- Curve Fitting Toolbox™
- Optimization Toolbox™
- Parallel Computing Toolbox™
- Simulink Design Optimization

Creation

Syntax

```
psObj = Battery.PulseSequence
```

Description

MATLAB creates a psObj = Battery.PulseSequence object that defines a pulse sequence.

Properties

Data — Raw data
m-by-5 array

An m-by-5 array of pulse sequence data. Use the addData object function to add the data. addData computes the charge and state of charge (SOC), using the assumption that the experimental test ranges is 0% to 100% SOC.

Array Element	Description	Unit
Data(m,1)	Time	s
Data(m,2)	Voltage	V
Data(m,3)	Current	A
Data(m,4)	Charge	A·s

Array Element	Description	Unit
`Data(m,5)`	State of charge (SOC)	Dimensionless

Data Types: `double`

`ModelName` — Name of model
character vector

Name of the model to use for simulation

Example: `'BatteryEstim3RC_PTBS'`

Data Types: `char`

`MetaData` — `Battery.MetaData` object properties
`0`-by-`1` array

`Battery.MetaData` object properties containing metadata for the data.

Data Types: `function_handle`

`Capacity` — Pulse sequence capacity
scalar

Capacity observed as the difference between lowest and highest energy, in A·s. Calculated by the `addData` method, but can be overwritten.

Example: `0.0`

Data Types: `double`

`Parameters` — `Battery.Parameters` object properties
`0`-by-`1` array

`Battery.Parameters` object containing the most recently determined battery equivalent circuit parameters.

Data Types: `function_handle`

`ParametersHistory` — `Battery.ParametersHistory` object properties
`0`-by-`1` array

`Battery.ParametersHistory` object array containing the history of the battery equivalent circuit parameters through different estimation steps. The last element is the most recent parameter set.

Data Types: `function_handle`

Object Functions

addData	Import pulse sequence experimental data
createPulses	Identify pulses and create pulse objects from experimental data
estimateInitialEmR0	Estimate open circuit voltage and series resistance
estimateInitialEmRx	Estimate open circuit voltage and RC pair resistance
estimateInitialTau	Estimate RC pair time constant
estimateParameters	Estimate parameters
getSocIdxForPulses	Return state of charge index for pulses
loadDataFromMatFile	Load pulse data from a MAT-file

plot	Plot pulse sequence data
plotIdentifiedPulses	Plot identified pulses
plotLatestParameters	Plot latest pulse sequence parameters
plotSimulationResults	Plot pulse sequence simulation results
populatePulseParameters	Populate pulse parameters
removePulses	Remove pulses from sequence
repairTimeVector	Repair time vector

Examples

Add File Data to Battery.PulseSequence Object

This example shows how to add data to a `Battery.PulseSequence` object.

Create a pulse sequence object.

```
psObj = Battery.PulseSequence;
disp(psObj)
```

Load data from a file.

```
FileName = 'Synthetic_LiPo_PulseDischarge.mat';
[time,voltage,current] = Battery.loadDataFromMatFile(FileName);
```

Add the data to the pulse sequence.

```
addData(psObj,time,voltage,current);
```

See Also

`Battery.MetaData` | `Battery.Parameters` | `Battery.Pulse` | `sdo.OptimizeOptions`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

addData

Import pulse sequence experimental data

Syntax

`addData(psObj,Time,Voltage,Current)`

Description

`addData(psObj,Time,Voltage,Current)` adds the pulse sequence experimental data to the `Battery.PulseSequence` object. The `Time`, `Voltage`, and `Current` input arrays must have equal lengths. `addData` computes the charge and state of charge (SOC), using the assumption that the experimental test range is 0% to 100% SOC.

Examples

Add Data to Battery.PulseSequence Object

This example shows how to add data to a `Battery.PulseSequence` object.

Create a pulse sequence object.

```
psObj = Battery.PulseSequence;
disp(psObj)
```

Load data from a file.

```
FileName = 'Synthetic_LiPo_PulseDischarge.mat';
[time,voltage,current] = Battery.loadDataFromMatFile(FileName);
```

Add the data to the pulse sequence.

```
addData(psObj,time,voltage,current);
```

Input Arguments

psObj — Instance of Battery.PulseSequence class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Time — Time
m-by-1 array

m-by-1 array of time data, in s.

Data Types: `double`

Voltage — Voltage
m-by-1 array

`m`-by-`1` array of voltage data, in V.

Data Types: `double`

`Current` — Current
`m`-by-`1` array

`m`-by-`1` array of current data, in A.

Data Types: `double`

See Also

`Battery.PulseSequence`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

loadDataFromMatFile

Load pulse data from a MAT-file

Syntax

```
[Time,Voltage,Current] = loadDataFromMatFile(FileName)
[Time,Voltage,Current] = loadDataFromMatFile(FileName,Name,Value)
```

Description

`[Time,Voltage,Current] = loadDataFromMatFile(FileName)` function loads pulse data from a MAT-file.

`[Time,Voltage,Current] = loadDataFromMatFile(FileName,Name,Value)` function loads pulse data from a MAT-file with additional options specified by one or more `Name,Value` pair arguments.

Examples

Load File Data to `Battery.PulseSequence` Object

This example shows how to add data to a `Battery.PulseSequence` object.

Create a pulse sequence object.

```
psObj = Battery.PulseSequence;
disp(psObj);
```

Load data from a file.

```
FileName = 'Synthetic_LiPo_PulseDischarge.mat';
[time,voltage,current] = Battery.loadDataFromMatFile(FileName);
```

Add the data to the pulse sequence.

```
addData(psObj,time,voltage,current);
```

Input Arguments

`FileName` — Path or file name
`untitled.mat` (default) | path, or MAT-file name

Path or file name of the MAT-file that contains the pulse sequence data.

Example: `'Synthetic_LiPo_PulseDischarge.mat'`

Data Types: `char`

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` *in quotes.*

Example: `Battery.loadDataFromMatFile(FileName,'TimeVariable','myTimeVariable')`

`TimeVariable` — Time variable in MAT-file
`time` (default) | `character vector`

Use this value to specify the time variable to search for in the MAT-file. If unspecified, the method searches for variables containing `'time'`.

Example: `Battery.loadDataFromMatFile(FileName,'TimeVariable','myTimeVariable')`

Data Types: `char`

`VoltageVariable` — Voltage variable in MAT-file
`volt` (default) | `character vector`

Use this value to specify the voltage variable to search for in the MAT-file. If unspecified, the method searches for variables containing `'voltage'`.

Example:
`Battery.loadDataFromMatFile(FileName,'VoltageVariable','myVoltageVariable')`

Data Types: `char`

`CurrentVariable` — Current variable in MAT-file
`current` (default) | `character vector`

Use this value to specify the current variable to search for in the MAT-file. If unspecified, the method searches for variables containing `'current'`.

Example:
`Battery.loadDataFromMatFile(FileName,'CurrentVariable','myCurrentVariable')`

Data Types: `char`

Output Arguments

`Time` — Time
`m`-by-1 array

`m`-by-1 array of time data, in s.

Data Types: `double`

`Voltage` — Voltage
`m`-by-1 array

`m`-by-1 array of voltage data, in V.

Data Types: `double`

`Current` — Current
m-by-1 array

m-by-1 array of current data, in A.

Data Types: `double`

See Also
`Battery.PulseSequence`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

createPulses

Identify pulses and create pulse objects from experimental data

Syntax

```
createPulses(psObj)
createPulses(psObj,Name,Value)
```

Description

`createPulses(psObj)` identifies the location of pulse events. Creates separate pulse objects from the `Battery.PulseSequence` object experimental data.

`createPulses(psObj,Name,Value)` identifies the location of pulse events. Creates separate pulse objects from the `Battery.PulseSequence` object experimental data with additional options specified by one or more `Name,Value` pair arguments.

Examples

Create Pulse Objects from Data

This example shows how to create pulse objects from data.

Create a pulse sequence object.

```
psObj = Battery.PulseSequence;
disp(psObj)
```

Load data from a file.

```
FileName = 'Synthetic_LiPo_PulseDischarge.mat';
[time,voltage,current] = Battery.loadDataFromMatFile(FileName);
```

Add the data to the pulse sequence.

```
addData(psObj,time,voltage,current);
```

Create pulse objects from data.

```
createPulses(psObj,...
    'CurrentOnThreshold',0.1,...
    'NumRCBranches',3,...
    'RCBranchesUse2TimeConstants',false,...
    'PreBufferSamples',10,...
    'PostBufferSamples',15);
```

Input Arguments

psObj — Instance of Battery.PulseSequence class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` *in quotes.*

Example: `createPulses(psObj,'CurrentOnThreshold',0.1)`

`CurrentOnThreshold` — Minimum current magnitude
`0.025` (default) | `scalar`

Use this value to specify the minimum current magnitude for identifying the pulse locations, in A. The `createPulses` function considers values below the `CurrentOnThrehsold` as relaxation or measurement noise.

Example: `createPulses(psObj,'CurrentOnThreshold',0.1)`

Data Types: `double`

`NumRCBranches` — Number of RC branches
`3` (default) | `scalar`

Use this value to specify the number of RC branches. To change the number of branches after an estimation, you must rerun `createPulses` along with any estimation steps. Rerunning ensures that the estimation parameters are the right size.

Example: `createPulses(psObj,'NumRCBranches',4)`

Data Types: `uint32`

`RCBranchesUse2TimeConstants` — Use load and relaxation time constants
`false`

The `createPulses` function does not support using separate time constants for load and relaxation when it estimates each RC branch. If you set the value to true, the `createPulses` function might produce an error.

Example: `createPulses(psObj,'RCBranchesUse2TimeConstants',false)`

Data Types: `logical`

`PreBufferSamples` — Data samples to retain before pulse estimation
`10` (default) | `scalar`

Use this value to specify the number of data samples to retain before pulse estimation. The buffer allows the estimation to focus on matching the measured data before the pulse begins.

Example: `createPulses(psObj,'PreBufferSamples',5)`

Data Types: `uint32`

`PostBufferSamples` — Data samples to retain for next estimation
`15` (default) | `scalar`

Use this value to specify the number of samples to retain before the next pulse estimation. The buffer allows the estimation to focus on matching the transition when the next pulse begins. Typically, the end transition of one pulse and the starting transition at the next pulse are at the same state of charge (SOC). Therefore, both transitions help determine the parameter values at that SOC breakpoint.

Example: `createPulses(psObj,'PostBufferSamples',14)`

Data Types: `uint32`

`PulseRequires2Samples` — Pulse requires two consecutive samples under current
`false` (default)

Use this value to specify that there must be two consecutive samples under current to define a pulse. Set to `true` if occasional noise spikes in the current measurement trigger a false pulse detection. By default, the value is `false`, indicating that a single sample above the threshold detects a pulse event.

Example: `createPulses(psObj,'PulseRequires2Samples',true)`

Data Types: `logical`

See Also

`Battery.PulseSequence`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

estimateInitialEmR0

Estimate open circuit voltage and series resistance

Syntax

```
estimateInitialEmR0(psObj)
estimateInitialEmR0(psObj,Name,Value)
```

Description

`estimateInitialEmR0(psObj)` estimates the open circuit voltage, *Em*, and series resistance, *Ro*, for the `Battery.PulseSequence` object data. For the estimation, the method uses data points around each pulse transition. The method uses estimated values to determine the minimum and maximum constraint values. The method stores the results in an `Battery.Parameters` object.

`estimateInitialEmR0(psObj,Name,Value)` estimates the open circuit voltage, *Em*, and series resistance, *Ro*, for the `Battery.PulseSequence` object data with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` *in quotes.*

Example:
`estimateInitialEmR0(psObj,'SetEmConstraints',false,'EstimateEm',true,'EstimateR0',true)`

`SetEmConstraints` — Use open circuit voltage constraints
`true` (default)

Use this value to specify if the method constrains the open circuit voltage, *Eo*, to within maximum or minimum values. To determine the maximum and minimum voltage, the method uses the voltage at the end of relaxation as a constraint for future estimation steps.

If the pulse is a discharge pulse, the voltage rises during relaxation. The final relaxation voltage is set to the minimum constraint for Eo at the corresponding state of charge (SOC).

If the pulse is a charge pulse, the voltage falls during relaxation. The final relaxation voltage is set to the maximum constraint at the corresponding SOC.

Example: `estimateInitialEmR0(psObj,'SetEmConstraints',false)`

Data Types: `logical`

`EstimateEm` — Estimate open circuit voltage
`true` (default) | `false`

Use this value to specify if the method estimates the open circuit voltage, *Em*. Use the default setting, `true`, unless you have already defined the *Em* values from outside analysis.

Example: `eestimateInitialEmR0(psObj,'EstimateEm',false)`

Data Types: `logical`

`EstimateR0` — Estimate series resistance
`true` (default) | `false`

Use this value to specify if the method estimates the series resistance, *R0*. Use the default setting, `true`, unless you have already defined the *R0* values from outside analysis.

Example: `estimateInitialEmR0(psObj,'EstimateR0',false)`

Data Types: `logical`

See Also
`Battery.PulseSequence`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

estimateInitialEmRx

Estimate open circuit voltage and RC pair resistance

Syntax

```
estimateInitialEmRx(psObj)
estimateInitialEmRx(psObj,Name,Value)
```

Description

`estimateInitialEmRx(psObj)` estimates the open circuit voltage, *Em*, and RC pair resistance, *Ex*, for the `Battery.PulseSequence` object data. For the estimation, the method solves a linear system of equations throughout the pulse sequence. The method stores the results in a `Battery.Parameters` object.

`estimateInitialEmRx(psObj,Name,Value)` estimates the open circuit voltage, *Em*, and RC pair resistance, *Ex*, for the `Battery.PulseSequence` object data with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` *in quotes.*

Example:
`estimateInitialEmRx(psObj,'IgnoreRelaxation',false,'ShowPlots',true,'ShowBeforePlots',true,'PlotDelay',0.5,'EstimateEm',true)`

`EstimateEm` — Estimate voltage
`true` (default) | `false`

Use this value to specify if the method estimates the open circuit voltage, *Em*.

Example: `estimateInitialEmRx(psObj,'EstimateEm',false)`

Data Types: `logical`

`RetainEm` — Retain voltage estimate
`true` (default) | `false`

Use this value to specify if the method retains the open circuit voltage, *Em*, estimate. Set to `true` if you want the method to use an external open circuit voltage to state of charge (SOC) relationship. If `EstimateEm` is `false`, this option does not apply.

Example: `estimateInitialEmRx(psObj,'RetainEm',false)`

Data Types: `logical`

`EstimateR0` — Estimate series resistance
`true` (default) | `false`

Use this value to specify if the method estimates the series resistance, *Ro*.

Example: `estimateInitialEmRx(psObj,'EstimateR0',false)`

Data Types: `logical`

`RetainR0` — Retain series resistance
`true` (default) | `false`

Use this value to specify if the method retains the identified series resistance, *Ro*, estimate. Set to `true` if you want the method to use an existing series resistance to state of charge (SOC) relationship. If `EstimateEm` is `false`, this option does not apply.

Example: `estimateInitialEmRx(psObj,'RetainR0',false)`

Data Types: `logical`

`ShowPlots` — Show estimation plots
`false` (default) | `true`

Use this value to specify if the method shows plots during each estimation step.

Example: `estimateInitialEmRx(psObj,'ShowPlots',true)`

Data Types: `logical`

`ShowBeforePlots` — Show before estimation plots
`false` (default) | `true`

Use this value to specify if the method shows before plots during each estimation step. If `ShowPlots` is `false`, this option does not apply.

Example: `estimateInitialEmRx(psObj,'ShowBeforePlots',true)`

Data Types: `logical`

`PlotDelay` — Plot delay
`0.0` (default) | `scalar`

Use this value to specify the time delay after showing the plots, in s.

Example: `estimateInitialEmRx(psObj,'PlotDelay',0.1)`

Data Types: `double`

`IgnoreRelaxation` — Estimate series resistance
`false` (default) | `true`

Use this value to specify if the method completely ignores the relaxation and fits only the main pulse.

Example: `estimateInitialEmRx(psObj,'IgnoreRelaxation',true)`

Data Types: `logical`

See Also

`Battery.PulseSequence`

Topics

“Generate Parameter Data for Datasheet Battery Block”
“Generate Parameter Data for Equivalent Circuit Battery Block”

Introduced in R2016b

estimateInitialTau

Estimate RC pair time constant

Syntax

```
estimateInitialTau(psObj)
estimateInitialTau(psObj,Name,Value)
```

Description

`estimateInitialTau(psObj)` estimates the RC pair time constant, *Tau* for the `Battery.PulseSequence` object data. For the estimation, the method fits the relaxation curve for each pulse. The method stores the results in an `Battery.Parameters` object.

`estimateInitialTau(psObj,Name,Value)` estimates the RC pair time constant, *Tau* for the `Battery.PulseSequence` object data with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` *in quotes.*

Example:
`estimateInitialTau(psObj,'UpdateEndingEm',false,'ShowPlots',true,'ReusePlotFigure',true,'UseLoadData',false,'PlotDelay',0.5)`

`ShowPlots` — Show estimation plots
`false` (default) | `true`

Use this value to specify if the method shows plots during each estimation step.

Example: `estimateInitialTau(psObj,'ShowPlots',true)`

Data Types: `logical`

`PlotDelay` — Plot delay
`0.0` (default) | `scalar`

Use this value to specify the time delay after showing the plots, in s.

Example: `estimateInitialTau(psObj,'PlotDelay',0.5)`

Data Types: `double`

`ReusePlotFigure` — Reuse plots
`true` (default) | `false`

Use this value to specify if the method reuses the same plot figure. If `false`, the estimation plots are in separate figure windows. If `ShowPlots` is `false`, the option does not apply.

Example: `estimateInitialTau(psObj,'ReusePlotFigure',true)`

Data Types: `logical`

`UpdateEndingEm` — Update voltage estimate
`false` (default) | `true`

Use this value to specify if the method updates the open circuit voltage estimate at the end of the relaxation, based on the curve fits.

Example: `estimateInitialTau(psObj,'UpdateEndingEm',true)`

Data Types: `logical`

`UseLoadData` — Plot delay
`false` (default) | `true`

Use this value to specify if the method uses the pulse load data, instead of pulse relaxation data, to estimate the time constant, *Tau*. By default, the setting is `false`, and the method uses the pulse relaxation to estimate the time constant.

Example: `estimateInitialTau(psObj,'UseLoadData',true)`

Data Types: `logical`

See Also

`Battery.PulseSequence`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

estimateParameters

Estimate parameters

Syntax

```
estimateParameters(psObj)
estimateParameters(psObj,Name,Value)
```

Description

`estimateParameters(psObj)` estimates the parameters in the `Battery.Parameters` object. The method stores the results in an `Battery.Parameters` object.

`estimateParameters(psObj,Name,Value)` estimates the parameters in the `Battery.Parameters` object data with additional options specified by one or more `Name,Value` pair arguments.

To use the `Battery.PulseSequence` object and methods, you need these products:

- Powertrain Blockset
- Curve Fitting Toolbox
- Optimization Toolbox
- Parallel Computing Toolbox
- Simulink Design Optimization

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Name-Value Pair Arguments

Specify optional pairs of arguments as `Name1=Value1,...,NameN=ValueN`, where `Name` is the argument name and `Value` is the corresponding value. Name-value arguments must appear after other arguments, but the order of the pairs does not matter.

Before R2021a, use commas to separate each name and value, and enclose `Name` *in quotes.*

Example:
`estimateParameters(psObj,'CarryParamToNextPulse',true,'ShowPlots',true,'EstimateEm',true,'RetainEm',true,'EstimateR0',true,'RetainR0',true)`

`CarryParamsToNextPulse` — Use results for next SOC
`false` (default) | `true`

Use this value to specify if the method uses the identified current pulse final state of charge (SOC) parameter values as the initial estimate for the parameter values at the next SOC.

Example: `estimateParameters(psObj,'CarryParamsToNextPulse',true)`

Data Types: `logical`

`EstimateEm` — Estimate voltage
`true` (default) | `false`

Use this value to specify if the method estimates the open circuit voltage, *Em*.

Example: `estimateParameters(psObj,'EstimateEm',false)`

Data Types: `logical`

`RetainEm` — Retain voltage estimate
`true` (default) | `false`

Use this value to specify if the method retains the identified open circuit voltage, *Em*, estimate. If `EstimateEm` is `false`, this option does to apply.

Example: `estimateParameters(psObj,'RetainEm',false)`

Data Types: `logical`

`EstimateR0` — Estimate series resistance
`true` (default) | `false`

Use this value to specify if the method estimates the series resistance, *R0*.

Example: `estimateParameters(psObj,'EstimateR0',false)`

Data Types: `logical`

`RetainR0` — Retain series resistance
`true` (default) | `false`

Use this value to specify if the method retains the series resistance, *Ro*, estimate. If `EstimateR0` is `false`, this option does to apply.

Example: `estimateParameters(psObj,'RetainR0',false)`

Data Types: `logical`

`SDOOptimizeOptions` — Specify optimization options
'`Method`' is `lsqnonlin` and '`UseParallel`' is `true` (default)

Use this value to specify the `sdo.OptimizeOptions` object options. For example:

```
SDOOptimizeOptions = sdo.OptimizeOptions(...
    'OptimizedModel',psObj.ModelName,...
    'Method','lsqnonlin',...
    'UseParallel','always')
```

`ShowPlots` — Show estimation plots
`false` (default) | `true`

Use this value to specify if the method shows plots during each estimation step.

Example: `estimateParameters(psObj,'ShowPlots',true)`

Data Types: `logical`

ReusePlotFigure — Reuse plots
true (default) | false

Use this value to specify if the method reuses the same plot figure. If false, the estimation plots are in separate figure windows. If ShowPlots is false, the option does not apply.

Example: estimateParameters(psObj,'ReusePlotFigure',true)

Data Types: logical

PlotDelay — Plot delay
5.0 (default) | scalar

Use this value to specify the time delay after showing the plots, in s.

Example: estimateParameters(psObj,'PlotDelay',0.1)

Data Types: double

PulseNumbers — Pulse numbers
1 (default) | scalar

Use this value to specify the pulse numbers to estimate. The default value, 1, is set to estimate all the pulses.

Data Types: uint32

See Also

Battery.PulseSequence | sdo.OptimizeOptions

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

getSocIdxForPulses

Return state of charge index for pulses

Syntax

```
idx=getSocIdxForPulses(psObj,pulseList)
```

Description

`idx=getSocIdxForPulses(psObj,pulseList)` returns the row vector index of the state of charge (SOC) lookup table breakpoints.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

`pulseList` — Index of pulses
`1:NumPulses` (default)

Index of pulses. For example, `1:10`.

Data Types: `int16`

Output Arguments

`idx` — Indices into SOC lookup table
1-by-`NumPulses` array

Indices into SOC lookup table.

Data Types: `int16`

See Also
`Battery.PulseSequence`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

plot

Plot pulse sequence data

Syntax

```
plot_handle = plot(psObj)
```

Description

`plot_handle = plot(psObj)` plots the data from a `Battery.PulseSequence` object.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Output Arguments

`plot_handle` — Plot handle
object handle

Handles to plot objects.

Data Types: `function_handle`

See Also

`Battery.PulseSequence`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

plotIdentifiedPulses

Plot identified pulses

Syntax

`plot_handle = plotIdentifiedPulses(psObj)`

Description

`plot_handle = plotIdentifiedPulses(psObj)` plots identified pulses from a `Battery.PulseSequence` object.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Output Arguments

`plot_handle` — Plot handle
object handle

Handles to plot objects.

Data Types: `function_handle`

See Also

`Battery.PulseSequence`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

plotLatestParameters

Plot latest pulse sequence parameters

Syntax

```
plot_handle = plotLatestParameters(psObj)
```

Description

`plot_handle = plotLatestParameters(psObj)` plots the latest pulse sequence parameters from a `Battery.PulseSequence` object.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

Output Arguments

`plot_handle` — Plot handle
object handle

Handles to plot objects.

Data Types: `function_handle`

See Also

`Battery.PulseSequence`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

plotSimulationResults

Plot pulse sequence simulation results

Syntax

```
plot_handle=plotSimulationResults(psObj)
plot_handle=plotSimulationResults(psObj,param)
```

Description

`plot_handle=plotSimulationResults(psObj)` plots the simulation results of the pulse sequence based on the current parameter values.

`plot_handle=plotSimulationResults(psObj,param)` plots the simulation results of the pulse sequence based on the parameter values specified by the `Battery.Parameter` object.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

`param` — Instance of `Battery.Parameter` class
`Battery.Parameter` object

`Battery.Parameter` object for the parameters that you want to analyze.

Output Arguments

`plot_handle` — Plot handle
object handle

Handles to plot objects.

Data Types: `function_handle`

See Also

`Battery.PulseSequence`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

populatePulseParameters

Populate pulse parameters

Syntax

```
populatePulseParameters(psObj)
```

Description

`populatePulseParameters(psObj)` populates parameters in the `Battery.PulseSequence` object based on the series of pulse objects. If the pulse objects are new, updated, or filtered, `populatePulseParameters` updates the identified pulse indices, SOC breakpoints, and parameters objects in `Battery.PulseSequence`.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

See Also

`Battery.PulseSequence`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

removePulses

Remove pulses from sequence

Syntax

`removePulses(psObj,idxRemove)`

Description

`removePulses(psObj,idxRemove)` removes pulses from sequence specified by the `Battery.PulseSequence` object.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

`idxRemove` — Index of pulse objects to remove
`1:NumPulses` (default)

Index of pulse objects to remove. For example, `1:10`.

Data Types: `int16`

See Also
`Battery.PulseSequence`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

repairTimeVector

Repair time vector

Syntax

```
repairTimeVector(psObj)
repairTimeVector(psObj,MinDeltaT)
```

Description

`repairTimeVector(psObj)` repairs common problems with the experimental time vector on the `Battery.PulseSequence` object.

`repairTimeVector(psObj,MinDeltaT)` repairs common problems with the experimental time vector on the `Battery.PulseSequence` object using a minimum time difference.

Input Arguments

`psObj` — Instance of `Battery.PulseSequence` class
`Battery.PulseSequence` object

`Battery.PulseSequence` object for the pulse sequence that you want to analyze.

`MinDeltaT` — Minimum time difference
scalar

Index of pulse objects to remove. For example, `1:10`.

Data Types: `double`

See Also
`Battery.PulseSequence`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

Battery.Pulse

Define a single pulse event

Description

Use the `Battery.Pulse` object to define a single experimental pulse event. To create a pulse object, use the `Battery.PulseSequence` object function `createPulses`.

To use the `Battery.Pulse` object and methods, you need these products:

- Powertrain Blockset
- Curve Fitting Toolbox
- Optimization Toolbox
- Parallel Computing Toolbox
- Simulink Design Optimization

Creation

Syntax

```
pulseObj = Battery.Pulse(Battery.PulseSequence)
```

Description

MATLAB creates a `pulseObj = Battery.Pulse(Battery.PulseSequence)` object that defines a single pulse event.

Properties

`Data` — Raw data
1-by-5 array

An 1-by-5 array of pulse event data.

Array Element	Description	Unit
`Data(1,1)`	Time	s
`Data(1,2)`	Voltage	V
`Data(1,3)`	Current	A
`Data(1,4)`	Charge	A·s
`Data(1,5)`	State of charge (SOC)	Dimensionless

Data Types: `double`

InitialCapVoltage — Initial capacitor voltage
array

Initial voltage of each capacitor during a pulse event, in V. Property set by the Battery.PulseSequence object function estimateParameters, based on the simulated end voltage or a prior pulse.

Data Types: double

InitialChargeDeficit — Initial charge deficit
0.0 (default) | scalar

Initial charge deficit at start of pulse event, in A·s. Property set by the Battery.PulseSequence object function createPulses when the function creates the series of Battery.Pulse objects.

Example: 0.0

Data Types: double

idxLoad — Indices to load data
[1 0] (default)

Indices to load data where the pulse event load begins and ends. Property set by the Battery.PulseSequence object function createPulses when the function creates the series of Battery.Pulse objects.

Data Types: int16

idxRelax — Indices to relaxation data
[1 0] (default)

Indices to relaxation data where the pulse event relaxation begins and ends. Property set by the Battery.PulseSequence object function createPulses when the function creates the series of Battery.Pulse objects.

Data Types: int16

idxPulseSequence — Index to first pulse event data
[] (default)

Index to first pulse event data point in the Battery.PulseSequence object data. Property set by the Battery.PulseSequence object function createPulses when the function creates the series of Battery.Pulse objects.

Data Types: int16

IsDischarge — Discharge pulse
true (default)

Use this value to specify if pulse is a discharge pulse event. Property set by the Battery.PulseSequence object function createPulses when the function creates the series of Battery.Pulse objects.

Data Types: logical

Parameters — Battery.Parameters object properties
0-by-1 array

`Battery.Parameters` object containing the most recently determined battery equivalent circuit parameters. Property set by the `Battery.PulseSequence` object function `createPulses` when the function creates the series of `Battery.Pulse` objects.

Data Types: `function_handle`

`ParametersHistory` — `Battery.ParametersHistory` object properties
`0`-by-`1` array

`Battery.ParametersHistory` object array containing the history of the battery equivalent circuit parameters through different estimation steps. The last element is the most recent parameter set.

Data Types: `function_handle`

Object Functions

plot	Plot pulse event data
getLoadData	Retrieve experimental data during load phase of pulse
getRelaxationData	Retrieve experimental data during relaxation phase of pulse
getTransitionData	Retrieve experimental data during transition phase of pulse

Examples

Create `Battery.Pulse` Object

This example shows how to create a `Battery.Pulse` object.

```
pulseObj = Battery.Pulse(psObj);
```

See Also

`Battery.MetaData` | `Battery.Parameters` | `Battery.PulseSequence` | `sdo.OptimizeOptions`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

plot

Plot pulse event data

Syntax

```
plot_handle=plot(pulseObj)
```

Description

`plot_handle=plot(pulseObj)` plots the data from a `Battery.Pulse` object.

Input Arguments

`pulseObj` — Instance of `Battery.Pulse` class
`Battery.Pulse` object

`Battery.Pulse` object for the pulse event that you want to analyze.

Output Arguments

`plot_handle` — Plot handle
object handle

Handles to plot objects.

Data Types: `function_handle`

See Also
`Battery.Pulse`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

getLoadData

Retrieve experimental data during load phase of pulse

Syntax

```
LoadData = plot(pulseObj,Buffer)
```

Description

`LoadData = plot(pulseObj,Buffer)` retrieves the experimental data from a `Battery.Pulse` object during the load phase of a pulse.

Input Arguments

`pulseObj` — Instance of `Battery.Pulse` class
`Battery.Pulse` object

`Battery.Pulse` object for the pulse event that you want to analyze.

`Buffer` — Number of samples
vector

Number of buffer samples before and after the load data, in the form `[BeforeBufferSize,AfterBufferSize]`. Use the buffer to ensure that the estimation has sufficient data before and after a transition.

Output Arguments

`LoadData` — Load data
array

Load data during pulse event.

Data Types: `double`

See Also

`Battery.Pulse`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

getRelaxationData

Retrieve experimental data during relaxation phase of pulse

Syntax

`RelaxationData = plot(pulseObj,Buffer)`

Description

`RelaxationData = plot(pulseObj,Buffer)` retrieves the experimental data from a `Battery.Pulse` object during the relaxation phase of a pulse.

Input Arguments

`pulseObj` — Instance of `Battery.Pulse` class
`Battery.Pulse` object

`Battery.Pulse` object for the pulse event that you want to analyze.

`Buffer` — Number of samples
vector

Number of buffer samples before and after the load data, in the form `[BeforeBufferSize,AfterBufferSize]`. Use the buffer to ensure that the estimation has sufficient data before and after a transition.

Output Arguments

`RelaxationData` — Relaxation data
array

Relaxation data during pulse event.

Data Types: `double`

See Also

`Battery.Pulse`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

getTransitionData

Retrieve experimental data during transition phase of pulse

Syntax

```
[TransitionDataBefore,TransitionDataAfter]=plot(pulseObj,idx)
[TransitionDataBefore,TransitionDataAfter]=plot(pulseObj,idx,Buffer)
```

Description

`[TransitionDataBefore,TransitionDataAfter]=plot(pulseObj,idx)` retrieves the transition data from a `Battery.Pulse` object during the transition phase of a pulse.

`[TransitionDataBefore,TransitionDataAfter]=plot(pulseObj,idx,Buffer)` retrieves buffered experimental data from a `Battery.Pulse` object during the transition phase of a pulse.

Input Arguments

`pulseObj` — Instance of `Battery.Pulse` class

`Battery.Pulse` object

`Battery.Pulse` object for the pulse event that you want to analyze.

`idx` — Transition data index

scalar

Index of transition data.

Data Types: `int16`

`Buffer` — Number of samples

vector

Number of buffer samples before and after the load data, in the form `[BeforeBufferSize,AfterBufferSize]`. Use the buffer to ensure that the estimation has sufficient data before and after a transition.

Output Arguments

`TransitionDataBefore` — Data before transition

array

Data before transition during pulse event.

Data Types: `double`

`TransitionDataAfter` — Data after transition

array

Data after transition during pulse event.

Data Types: `double`

See Also
`Battery.Pulse`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

Battery.Parameters

Define battery equivalent circuit parameters

Description

Use the `Battery.Parameters` object to define the battery equivalent circuit parameters. `Battery.Parameters` objects are contained in the `Battery.PulseSequence` and `Battery.Pulse` objects. The pulse sequence estimation sets some of the `Battery.Parameters` properties. You can override the properties by manually setting the properties. The number of pulses, *N*, in the dataset determines the length of each array.

Creation

Syntax

`paramObj = Battery.Parameters`

Description

MATLAB creates a `paramObj = Battery.Parameters` object that defines the battery equivalent circuit parameters.

Properties

`SOC` — State of charge breakpoints
1-by-11 array (default)

A 1-by-N array of the state of charge (SOC) breakpoints.

Data Types: `double`

`Em` — Open circuit voltage
1-by-11 array (default)

A 1-by-N array of the open circuit voltage, in V.

Data Types: `double`

`EmMin` — Minimum open circuit voltage
1-by-11 array (default)

A 1-by-N array of the minimum open circuit voltage, in V.

Data Types: `double`

`EmMax` — Maximum open circuit voltage
1-by-11 array (default)

A 1-by-N array of the maximum open circuit voltage, in V.

Data Types: `double`

`R0` — Terminal resistance
1-by-11 array (default)

A 1-by-N array of the terminal resistance, in Ohms.

Data Types: `double`

`R0Min` — Minimum terminal resistance
1-by-11 array (default)

A 1-by-N array of the minimum terminal resistance, in Ohms.

Data Types: `double`

`R0Max` — Maximum terminal resistance
1-by-11 array (default)

A 1-by-N array of the maximum terminal resistance, in Ohms.

Data Types: `double`

`Rx` — RC pair resistance
3-by-11 array (default)

A 3-by-N array of the RC pair resistance, in Ohms.

Data Types: `double`

`RxMin` — Minimum RC pair resistance
3-by-11 array (default)

A 3-by-N array of the minimum RC pair resistance, in Ohms.

Data Types: `double`

`RxMax` — Maximum RC pair resistance
3-by-11 array (default)

A 3-by-N array of the maximum RC pair resistance, in Ohms.

Data Types: `double`

`Tx` — RC pair time constant
3-by-11 array (default)

A 3-by-N array of the RC pair time constant, in s.

Data Types: `double`

`TxMin` — Minimum RC pair time constant
3-by-11 array (default)

A 3-by-N array of the minimum RC pair time constant, in s.

Data Types: `double`

`TxMax` — Maximum RC pair time constant
3-by-11 array (default)

A 3-by-N array of the maximum RC pair time constant, in s.

Data Types: double

Object Functions

lookupSocFromVoltage	Determine SOC from voltage
plot	Plot battery parameter data

Examples

Create Battery.Parameters Object

This example shows how to create a Battery.Parameters object.

Create a Battery.Parameters object.

```
paramObj=Battery.Parameters;
```

See Also

Battery.MetaData | Battery.PulseSequence | Battery.Pulse | sdo.OptimizeOptions

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

lookupSocFromVoltage

Determine SOC from voltage

Syntax

`SOC=lookupSocFromVoltage(paramObj,Voltage)`

Description

`SOC=lookupSocFromVoltage(paramObj,Voltage)` calculates the state of charge (SOC) from the voltage for a given open-circuit voltage. Use `lookupSocFromVoltage` after you know the open-circuit voltage, *Em*, value.

Input Arguments

`paramObj` — Instance of `Battery.Parameters` class
`Battery.Parameters` object

`Battery.Parameters` object for the battery that you want to analyze.

`Voltage` — Open circuit voltage
scalar

Open circuit voltage, in V.

Data Types: `char`

Output Arguments

`SOC` — State of charge
scalar

State of charge.

Data Types: `double`

See Also

`Battery.Parameters`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

plot

Plot battery parameter data

Syntax

```
plot_handle=plot(paramObj)
plot_handle=plot(paramObj,LegendNames)
```

Description

`plot_handle=plot(paramObj)` plots the data from a `Battery.Parameters` object.

`plot_handle=plot(paramObj,LegendNames)` plots the data from a `Battery.Parameters` object with the legend names.

Input Arguments

`paramObj` — Instance of `Battery.Pulse` class
`Battery.Parameters` object

`Battery.Parameters` object for the battery that you want to analyze.

`LegendNames` — Plot legends
character vector

Name of plot legends.

Data Types: `char`

Output Arguments

`plot_handle` — Plot handle
object handle

Handles to plot objects.

Data Types: `function_handle`

See Also

`Battery.Parameters`

Topics

"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

Battery.MetaData

Define battery metadata

Description

Use the `Battery.MetaData` object to define the battery metadata. A `Battery.PulseSequence` object contains the `Battery.MetaData` object. You must specify the metadata values.

Creation

Syntax

`batmetaObj = Battery.MetaData`

Description

MATLAB creates a `batmetaObj = Battery.MetaData` object that defines the battery metadata.

Properties

`BatteryId` — Battery identification
character vector

Battery identification name.

Data Types: `double`

`RatingAh` — Battery rating
character vector

Battery rating.

Data Types: `char`

`Name` — Dataset name
character vector

Dataset name.

Data Types: `char`

`Date` — Dataset date
character vector

Dataset date.

Data Types: `char`

`Source` — Dataset source
character vector

Dataset source.

Data Types: `char`

`TestType` — Experimental data type
character vector

Test type, for example charge or discharge.

Data Types: `char`

`TestCurrent` — Test current
scalar

Test current, in A.

Data Types: `double`

`TestTemperature` — Test temperature
scalar

Test temperature, in C.

Data Types: `double`

Examples

Create `Battery.MetaData` Object and Set Properties

This example shows how to create a `Battery.MetaData` object and set properties.

Create a `Battery.MetaData` object.

```
batmetaObj=Battery.MetaData;
```

Set `Battery.MetaData` properties.

```
batmetaObj.BatteryId='myBatteryId';
batmetaObj.RatingAh='myRatingAh';
batmetaObj.Name='myName';
batmetaObj.Date='myDate';
batmetaObj.Source='mySource';
batmetaObj.TestType='Charge';
batmetaObj.TestCurrent=300;
batmetaObj.TestCurrent=120;
```

Display `Battery.MetaData` properties.

```
disp(batmetaObj)
```

See Also

`Battery.Parameters` | `Battery.PulseSequence` | `Battery.Pulse`

Topics
"Generate Parameter Data for Datasheet Battery Block"
"Generate Parameter Data for Equivalent Circuit Battery Block"

Introduced in R2016b

9

Apps

Virtual Vehicle Composer

Configure, build, and analyze a virtual automotive vehicle

Description

The **Virtual Vehicle Composer** app enables you to configure and build a virtual vehicle that you can use for system-level performance analysis, including component sizing, fuel economy, drive cycle tracking, software integration testing, and hardware-in-the-loop (HIL) testing. Use the app to quickly enter your vehicle parameter data, build a virtual vehicle model, run test scenarios, and analyze the results.

The virtual vehicle model contains the blocks and reference application subsystems available with Powertrain Blockset and Vehicle Dynamics Blockset™. You can use the app to quickly configure the architecture and enter parameter data.

If you have Powertrain Blockset, use the app to:

- Design tradeoff analysis and component sizing.
- Configure hybrid-electric vehicle (HEV) architectures.

If you have Vehicle Dynamics Blockset, use the app to:

- Analyze ride-and-handling effects of standard test maneuvers.
- Visualize your virtual vehicle in Unreal Engine® simulation environment.

To build, operate, and analyze your virtual vehicle, use **Composer** tab in the **Virtual Vehicle Composer** to follow these workflow steps:

Step	Section	Button	Description
1	**Configure**	**Vehicle Data**	Specify the vehicle architecture, dynamics model, chassis, powertrain, and driver. For each selection, enter the vehicle parameter data.
2		**Vehicle Scenario and Test**	Select the scenario to use to test your virtual vehicle. Options include drive cycle scenarios for longitudinal studies and standard test maneuvers for vehicle dynamics studies.
3		**Data Logging Editor**	Select the model signal data to log when operating your virtual vehicle. Options include vehicle position, velocity, and acceleration.
4	**Build**	**Virtual Vehicle**	Build your virtual vehicle. When you build, the **Virtual Vehicle Composer** creates a Simulink model that contains the vehicle architecture and the data that you specify in the configuration.
5	**Operate**	**Run Test Plan**	Simulate your model in the scenarios that you specify in step 2.
6	**Analyze**	**Simulation Data Inspector**	Use the Simulation Data Inspector to view and inspect the simulation signals that you select in step 3.

Required Products

The **Virtual Vehicle Composer** requires either of these products:

- “Powertrain Blockset”
- “Vehicle Dynamics Blockset”

  If you want to run your virtual vehicle in the Unreal Engine 3D simulation environment, see the requirements in “Unreal Engine Simulation Environment Requirements and Limitations” (Vehicle Dynamics Blockset).

Vehicle Data

Use the app to quickly enter your virtual vehicle parameter data for the vehicle architecture, vehicle dynamics model, chassis, powertrain, and driver. For each selection, enter the parameter data.

Parameter	Description
Vehicle Architecture	Use the parameters to specify the vehicle type. By default, the parameter is set to `Conventional Vehicle`. The conventional vehicle architecture has a spark-ignition (SI) internal combustion engine, transmission, chassis, and associated powertrain control algorithms. If you have Powertrain Blockset, you can specify these model architectures for hybrid electric vehicles (HEVs). The HEV and EV model architectures include an internal combustion engine, chassis, transmission, battery, motor, generator, and associated powertrain control algorithms.
Vehicle Model	Use the parameter setting `Longitudinal Vehicle Dynamics` to configure a model suitable for fuel economy and energy management analysis. If you have Vehicle Dynamics Blockset, you can specify `Lateral Vehicle Dynamics` to configure a model suitable for vehicle handling, stability, and ride comfort analysis. The virtual vehicle uses the Z-up coordinate system as defined in SAE J670 and ISO 8855. For more information, see “Coordinate Systems in Vehicle Dynamics Blockset” (Vehicle Dynamics Blockset).

Parameter	Description
Chassis	Use the **Chassis** parameters to select the tire, brake type, steering system, and suspension systems for your virtual vehicle. If you have Powertrain Blockset, you can set **Tire** to `Longitudinal Tire`, which implements a tire model suitable for longitudinal vehicle dynamics studies, including fuel economy and energy management analysis. If you have Vehicle Dynamics Blockset, you can set **Tire** to `Longitudinal Combined Slip Tire`, which implements a tire model suitable for lateral vehicle dynamics studies, including vehicle handling, stability, and ride comfort analysis. The model implements longitudinal and lateral behavior of a wheel characterized by the Magic Formula. You can use fitted tire data sets provided by the Global Center for Automotive Performance Simulation (GCAPS). If you have Vehicle Dynamics Blockset and set **Vehicle Model** to `Lateral Vehicle Dynamics`, you can specify **Steering System** and **Suspension** parameters.
Powertrain	Select the engine, transmission, drivetrain, differential system, vehicle control unit, and electrical system parameters for your virtual vehicle. The available parameters depend on the product license, vehicle architecture, and vehicle model.
Driver	The parameter setting `Longitudinal Driver` implements a longitudinal speed-tracking controller. If you have Vehicle Dynamics Blockset you can set **Driver** to `Predictive Driver` to track longitudinal velocity and a lateral reference displacement.
Environment	The parameter setting `Standard Ambient` implements an ambient environment model.

Vehicle Scenario and Test

Select the scenario to use to test your virtual vehicle.

If you set **Scenario** to `Drive Cycle`, you can use:

- Drive cycles from predefined sources. By default, the block includes the `FTP–75` drive cycle. To install additional drive cycles from a support package, see "Install Drive Cycle Data". The support package has drive cycles that include the gear shift schedules, for example `JC08` and `CUEDC`.
- Workspace variables that define your own drive cycles.
- `.mat`, `.xls`, `.xlsx`, or `.txt` files.
- Wide open throttle (WOT) parameters, including initial and nominal reference speed, deceleration start time, and final reference speed.

If you have Vehicle Dynamics Blockset and set **Vehicle Model** to `Lateral Vehicle Dynamics`, you can select maneuvers for vehicle handling, stability, and ride analysis. Maneuvers include:

- `Double Lane Change`
- `Increasing Steer`
- `Constant Radius`

If you want to run your virtual vehicle in the Unreal Engine 3D simulation environment, set **Simulation 3D** to `Enable`. For hardware requirements, see "Unreal Engine Simulation Environment Requirements and Limitations" (Vehicle Dynamics Blockset).

Data Logging Editor

Select the model signal data to log when operating your virtual vehicle. Options include vehicle position, velocity, and acceleration. By default, the app lists frequently-used signals.

Virtual Vehicle

Build your virtual vehicle. When you build, the **Virtual Vehicle Composer** creates a Simulink model that contains the specified vehicle architecture and data.

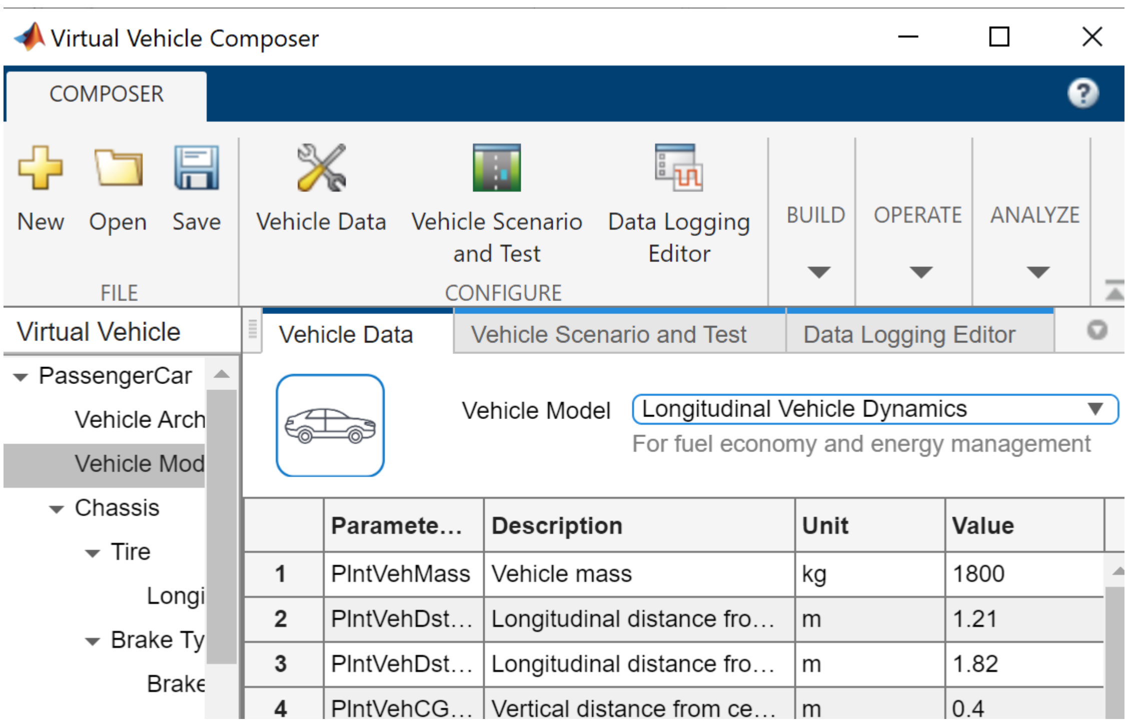
Run Test Plan

Simulate your model in the scenario that you specified in **Vehicle Scenario and Test**.

Simulation Data Inspector

Use the Simulation Data Inspector to view and inspect the simulation signals.

If you run your virtual vehicle through more than one test scenario, the Simulation Data Inspector displays the results from the last simulation. To see results from previous simulations, load the archived results.



Open the Virtual Vehicle Composer App

- MATLAB Toolstrip: On the **Apps** tab, under **Automotive**, click the app icon.

- MATLAB Command Window: Enter `virtualVehicleComposer`.

Examples

- "Get Started with the Virtual Vehicle Composer"

Parameters

Architecture and Model

`Vehicle Architecture` — Hybrid electric, conventional, or electric vehicle
`Conventional Vehicle` | `Electric Vehicle` | `Hybrid Electric IPS` | `Hybrid Electric MM` | `Hybrid Electric P0` | `Hybrid Electric P1` | `Hybrid Electric P2` | `Hybrid Electric P3` | `Hybrid Electric P4`

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Conventional Vehicle`	✔	✔	Model architecture for a vehicle with a spark-ignition (SI) internal combustion engine, transmission, and associated powertrain control algorithms.
`Electric Vehicle`	✔	✔	Model architecture for an electric vehicle (EV) with a motor-generator, battery, direct-drive transmission, and associated powertrain control algorithms.
`Hybrid Electric IPS`	✔		Model architecture for a input power split (IPS) hybrid electric vehicle (HEV) with an internal combustion engine, transmission, battery, motor, generator, and associated powertrain control algorithms.
`Hybrid Electric MM`	✔		Model architecture for a multimode HEV with an internal combustion engine, transmission, battery, motor, generator, and associated powertrain control algorithms.
`Hybrid Electric P0`	✔		Model architecture for a HEV P0 with an internal combustion engine, transmission, battery, motor, generator, and associated powertrain control algorithms.
`Hybrid Electric P1`	✔		Model architecture for a HEV P1 with an internal combustion engine, transmission, battery, motor, generator, and associated powertrain control algorithms.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Hybrid Electric P2`	✔		Model architecture for a HEV P2 with an internal combustion engine, transmission, battery, motor, generator, and associated powertrain control algorithms.
`Hybrid Electric P3`	✔		Model architecture for a HEV P3 with an internal combustion engine, transmission, battery, motor, generator, and associated powertrain control algorithms.
`Hybrid Electric P4`	✔		Model architecture for a HEV P4 with an internal combustion engine, transmission, battery, motor, generator, and associated powertrain control algorithms.

`Vehicle Model` — Virtual vehicle longitudinal or lateral vehicle dynamics
`Longitudinal vehicle dynamics` | `Lateral Vehicle Dynamics`

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Longitudinal Vehicle Dynamics`	✔	✔	Model suitable for fuel economy and energy management analysis.
`Lateral Vehicle Dynamics`		✔	Model suitable for vehicle handling, stability, and ride comfort analysis.

Chassis

`Tire` — Virtual vehicle tires
`Longitudinal Tire` | `Longitudinal Combined Slip Tire`

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Longitudinal Tire`	✔	✔	Tire model suitable for longitudinal vehicle dynamics studies, including fuel economy and energy management analysis.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Longitudinal Combined Slip Tire`		✔	Tire models suitable for lateral vehicle dynamics studies, including vehicle handling, stability, and ride comfort analysis. Tire model implements the longitudinal and lateral behavior of a wheel characterized by the Magic Formula. You can use fitted tire data sets provided by the Global Center for Automotive Performance Simulation (GCAPS) for tires, including: • `Light passenger car 205/60R15` • `Mid-size passenger car 235/45R18` • `Performance car 225/40R19` • `SUV 265/50R20` • `Light truck 275/65R18` • `Commercial truck 295/75R22.5`

`Brake Type` — Virtual vehicle brakes
`Disc` | `Drum` | `Mapped`

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Disc`	✔	✔	Brake model converts the brake cylinder pressure into a braking force.
`Drum`	✔	✔	Brake model converts the applied force and brake geometry into a net braking torque.
`Mapped`	✔	✔	Brake model is a function of the wheel speed and applied brake pressure.

`Brake Control` — Brake control
`Bang Bang ABS` | `Open Loop` | `Five-State ABS`

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Bang Bang ABS`	✔	✔	Anti-lock braking system (ABS) feedback controller that switches between two states to regulate wheel slip. The bang-bang control minimizes the error between the actual slip and the desired slip. For the desired slip, the controller uses the slip value at which the mu-slip curve reaches a peak value. This desired slip value is optimal for minimum braking distance.
`Open Loop`	✔	✔	Open loop brake control. The controller sets the brake pressure command to a reference brake pressure based on the brake command.
`Five-State ABS`	✔	✔	Five-state ABS controller that uses logic-switching based on wheel deceleration and vehicle acceleration to control the braking pressure at each wheel. Consider using five-state ABS control to prevent wheel lock-up, decrease braking distance, or maintain yaw stability during the maneuver. The default ABS parameters are set to work on roads that have a constant friction coefficient scaling factor of 0.6.

Steering System — Steering
`Mapped` | `Kinematic` | `Dynamic`

If you have Vehicle Dynamics Blockset and set **Vehicle Model** to `Lateral Vehicle Dynamics`, you can specify these parameters.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Mapped`		✔	Mapped rack-and-pinion steering model.
`Kinematic`		✔	Kinematic model for ideal rack-and-pinion steering. Gears convert the steering rotation into linear motion.
`Dynamic`		✔	Dynamic model for ideal rack-and-pinion steering. Gears convert the steering rotation into linear motion.

Suspension — Suspension
`Kinematics and Compliance Independent Suspension` | `MacPherson Front Suspension`
`Solid Axle Rear Suspension`

If you have Vehicle Dynamics Blockset and set **Vehicle Model** to `Lateral Vehicle Dynamics`, you can specify these parameters.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Kinematics and Compliance Independent Suspension`		✔	Kinematics and compliance (K & C) test suspension characteristics measured from simulated or actual laboratory suspension tests.
`MacPherson Front Suspension Solid Axle Rear Suspension`		✔	Independent MacPherson suspension for multiple axles with multiple tracks per axle.

Powertrain

Engine — Virtual vehicle engine
`SI Mapped Engine` | `Simple Engine` | `CI Engine` | `CI Mapped Engine` | `SI Engine` | `CI Mapped Engine`

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Simple Engine`	✔	✔	Simplified engine model using a maximum torque verses engine speed table, two scalar fuel mass properties, and one scalar engine efficiency parameter to estimate engine torque and fuel flow. Selecting `Simple Engine` sets the **Engine Control Unit** parameter to `Simple ECU`.
`CI Engine`	✔		Compression-ignition (CI) engine from intake to the exhaust port. Selecting `CI Engine` sets the **Engine Control Unit** parameter to `CI Engine Controller`.
`CI Mapped Engine`	✔	✔	Mapped CI engine model using power, air mass flow, fuel flow, exhaust temperature, efficiency, and emission performance lookup tables. Selecting `CI Mapped Engine` sets the **Engine Control Unit** parameter to `CI Engine Controller`.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`SI Engine`	✔		Spark-ignition (SI) engine from intake to exhaust port. Selecting `SI Engine` sets the **Engine Control Unit** parameter to `SI Engine Controller`.
`SI Mapped Engine`	✔	✔	Mapped SI engine model using power, air mass flow, fuel flow, exhaust temperature, efficiency, and emission performance lookup tables. Selecting `SI Mapped Engine` sets the **Engine Control Unit** parameter to `SI Engine Controller`.
`SI DL Engine`	✔		Deep learning SI engine. Available if you have the Deep Learning Toolbox™ and Statistics and Machine Learning Toolbox™ licenses. Use this setting to generate a dynamic deep learning SI engine model to use for powertrain control, diagnostic, and estimator algorithm design. Selecting `SI DL Engine` sets the **Engine Control Unit** parameter to `SI Engine Controller`.

`Transmission` — Virtual vehicle transmission
`Ideal Fixed Gear Transmission` | `Automatic Transmission with Torque Converter` | `Automated Manual Transmission` | `No Transmission`

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
`Ideal Fixed Gear Transmission`	✔	✔	Idealized fixed-gear transmission without a clutch or synchronization. Use this setting to model the overall gear ratio and power loss when you do not need a detailed transmission model.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
Automated Manual Transmission	✔		Ideal automated transmission (AMT). An AMT is a manual transmission with additional actuators and an electronic control unit (ECU) to regulate clutch and gear selection based on commands from a controller. Specify the number of gears as an integer vector with corresponding gear ratios, inertias, viscous damping, and efficiency factors. The clutch and synchronization engagement rates are linear and adjustable.
Automatic Transmission with Torque Converter	✔		Automatic transmission with a torque converter.
No Transmission	✔		No transmission.

Dependencies

To enable this parameter, set **Vehicle Architecture** to any of these:

- Conventional Vehicle
- Hybrid Electric Vehicle P0
- Hybrid Electric Vehicle P1
- Hybrid Electric Vehicle P2
- Hybrid Electric Vehicle P3
- Hybrid Electric Vehicle P4

Transmission Control Unit — Virtual vehicle transmission control
Driver Pass Through | PRNDL Controller

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
Driver Pass Through	✔	✔	No transmission control optimization.
PRNDL Controller	✔	✔	Controller that optimizes forward, reverse, neutral, park, and N-speed gear shift scheduling for fuel economy.

Dependencies

To enable this parameter, set **Vehicle Architecture** to any of these:

- Conventional Vehicle
- Hybrid Electric Vehicle P0
- Hybrid Electric Vehicle P1
- Hybrid Electric Vehicle P2
- Hybrid Electric Vehicle P3
- Hybrid Electric Vehicle P4

Drivetrain — Virtual vehicle drivetrain
One Actuator Input | Two Actuator Inputs AWD

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
One Actuator Input	✔	✔	Use One Actuator Input to configure the drivetrain for: • Front Wheel Drive • Rear Wheel Drive • All Wheel Drive
Two Actuator Inputs AWD	✔		To enable this parameter, set **Vehicle Architecture** to Hybrid Electric Vehicle P4.

Differential System — Virtual vehicle differential system
Open Differential | Active Differential | Limited Slip Differential

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
Open Differential	✔	✔	Differential as a planetary bevel gear train. The block matches the driveshaft bevel gear to the crown (ring) bevel gear. You can specify: • Carrier-to-driveshaft ratio • Crown wheel location • Viscous and damping coefficients for the axles and carrier

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
Active Differential		✔	Active differential that accounts for the power transfer from the transmission to the axles. The model implements the active differential as an open differential coupled to either a spur or a planetary differential gear set.
Limited Slip Differential	✔	✔	Differential as a planetary bevel gear train. The block matches the driveshaft bevel gear to the crown (ring) bevel gear. You can specify: • Carrier-to-driveshaft ratio • Crown wheel location • Viscous and damping coefficients for the axles and carrier • Type of slip coupling

Electrical System — Virtual vehicle electric machine and energy storage
Electrical System 1EM BEV Battery | Electrical System 1EM BEV Ideal Voltage Source | Electrical System 2EM HEV | Electrical System 1EM HEV

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Electrical System Settings	Powertrain Blockset	Vehicle Dynamics Blockset	Vehicle Architecture	Description
Electrical System 1EM BEV Battery	✔		Electric Vehicle	• Mapped motor and drive electronics operating in torque-control mode. • Lithium ion battery model based off of discharge characteristics taken at different temperatures.
Electrical System 1EM BEV Ideal Voltage Source	✔	✔	Electric Vehicle	• Mapped motor and drive electronics operating in torque-control mode. • Ideal voltage source battery model.

Electrical System Settings	Powertrain Blockset	Vehicle Dynamics Blockset	Vehicle Architecture	Description
Electrical System 2EM HEV	✔		• Hybrid Electric Vehicle IPS • Hybrid Electric Vehicle MM	• Two mapped motors and drive electronics operating in torque-control mode. • Lithium ion battery model based off of discharge characteristics taken at different temperatures.
Electrical System 1EM HEV	✔		• Hybrid Electric Vehicle P0 • Hybrid Electric Vehicle P1 • Hybrid Electric Vehicle P2 • Hybrid Electric Vehicle P3 • Hybrid Electric Vehicle P4	• Two mapped motors and drive electronics operating in torque-control mode. • Lithium ion battery model with DC-DC conversion.

Use the **Electrical Machine** parameters to specify a mapped motor and drive electronics operating in torque-control mode.

Use the **Energy Storage** parameters to specify a datasheet battery model for a lithium-ion battery.

Vehicle Control Unit — HEV and EV virtual vehicle control
EV 1EM | HEVIPS RuleBased | HEVMM RuleBased | HEVP0 Optimal | HEVP1 Optimal | HEVP2 Optimal | HEVP3 Optimal | HEVP4 Optimal

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Vehicle Architecture	Description
EV 1EM	✔	✔	Electric Vehicle	Controls the motor with torque arbitration and power management. Implements regenerative braking.
HEVIPS RuleBased	✔		Hybrid Electric Vehicle IPS	Controls the motor, generator, and engine through a set of rules and decision logic implemented in Stateflow.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Vehicle Architecture	Description
HEVMM RuleBased	✔		Hybrid Electric Vehicle MM	
HEVP0 Optimal	✔		Hybrid Electric Vehicle P4	Implements an equivalent consumption minimization strategy (ECMS) to control the energy management of hybrid electric vehicles (HEVs). The strategy optimizes the torque split between the engine and motor to minimize energy consumption while maintaining the battery state of charge (SOC).
HEVP1 Optimal	✔		Hybrid Electric Vehicle P4	
HEVP2 Optimal	✔		Hybrid Electric Vehicle P4	
HEVP3 Optimal	✔		Hybrid Electric Vehicle P4	
HEVP4 Optimal	✔		Hybrid Electric Vehicle P4	

Driver — Virtual vehicle driver
Longitudinal Driver|Predictive Driver

If you have Vehicle Dynamics Blockset you can set **Driver** to Predictive Driver to track longitudinal velocity and a lateral reference displacement.

These parameters depend on the product license. This table summarizes the parameters available with Powertrain Blockset or Vehicle Dynamics Blockset.

Setting	Powertrain Blockset	Vehicle Dynamics Blockset	Description
Longitudinal Driver	✔	✔	Implements a longitudinal speed-tracking controller.
Predictive Driver		✔	Track longitudinal velocity and a lateral reference displacement. Available when you set **Vehicle Model** to Lateral Vehicle Dynamics.

Environment — Virtual vehicle environment
Standard Ambient

The parameter setting `Standard Ambient` implements an ambient environment model.

Programmatic Use

Entering the command `virtualVehicleComposer` opens a new session of the app, enabling you to configure, build, and analyze your virtual vehicle.

See Also

Topics
"Get Started with the Virtual Vehicle Composer"
"Simulation Data Inspector"
"How 3D Simulation for Vehicle Dynamics Blockset Works" (Vehicle Dynamics Blockset)

Introduced in R2022a