Powertrain Blockset™

Reference

MATLAB® & SIMULINK®

R2018a

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Powertrain Blockset™ Reference

Revision History

October 2016	Online only	New for Version 1.0 (Release 2016b+)
March 2017	Online only	Revised for Version 1.1 (Release 2017a)
September 2017	Online only	Revised for Version 1.2 (Release 2017b)
March 2018	Online only	Revised for Version 1.3 (Release 2018a)

Contents

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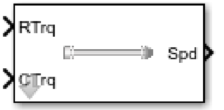
Drivetrain Blocks — Alphabetical List

Rotational Inertia

Ideal mechanical rotational inertia

Library: Drivetrain / Couplings



Description

The Rotational Inertia block implements an ideal mechanical rotational inertia.

Ports

Input

`RTrq` — Input torque
`scalar`

Applied input drive shaft torque, in N·m.

Dependencies

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

`CTrq` — Load torque
`scalar`

Load drive shaft torque, in N·m.

Dependencies

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

`Inertia` — Input
`scalar`

Additional inertia input, in kg*m^2.

Dependencies

To create this port, select the **External inertia input** parameter.

Output

Spd — Drive shaft speed
`scalar`

Angular drive shaft speed, in rad/s.

Dependencies

To create 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 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:

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

Specifying `Two-way connection` creates these ports:

- `R`
- `C`

`Rotational inertia, J` — Inertia
`scalar`

Rotational inertia, in kg*m^2.

`Torsional damping, b` — Damping
`scalar`

Torsional damping, in N·m· s/rad.

`Initial velocity, omega_o` — Angular
`scalar`

Initial angular velocity, in rad/s.

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

Select to create an input port for additional inertia.

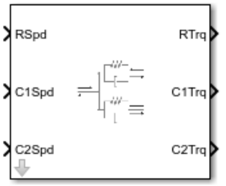
See Also

Split Torsional Compliance | Torsional Compliance

Introduced in R2017a

Split Torsional Compliance

Split torsional coupler
Library: Drivetrain / Couplings



Description

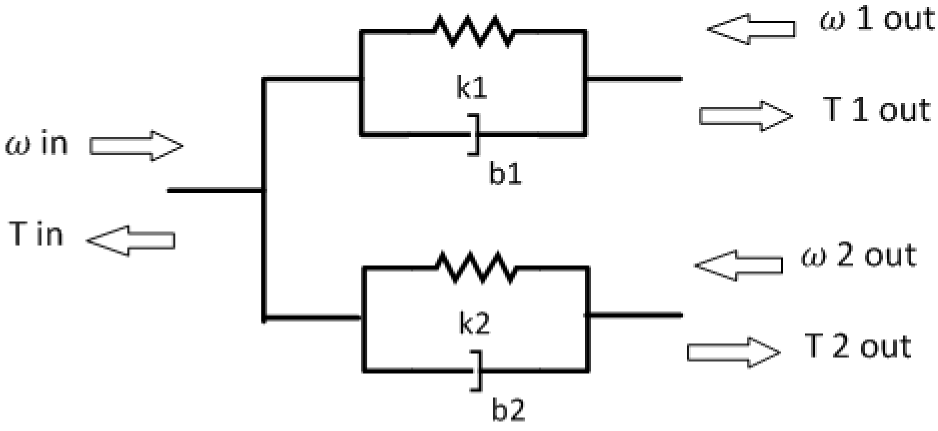
The Split Torsional Compliance block implements parallel spring-damper coupling between shafts. You can specify the type of coupling by selecting one of the **Coupling Configuration** parameters:

- `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.

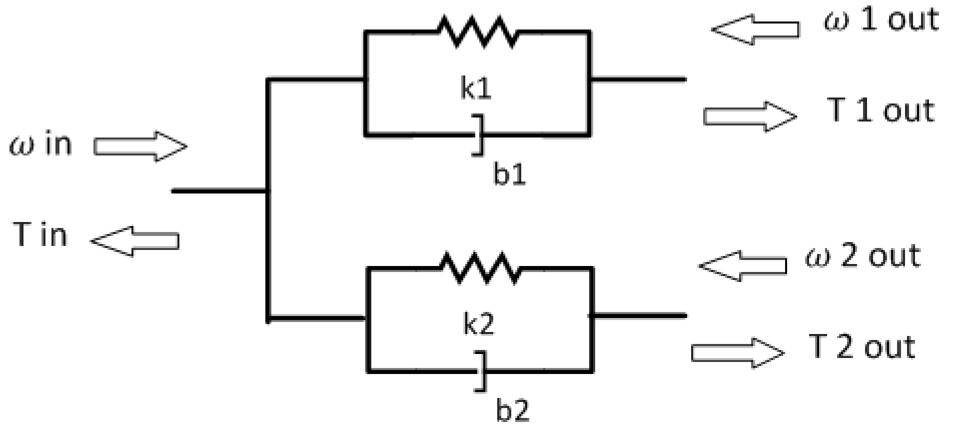
The equations use these variables.

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
b_1, b_2	First, second shaft viscous damping

k_1, k_2	First, second shaft torsional stiffness

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
b_1, b_2	First, second shaft viscous damping
k_1, k_2	First, second shaft torsional stiffness

Ports

Input

RSpd — Input shaft speed
`scalar`

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

Dependencies

To create 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 create 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 create 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 create 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 create 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 create 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 create 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 create 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 create this port, select:

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

Output

RTrq — Input shaft torque

`scalar`

Input shaft torque, T_{in}, in N·m.

Dependencies

To create 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 create 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 create 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 create 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 create 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 create 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 create 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 create 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 create 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.

Coupling 1

`Torsional stiffness, k1` — Stiffness

`scalar`

Rotational inertia, k_1, in N·m/rad.

`Torsional damping, b1` — Damping

`scalar`

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

Damping cutoff frequency, omega1_c — Frequency
scalar

Damping cutoff frequency, in rad/s.

Coupling 2

Torsional stiffness, k2 — Stiffness
scalar

Rotational inertia, k_2, in N·m/rad.

Torsional damping, b2 — Damping
scalar

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

Damping cutoff frequency, omega2_c — Frequency
scalar

Damping cutoff frequency, in rad/s.

See Also

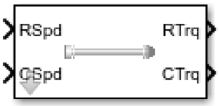
Rotational Inertia | Torsional Compliance

Introduced in R2017b

Torsional Compliance

Parallel spring-damper

Library: Drivetrain / Couplings



Description

The Torsional Compliance block implements a parallel spring-damper.

Ports

Input

RSpd — Input angular velocity
`scalar`

Input angular velocity, in rad/s.

Dependencies

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

CSpd — Load torque angular velocity
`scalar`

Input angular velocity due to load torque, in rad/s.

Dependencies

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

Output

`RTrq` — Input torque
`scalar`

Applied input drive shaft torque, in N·m.

Dependencies

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

`CTrq` — Load torque
`scalar`

Load drive shaft torque, in N·m.

Dependencies

To create 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 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:

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

Specifying `Two-way connection` creates these ports:

- `R`
- `C`

`Torsional stiffness, k` — Inertia
`scalar`

Torsional stiffness, in N·m/rad.

`Torsional damping, b` — Damping
`scalar`

Torsional damping, in N·m· s/rad.

`Initial deflection, theta_o` — Angular
`scalar`

Initial deflection, in rad.

`Initial velocity difference, domega_o` — Angular
`scalar`

Initial velocity difference, in rad/s.

`Damping cut-off frequency, omega_c` — Frequency
`scalar`

Damping cut-off frequency, in rad/s.

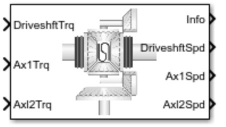
See Also

Rotational Inertia | Split Torsional Compliance

Introduced in R2017a

Limited Slip Differential

Limited differential as a planetary bevel gear
Library: Drivetrain / Final Drive Unit



Description

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

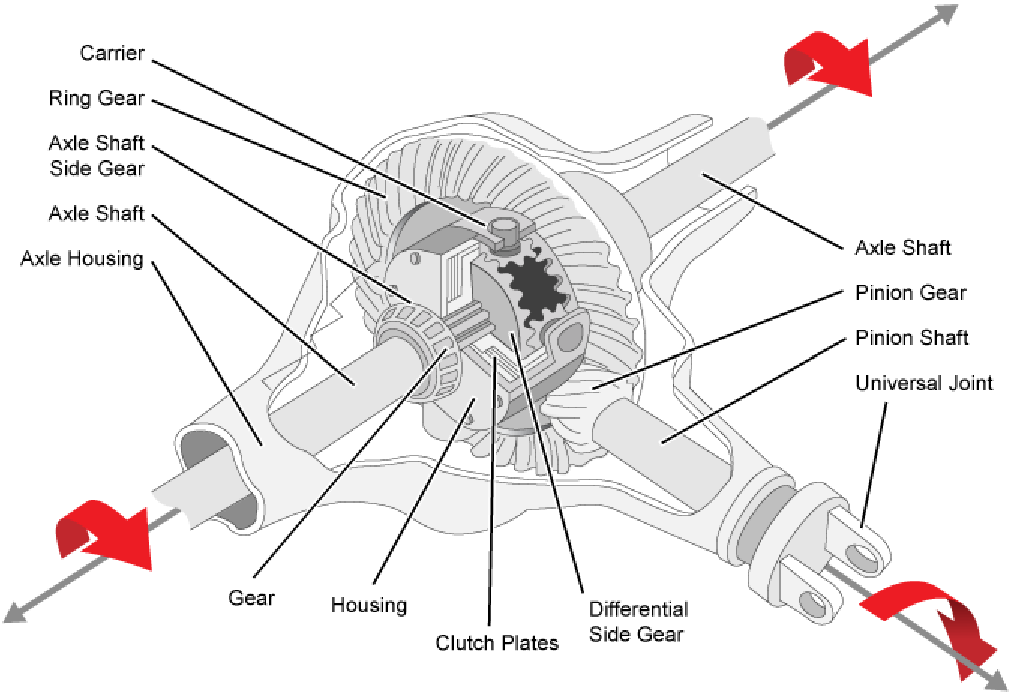
- Carrier-to-drive shaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier
- Type of slip coupling

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.



Equations

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	$\dot{\omega}_d J_d = T_d - \omega_d b_d - T_i$
Left Axle	$\dot{\omega}_1 J_1 = T_1 - \omega_1 b_1 - T_{i1}$
Right Axle	$\dot{\omega}_2 J_2 = T_2 - \omega_2 b_2 - T_{i2}$

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

$$T_1 = T_2 = \frac{N}{2} T_i + T_c$$

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

The equations use these variables.

N	Carrier-to-drive shaft 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
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 Limited Slip Differential have these parameter settings:

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

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.

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

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

$$R_{eff} = \frac{2(R_o{}^3 - R_i{}^3)}{3(R_o{}^2 - R_i{}^2)}$$

The angular velocities of the axles determine the slip speed.

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

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.

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

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.

$$T_1 = T_2 = \frac{N}{2}T_i$$

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

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.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal		Description	Units
`Driveshft`	`DriveshftTrq`	Drive shaft torque	N·m
	`DriveshftSpd`	Drive shaft speed	rad/s
`Axl1`	`Axl1Trq`	Axle 1 torque	N·m

Signal		Description	Units
	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

DriveshftSpd — Angular speed
scalar

Drive shaft 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

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 drive shaft.

Carrier to drive shaft ratio, NC/ND — Ratio
scalar

Carrier-to-drive shaft gear ratio, N.

Carrier inertia, Jd — Inertia
scalar

Rotational inertia of the crown gear assembly, J_d, in kg*m^2. You can include the drive shaft inertia.

`Carrier damping, bd` — Damping
`scalar`

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

`Driveshaft 1 inertia, Jw1` — Inertia
`scalar`

Driveshaft 1 rotational inertia, J_1, in kg*m^2.

`Driveshaft 1 damping, bw1` — Damping
`scalar`

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

`Driveshaft 2 inertia, Jw2` — Inertia
`scalar`

Driveshaft 2 rotational inertia, J_2, in kg*m^2.

`Driveshaft 2 damping, bw2` — Damping
`scalar`

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

`Driveshaft 1 initial velocity, omegaw1o` — Angular velocity
`scalar`

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

`Driveshaft 2 initial velocity, omegaw2o` — Angular velocity
`scalar`

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

Slip Coupling

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

Specify the type of torque coupling.

`Number of disks, Ndisks` — Torque coupling
`scalar`

Number of disks.

Dependencies

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

`Effective radius, Reff` — Radius
`scalar`

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

$$R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$$

The equation uses these variables.

R_o	Annular disk outer radius
R_i	Annular disk inner radius

Dependencies

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

`Nominal preload force, Fc` — Force
`scalar`

Nominal preload force, in N.

Dependencies

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

`Friction coefficient vector, mu` — Friction
`vector`

Friction coefficient vector.

Dependencies

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

`Slip speed vector, dw` — Angular velocity
`vector`

Slip speed vector, in rad/s.

Dependencies

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

`Torque - slip speed vector, Tdw` — Torque
`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
`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
`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
`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
`scalar`

Coupling time constant, in s.

References

[1] Deur, J., Ivanović, V., Hancock, M., and Assadian, F. *Modeling and analysis of active differential dynamics*. Journal of Dynamic Systems, Measurement, and Control 132.6 (2010): 061501.

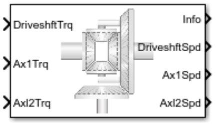
See Also

Open Differential

Introduced in R2017a

Open Differential

Differential as a planetary bevel gear
Library: Drivetrain / Final Drive Unit



Description

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

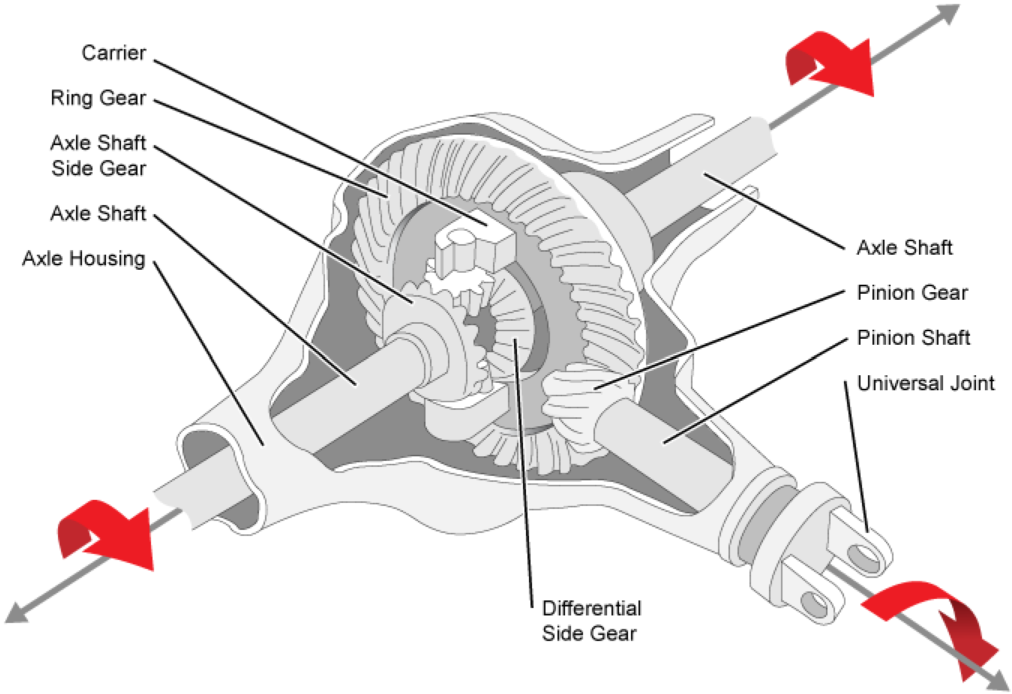
- Carrier-to-drive shaft ratio
- Crown wheel location
- Viscous and damping coefficients for the axles and carrier

Use the Open Differential block to:

- Dynamically couple the post-transmission drive shaft 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.



Equations

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	$\dot{\omega}_d J_d = T_d - \omega_d b_d - T_i$
Left Axle	$\dot{\omega}_1 J_1 = T_1 - \omega_1 b_1 - T_{i1}$
Right Axle	$\dot{\omega}_2 J_2 = T_2 - \omega_2 b_2 - T_{i2}$

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

$$T_1 = T_2 = \frac{N}{2} T_i$$

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

The equations use these variables.

N	Carrier-to-drive shaft gear ratio
J_d	Rotational inertia of the crown gear assembly
b_d	Crown gear linear viscous damping
ω_d	Drive shaft angular 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
T_d	Drive shaft torque
T_1	Axle 1 torque
T_2	Axle 2 torque
T_i	Drive shaft 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.

Output

Info — Bus signal
bus

Bus signal containing these block calculations.

Signal		Description	Units
Driveshft	DriveshftTrq	Drive shaft torque	N·m
	DriveshftSpd	Drive shaft 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

DriveshftSpd — Angular speed
scalar

Drive shaft 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

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 drive shaft.

Carrier to drive shaft ratio, Ndiff — Ratio
scalar

Carrier-to-drive shaft gear ratio, N, dimensionless.

Carrier inertia, Jd — Inertia
scalar

Rotational inertia of the crown gear assembly, J_d, in kg*m^2. You can include the drive shaft inertia.

Carrier damping, bd — Damping
scalar

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

Axle 1 inertia, Jw1 — Inertia
scalar

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

Axle 1 damping, bw1 — Damping
scalar

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

`Axle 2 inertia, Jw2` — Inertia
`scalar`

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

`Axle 2 damping, bw2` — Damping
`scalar`

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

`Axle 1 initial velocity, omegaw1o` — Angular velocity
`scalar`

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

`Axle 2 initial velocity, omegaw2o` — Angular velocity
`scalar`

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

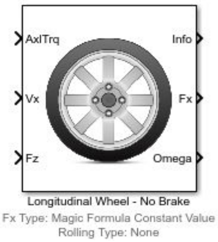
See Also

Limited Slip Differential

Introduced in R2017a

Longitudinal Wheel

Longitudinal wheel with disc, drum, or mapped brake
Library: Drivetrain / Wheels



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.

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.

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.
`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.

$$\dot{T}_d = \frac{\omega R_e}{L_e + \omega R_e}\left(F_x R_e + M_y\right)$$

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.

Setting	Block Implementation
`Pressure and velocity`	Block uses the method in *Stepwise Coastdown Methodology for Measuring Tire Rolling Resistance*. The rolling resistance is a function of tire pressure, normal force, and velocity. Specifically, $M_y = R_e\{a + b\lvert V_x\rvert + cV_x^2\}\{F_z^\beta p_i^\alpha\}\tanh(4V_x)$
`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 $T_S < \lvert T_i + T_f - \omega b\rvert$	Unlocked	$T_f = T_k$ where, $T_k = F_c R_{eff}\mu_k \tanh[4(-\omega_d)]$	$\dot{\omega}J = -\omega b + T_i + T_o$
$\omega = 0$ and $T_S \geq \lvert T_i + T_f - \omega b\rvert$	Locked	$T_s = F_c R_{eff}\mu_s$ $T_f = T_s$ $R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$	$\omega = 0$

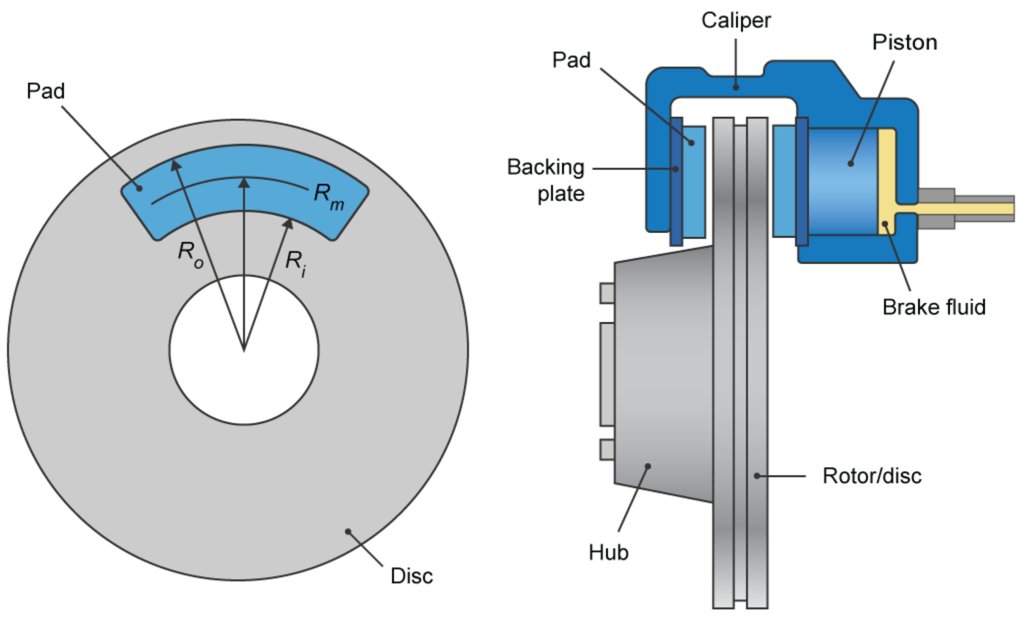
The equations use these variables.

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
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

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.

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

$$R_m = \frac{R_o + R_i}{2}$$

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

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.

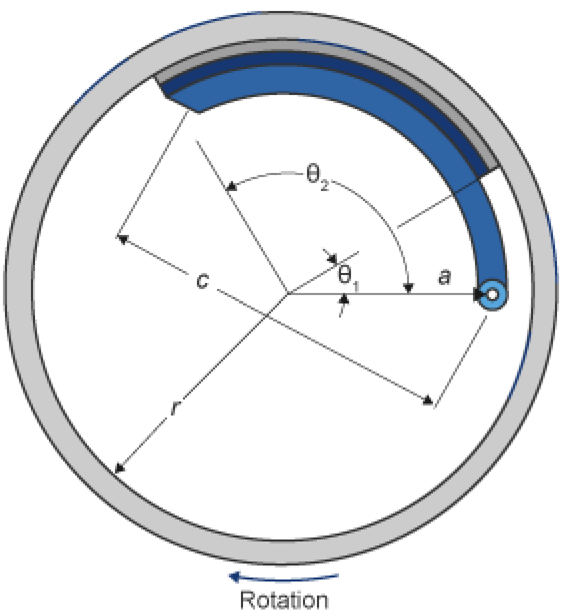
The simplex drum brake model uses the applied force and brake geometry to calculate a net torque for each brake shoe. The drum model assumes that the actuators and shoe geometry are symmetrical for both sides, allowing a single set of geometry and friction parameters to be used for both shoes.

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

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

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

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



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

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

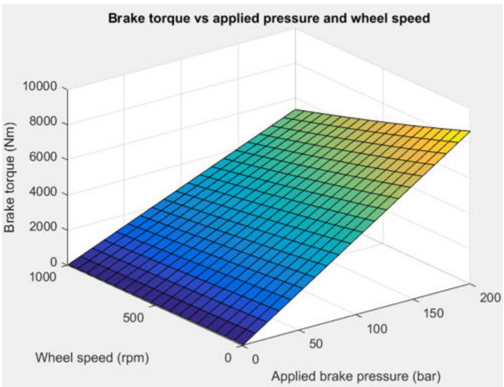
$$T = \begin{cases} f_{brake}(P,N) & \text{when } N \neq 0 \\ \left(\dfrac{\mu_{static}}{\mu}\right) f_{brake}(P,N) & \text{when } N = 0 \end{cases}$$

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.

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:

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

The slope of f at κ = 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

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:

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

where:

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

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

$$D_x = \mu_x F_z \varsigma_1$$

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

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

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

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

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

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

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.

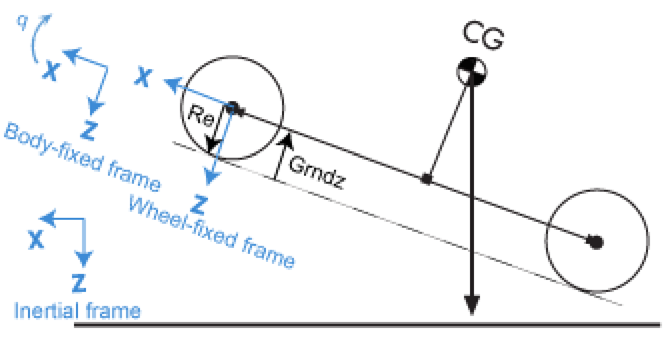
$$\ddot{z}m = Fztire - F_z - mg$$

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

Ports

Input

`BrkPrs` — Brake pressure
`scalar`

Brake pressure, in Pa.

Dependencies

To create 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`

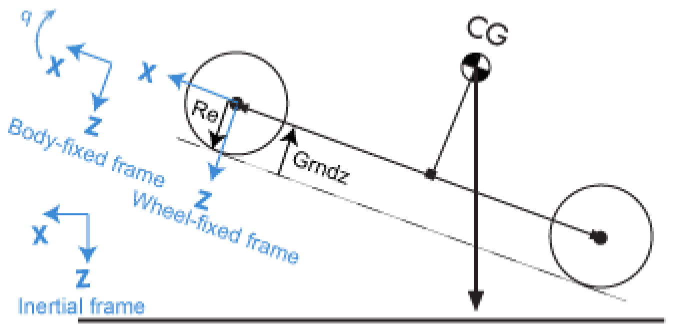
Axle longitudinal velocity along vehicle(body)-fixed *x*-axis, in m/s.

`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 create this port, select **Input friction scale factor**.

TirePrs — Tire pressure
scalar

Tire pressure, in Pa.

Dependencies

To create 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**.

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
`Fx`	Longitudinal vehicle force along body-fixed *x*-axis	N
`Fz`	Vertical vehicle force along body-fixed *z*-axis	N
`My`	Rolling resistance torque 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
`BrkTrq`	Brake torque about body-fixed *y*-axis	N·m
`BrkPrs`	Brake pressure	Pa

Signal	Description	Units
z	Wheel vertical deflection along wheel-fixed *z*-axis	m
zdot	Wheel vertical velocity along wheel-fixed *z*-axis	m/s
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

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 create 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 create 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**

Selecting	Enables These Parameters
	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** **Slip speed decay function scaling factor, lam_muV** **Longitudinal shape scaling factor, lam_Cx** **Longitudinal curvature scaling factor, lam_Ex** **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` | `Magic Formula` | `Mapped torque`

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

Setting	Block Implementation
`None`	None

Setting	Block Implementation
`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.
`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	Enables These 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	Enables These Parameters
`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.

Block Name	Brake Type Setting	Brake Implementation
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.

`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
`scalar`

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

`Wheel inertia, Iyy` — Inertia
`scalar`

Wheel inertia, in Km*m^2.

`Wheel initial angular velocity, omegao` — Wheel speed
`scalar`

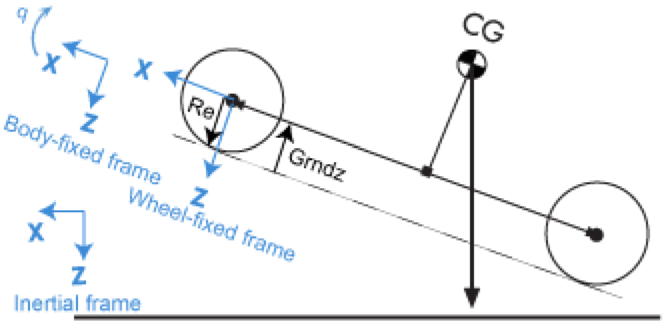
Initial angular velocity of wheel, along body-fixed *y*-axis, in rad/s.

`Relaxation length, Lrel` — Relaxation length
`scalar`

Wheel relaxation length, in m.

`Loaded radius, Re` — Loaded radius
`scalar`

Loaded wheel radius, Re, in m.



Unloaded radius, UNLOADED_RADIUS — Unloaded radius
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
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
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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
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 fuction scaling factor, lam_muV — Factor
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
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
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
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
`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
`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
`scalar`

Velocity independent force coefficient, in s/m.

Dependencies

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

`Linear velocity force component, bMy` — Force component
`scalar`

Linear velocity force component, in s/m.

Dependencies

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

`Quadratic velocity force component, cMy` — Force component
`scalar`

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

Dependencies

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

`Tire pressure exponent, alphaMy` — Pressure exponent
`scalar`

Tire pressure exponent, dimensionless.

Dependencies

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

`Normal force exponent, betaMy` — Force exponent
`scalar`

Normal force exponent, dimensionless.

Dependencies

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

Magic Formula

`Rolling resistance torque coefficient, QSY1` — Torque coefficient
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`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
`scalar`

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

`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

`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

`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
`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
`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
`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
`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
`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
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
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
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.

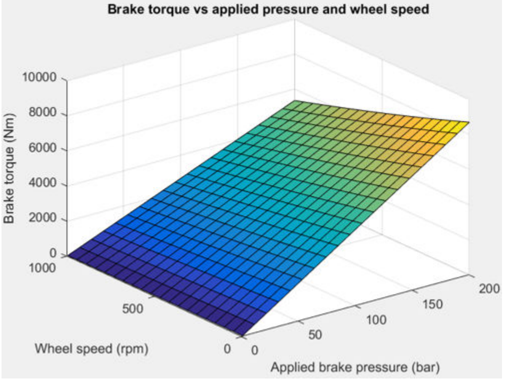
Dependencies

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
`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
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
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
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
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
scalar

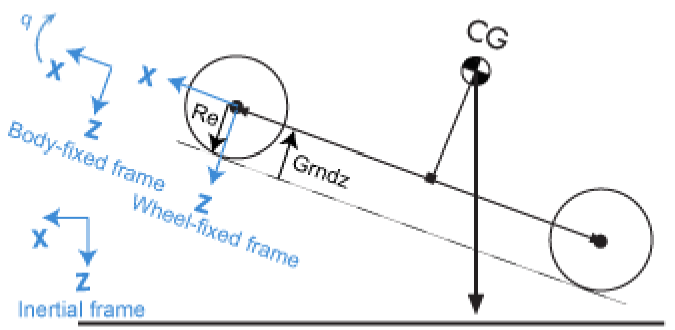
Gravitational acceleration, in m/s^2.

Dependencies

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

`Ground displacement, Gndz` — Displacement
`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
`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
`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
`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
`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
`scalar`

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
`scalar`

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

`Maximum normal force, FZMAX` — Force
`scalar`

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

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

Maximum allowable absolute slip ratio, dimensionless.

`Velocity tolerance used to handle low velocity situations, VXLOW` — Tolerance
`scalar`

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

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.

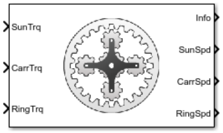
See Also

Drive Cycle Source | Longitudinal Driver

Introduced in R2017a

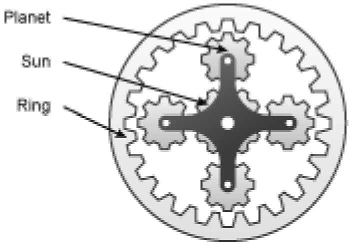
Planetary Gear

Ideal planetary gear with sun, ring, and carrier
Library: 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.

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

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
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	Variable	Units
Sun	`SunTrq`	Sun gear applied torque	T_s	N.m

Signal		Description	Variable	Units
	SunSpd	Sun gear angular speed	ω_s	rad/s
Carr	CarrTrq	Carrier gear applied torque	T_c	N.m
	CarrSpd	Carrier gear angular speed	ω_c	rad/s
Ring	RingTrq	Ring gear applied torque	T_r	N.m
	RingSpd	Ring gear angular speed	ω_r	rad/s

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
scalar

Sun-to-planet gear ratio, dimensionless.

Sun to ring ratio, Nsr — Ratio
scalar

Sun-to-ring gear ratio, dimensionless.

Sun inertia, Js — Inertia
scalar

Sun gear inertia, J_s, in kg*m^2.

Planet inertia, Jp — Inertia
scalar

Planet gear inertia, J_p, in kg*m^2.

Ring inertia, Jr — Inertia
scalar

Ring gear inertia, J_r, in kg*m^2.

Carrier inertia, Jc — Inertia
scalar

Carrier gear inertia, J_c, in kg*m^2.

Sun viscous damping, bs — Damping
scalar

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

Ring viscous damping, br — Damping
scalar

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

Planet viscous damping, bp — Damping
scalar

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

Carrier viscous damping, bc — Damping
scalar

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

Initial sun velocity, ws_o — Angular speed
scalar

Initial sun gear angular speed, in rad/s.

Initial carrier velocity, wc_o — Angular speed
scalar

Initial carrier gear angular speed, in rad/s.

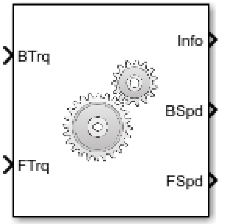
See Also

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

Introduced in R2017a

Gearbox

Ideal rotational gearbox
Library: 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.

$$\dot{\omega}_B J_B = \omega_B b_B + N T_F$$
$$\dot{\omega}_F J_F = \omega_F b_F + T_F$$

This constraint equation reduces the system to a 1 DOF system.

$$\omega_B = N \omega_F$$

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

$$N T_B + T_F = 0$$

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

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`.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal		Description	Variable	Units
Base	`BaseTrq`	Base gear input torque	T_B	N.m
	`BaseSpd`	Base gear angular velocity	ω_B	rad/s
Flwr	`FlwrTrq`	Follower gear torque	T_F	N.m
	`FlwrSpd`	Follower gear angular velocity	ω_F	rad/s

BSpd — Base gear angular velocity
`scalar`

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

Dependencies

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

FSpd — Follower gear angular velocity
`scalar`

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

Dependencies

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

F — Follower 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`

`Follower 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.

`Follower to base gear ratio, N` — Ratio

`scalar`

Base-to-follower gear ratio, dimensionless.

`Base shaft inertia, J1` — Inertia

`scalar`

Base shaft inertia, in kg*m^2.

`Follower shaft inertia, J2` — Inertia
`scalar`

Follower shaft inertia, in kg*m^2.

`Base viscous shaft damping, b1` — Damping
`scalar`

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

`Follower viscous shaft damping, b2` — Damping
`scalar`

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

`Base shaft initial velocity, w1_o` — Initial velocity
`scalar`

Base shaft initial velocity, in rad/s.

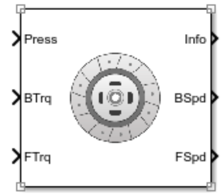
See Also

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

Introduced in R2017a

Disc Clutch

Idealized disc clutch coupler
Library: 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 $T_{fmax} < \left\| \frac{J_o T_i - (J_o b_i - J_i b_o)\omega_{i/o}}{J_o + J_i} \right\|$

Clutch Condition	When
Locked	$\omega_i = \omega_o$ and $T_{fmax} < \left\| T_i - \frac{J_i(b_i + b_o)\omega_i}{J_o + J_i} - b_o\omega_i \right\|$

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, $T_k = N_{disc} P_c A_{eff} R_{eff} \mu_k \tanh\left[4(\omega_i - \omega_o)\right]$	$\dot{\omega}_i J_i = T_i - T_f - \omega_i b_i$ $\dot{\omega}_o J_o = T_f + T_o - \omega_o b_o$
Locked	$R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$ $T_{fmax} = T_s$ where, $T_s = N_{disc} P_c A_{eff} R_{eff} \mu_s$	$\dot{\omega}_i (J_o + J_i) = T_o - \omega_i (b_i + b_o) + T_i$ $\omega_i = \omega_o$

The equations use these variables.

$R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$

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
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	Variable	Units
Base	BTrq	Applied input torque, typically from the engine crankshaft or dual mass flywheel damper	T_i	N.m
	BSpd	Applied drive shaft angular speed input	ω_i	rad/s
Flwr	FTrq	Applied load torque, typically from the differential	T_o	N.m
	FSpd	Drive shaft angular speed output	ω_o	rad/s
Cltch	CltchForce	Applied clutch force	F_c	N
	CltchLocked	Clutch lock status	NA	NA

Signal		Description	Variable	Units
	CltchSpd Ratio	Clutch speed ratio	ω_o/ω_i	NA
	CltchEta	Clutch power transmission efficiency	η	NA

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
`scalar`

Clutch force equivalent net radius, in m.

`Number of disks, Ndisk` — Ratio
`scalar`

Number of disks, dimensionless.

`Effective applied pressure area, Aeff` — Pressure area
`scalar`

Effective applied pressure area, in m^2.

`Input shaft inertia, Jin` — Inertia
`scalar`

Input shaft inertia, in kg*m^2.

`Output shaft inertia, Jout` — Inertia
`scalar`

Output shaft inertia, in kg*m^2.

`Kinetic friction coefficient, muk` — Coefficient
`scalar`

Kinetic friction coefficient, dimensionless.

`Static friction coefficient, mus` — Coefficient
`scalar`

Static friction coefficient, dimensionless.

`Input shaft viscous damping, bin` — Damping
`scalar`

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

`Output shaft viscous damping, bout` — Damping
`scalar`

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

`Initial input shaft velocity, win_o` — Initial velocity
`scalar`

Input shaft initial velocity, in rad/s.

`Initial output shaft velocity, wout_o` — Initial velocity
`scalar`

Input shaft initial velocity, in rad/s.

`Clutch actuation time constant, tauC` — Constant
`scalar`

Clutch actuation time constant, in s.

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

Select to lock clutch initially.

See Also

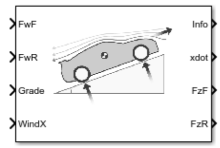
Planetary Gear | Rotational Inertia | Torque Converter | Torsional Compliance

Introduced in R2017a

Vehicle Dynamics Blocks — Alphabetical List

Vehicle Body 1DOF Longitudinal

Two-axle vehicle in forward and reverse motion
Library: Vehicle Dynamics



Description

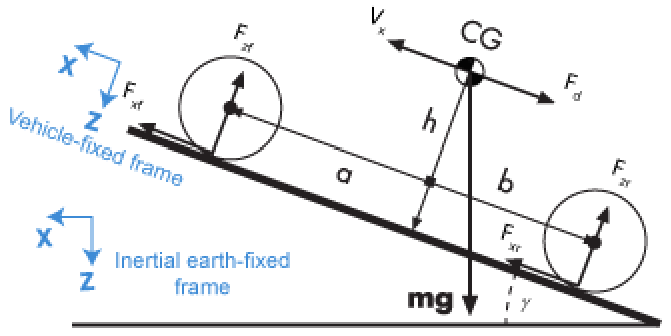
The Vehicle Body 1DOF Longitudinal block implements a one degree-of-freedom (1DOF) rigid vehicle body with constant mass undergoing longitudinal (that is, forward and reverse) motion. Use the block:

- 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.

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 CG.



The Vehicle Body 1DOF Longitudinal block implements these equations.

$$m\dot{V}_x = F_x - F_d - mg \cdot \sin\gamma$$

$$F_x = N_f F_{xf} + N_r F_{xr}$$

$$F_d = \frac{1}{2} C_d \rho A (V_x + V_w)^2 \cdot \mathrm{sgn}(V_x + V_w)$$

Zero normal acceleration and zero pitch torque determine the normal force on each front and rear wheel.

$$F_{zf} = \frac{-h(F_d + mg\sin\gamma + m\dot{V}_x) + b \cdot mg\cos\gamma}{N_f(a+b)}$$

$$F_{zr} = \frac{+h(F_d + mg\sin\gamma + m\dot{V}_x) + a \cdot mg\cos\gamma}{N_r(a+b)}$$

The wheel normal forces satisfy this equation.

$$N_f F_{zf} + N_r F_{zr} = mg\cos\gamma$$

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_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.
V_w	Wind speed. When $V_w > 0$, the wind is headwind. When $V_w < 0$, the wind is tailwind.
N_f, N_r	Number of wheels on front and rear axle, respectively
γ	Angle of road grade, in degrees
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	Frontal area
ρ	Mass density of air
g	Gravitational acceleration

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

`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, V_w, along vehicle-fixed `x`-axis, in m/s.

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

Signal				Description	Value	Units
			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 earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed (input - grade angle)	rad
			psi	Rotation of vehicle-fixed frame about 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

Signal				Description	Value	Units
			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
			Zdot	Rear axle velocity along the earth-fixed Z-axis	Computed	m/s
BdyFrm	Cg	Disp	x	Vehicle CG displacement along vehicle-fixed x-axis	Computed	m
			y	Vehicle CG displacement along vehicle-fixed y-axis	0	m
			z	Vehicle CG displacement along vehicle-fixed z-axis	0	m
		Vel	xdot	Vehicle CG velocity along vehicle-fixed x-axis	Computed	m/s
			ydot	Vehicle CG velocity along vehicle-fixed y-axis	0	m/s

Signal				Description	Value	Units
			zdot	Vehicle CG velocity along 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 vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CG acceleration along vehicle-fixed y-axis	0	gn
			az	Vehicle CG acceleration along vehicle-fixed z-axis	0	gn
	Forces	Body	Fx	Net force on vehicle CG along vehicle-fixed x-axis	0	N
			Fy	Net force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Net force on vehicle CG along vehicle-fixed z-axis	0	N
		Ext	Fx	External force on vehicle CG along vehicle-fixed x-axis	0	N

Signal					Description	Value	Units
			Fy		External force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz		External force on vehicle CG along vehicle-fixed z-axis	0	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 vehicle-fixed x-axis	0	N
				Fy	Front tire force, along vehicle-fixed y-axis	0	N
				Fz	Front tire force, along vehicle-fixed z-axis	Computed	N
			RearTire	Fx	Rear tire force, along vehicle-fixed x-axis	0	N

Signal					Description	Value	Units
				Fy	Rear tire force, along vehicle-fixed y-axis	0	N
				Fz	Rear tire force, along vehicle-fixed z-axis	Computed	N
		Drag	Fx		Drag force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy		Drag force on vehicle CG along vehicle-fixed y-axis	Computed	N
			Fz		Drag force on vehicle CG along vehicle-fixed z-axis	Computed	N
		Grvty	Fx		Gravity force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy		Gravity force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz		Gravity force on vehicle CG along vehicle-fixed z-axis	Computed	N
	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

Signal				Description	Value	Units
			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
	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
	Pwr	PwrExt		Applied external power	Computed	W
		Drag		Power loss due to drag	Computed	W

xdot — Vehicle body longitudinal velocity
scalar

Vehicle body longitudinal velocity along the earth-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 vehicle-fixed z-axis, in N.

Parameters

Longitudinal

`Number of wheels on front axle, NF` — Front wheel count
`scalar`

Number of wheels on front axle, N_F, dimensionless.

`Number of wheels on rear axle, NR` — Rear wheel count
`scalar`

Number of wheels on rear axle, N_R, dimensionless.

`Mass, m` — Vehicle mass
`scalar`

Vehicle mass, M, in kg.

`Horizontal distance from CG to front axle, a` — Front axle distance
`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
`scalar`

Horizontal distance b from the vehicle CG to the rear wheel axle, in m.

`CG height above axles, h` — Height
`scalar`

Height of vehicle CG above the ground, h, in m.

`Drag coefficient, Cd` — Drag
`scalar`

Air drag coefficient, C_d.

Frontal area, Af — Area
scalar

Effective vehicle cross-sectional area, A, to calculate the aerodynamic drag force on the vehicle, in m^2.

Initial position, x_o — Position
scalar

Vehicle body longitudinal initial position along the vehicle-fixed x-axis, x_o, in m.

Initial velocity, xdot_o — Velocity
scalar

Vehicle body longitudinal initial velocity along the vehicle-fixed x-axis, $\dot{x}_0$, in m/s.

Environment

Absolute Pressure, Pabs — Pressure
scalar

Environmental absolute pressure, P, in Pa.

Air Temp, T — Temperature
scalar

Environmental absolute temperature, T, in K.

Gravitational acceleration, g — Gravity
scalar

Gravitational acceleration, g, in m/s^.

See Also

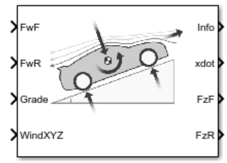
Vehicle Body 3DOF Longitudinal | Vehicle Body Total Road Load

Introduced in R2017a

Vehicle Body 3DOF Longitudinal

3DOF rigid vehicle body to calculate longitudinal, vertical, and pitch motion

Library: Vehicle Dynamics



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.

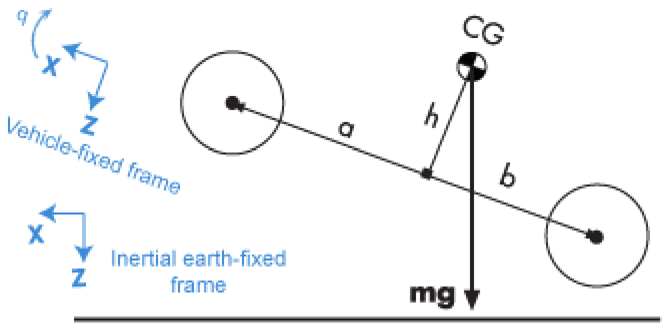
You can specify the type of axle attachment to the vehicle:

- 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:

$$F_x = F_{wF} + F_{wR} - F_{d,x} - F_{sx,F} - F_{sx,R} + F_{g,x}$$
$$F_z = F_{d,z} - F_{sz,F} - F_{sz,R} + F_{g,z}$$
$$M_y = aF_{sz,F} - bF_{sz,R} + h\left(F_{wF} + F_{wR} + F_{sx,F} + F_{sx,R}\right) - M_{d,y}$$



The equations use these variables.

F_x	Longitudinal force on vehicle
F_z	Normal force on vehicle
M_y	Torque on vehicle about 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 vehicle-fixed frame
$M_{d,y}$	Torque due to drag on vehicle about 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 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 vehicle-fixed x-axis
$z, \dot{z}, \ddot{z}$	Vehicle normal position, velocity, and acceleration along 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 vehicle-fixed x-axis
C_l	Lateral air drag coefficient acting along vehicle-fixedz-axis
C_{pm}	Air drag pitch moment acting about vehicle-fixed y-axis
A_f	Frontal area
P_{abs}	Environmental absolute pressure
R	Atmospheric specific gas constant
T	Environmental air temperature
w	Wind speed along vehicle-fixed axis

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:

$$Fs_F = N_F\left[Fk_F + Fb_F\right]$$

$$Fs_R = N_R\left[Fk_R + Fb_R\right]$$

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.

$$dZ_F = Z_F - \overline{Z}_F$$
$$dZ_R = Z_R - \overline{Z}_R$$
$$d\dot{Z}_F = \dot{Z}_F - \dot{\overline{Z}}_F$$
$$d\dot{Z}_R = \dot{Z}_R - \dot{\overline{Z}}_R$$

When the **Ground interaction type** parameter is `Grade angle`, the axle vertical positions ($\overline{Z}_F, \overline{Z}_R$) and velocities ($\dot{\overline{Z}}_F, \dot{\overline{Z}}_R$) 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:

$$F_{d,x} = \frac{1}{2TR} C_d A_f P_{abs} (\dot{x} - w)^2$$
$$F_{d,z} = \frac{1}{2TR} C_l A_f P_{abs} (\dot{x} - w)^2$$
$$M_{d,y} = \frac{1}{2TR} C_{pm} A_f P_{abs} (\dot{x} - w)^2 (a + b)$$

Ports

Input

`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 vehicle-fixed `z`-axis, in N.

Dependencies

To create 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 vehicle-fixed `z`-axis, in N.

Dependencies

To create this port, for the **Ground interaction type** parameter, select `External suspension`.

`WindXYZ` — Wind speed
`vector`

Longitudinal wind speed, $V_{windxyz}$, in m/s.

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 create 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 create 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

Signal				Description	Value	Units
			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 earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about 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

Signal				Description	Value	Units
	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
			Zdot	Rear axle velocity along the earth-fixed Z-axis	Computed	m/s
BdyFrm	Cg	Disp	x	Vehicle CG displacement along vehicle-fixed x-axis	Computed	m
			y	Vehicle CG displacement along vehicle-fixed y-axis	0	m
			z	Vehicle CG displacement along vehicle-fixed z-axis	Computed	m
		Vel	xdot	Vehicle CG velocity along vehicle-fixed x-axis	Computed	m/s
			ydot	Vehicle CG velocity along vehicle-fixed y-axis	0	m/s
			zdot	Vehicle CG velocity along vehicle-fixed z-axis	Computed	m/s

Signal				Description	Value	Units
		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 vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CG acceleration along vehicle-fixed y-axis	0	gn
			az	Vehicle CG acceleration along vehicle-fixed z-axis	Computed	gn
	Forces	Body	Fx	Net force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Net force on vehicle CG along vehicle-fixed z-axis	Computed	N
		Ext	Fx	External force on vehicle CG along vehicle-fixed x-axis	0	N
			Fy	External force on vehicle CG along vehicle-fixed y-axis	0	N

Signal					Description	Value	Units
			Fz		External force on vehicle CG along vehicle-fixed z-axis	0	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 vehicle-fixed x-axis	0	N
				Fy	Front tire force, along vehicle-fixed y-axis	0	N
				Fz	Front tire force, along vehicle-fixed z-axis	Computed	N
			RearTire	Fx	Rear tire force, along vehicle-fixed x-axis	0	N
				Fy	Rear tire force, along vehicle-fixed y-axis	0	N
				Fz	Rear tire force, along vehicle-fixed z-axis	Computed	N

Signal				Description	Value	Units
		Drag	Fx	Drag force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Drag force on vehicle CG along vehicle-fixed y-axis	Computed	N
			Fz	Drag force on vehicle CG along vehicle-fixed z-axis	Computed	N
		Grvty	Fx	Gravity force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Gravity force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Gravity force on vehicle CG along vehicle-fixed z-axis	Computed	N
	Moments	Body	Mx	Body moment on vehicle CG about vehicle-fixed x-axis	0	N·m
			My	Body moment on vehicle CG about vehicle-fixed y-axis	Computed	N·m
			Mz	Body moment on vehicle CG about vehicle-fixed z-axis	0	N·m
		Drag	Mx	Drag moment on vehicle CG about vehicle-fixed x-axis	0	N·m
			My	Drag moment on vehicle CG about vehicle-fixed y-axis	Computed	N·m

Signal				Description	Value	Units
			Mz	Drag moment on vehicle CG about vehicle-fixed z-axis	0	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
	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

Signal			Description	Value	Units
	Pwr	PwrExt	Applied external power	Compute d	W
		Drag	Power loss due to drag	Compute d	W

xdot — Vehicle longitudinal velocity
scalar

Vehicle CG velocity along vehicle-fixed x-axis, in m/s.

FzF — Front axle normal force
scalar

Normal force on front axle, Fz_F, along vehicle-fixed z-axis, in N.

FzR — Rear axle normal force
scalar

Normal force on rear axle, Fz_R, along vehicle-fixed z-axis, in N.

Parameters

Longitudinal

Number of wheels on front axle, NF — Front wheel count
scalar

Number of wheels on front axle, N_F, dimensionless.

Number of wheels on rear axle, NR — Rear wheel count
scalar

Number of wheels on rear axle, N_R, dimensionless.

Mass, m — Vehicle mass
scalar

Vehicle mass, m, in kg.

Horizontal distance from CG to front axle, a — Front axle distance
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
scalar

Horizontal distance b from the vehicle CG to the rear wheel axle, in m.

CG height above axles, h — Height
scalar

Height of vehicle CG above the axles, h, in m.

Drag coefficient, Cd — Drag
scalar

Air drag coefficient, C_d, dimensionless.

Frontal area, Af — Area
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
scalar

Vehicle body longitudinal initial position along earth-fixed x-axis, x_o, in m.

Initial velocity, xdot_o — Velocity
scalar

Vehicle body longitudinal initial velocity along earth-fixed x-axis, $\dot{x}_0$, in m/s.

Vertical

Lift coefficient, Cl — Lift
scalar

Lift coefficient, C_l, dimensionless.

`Initial vertical position, z_o` — Position
`scalar`

Initial vertical CG position, z_o, along the vehicle-fixed `z`-axis, in m.

`Initial vertical velocity, zdot_o` — Velocity
`scalar`

Initial vertical CG velocity, $zdot_o$, along the vehicle-fixed `z`-axis, in m.

Pitch

`Inertia, Iyy` — About body y-axis
`scalar`

Vehicle body moment of inertia about body `z`-axis.

`Pitch drag moment coefficient, Cpm` — Drag coefficient
`scalar`

Pitch drag moment coefficient, dimensionless.

`Initial pitch angle, theta_o` — Pitch
`scalar`

Initial pitch angle about body `z`-axis, in rad.

`Initial angular velocity, q_o` — Pitch velocity
`scalar`

Initial vehicle body angular velocity about body `z`-axis, in rad/s.

Suspension

`Front axle stiffness force data, FskF` — Force
`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
`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
`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
`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
`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
`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

`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

`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 Pressure, Pabs` — Pressure

`scalar`

Environmental absolute pressure, P_{abs}, in Pa.

`Air Temp, T` — Temperature

`scalar`

Environmental absolute temperature, T, in K.

`Gravitational acceleration, g` — Gravity

`scalar`

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.

See Also

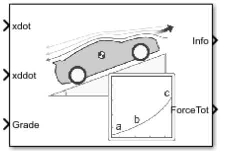
Vehicle Body 1DOF Longitudinal | Vehicle Body Total Road Load

Introduced in R2017a

Vehicle Body Total Road Load

Vehicle motion using coast-down testing coefficients

Library: Vehicle Dynamics



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.

Equations

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.

$$P_{total} = F_{total}\dot{x}$$
$$P_{road} = F_{road}\dot{x}$$

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 vehicle-fixed frame
$\dot{x}$	Vehicle longitudinal velocity with respect to ground, in 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

Ports

Input

`xdot` — Vehicle longitudinal velocity
`scalar`

Vehicle total longitudinal velocity, $\dot{x}$, in m/s.

Dependencies

To create 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 create this port, for the **Input Mode** parameter, select `Kinematic`.

`PwrTot` — Tractive input power
`scalar`

Tractive input power, P_{total}, in W.

Dependencies

To create this port, for the **Input Mode** parameter, select `Power`.

`ForceTot` — Tractive input force
`scalar`

Tractive input force, F_{total}, in N.

Dependencies

To create 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
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 earth-fixed X-axis (roll)	0	rad
			theta	Rotation of vehicle-fixed frame about earth-fixed Y-axis (pitch)	Computed	rad
			psi	Rotation of vehicle-fixed frame about earth-fixed Z-axis (yaw)	0	rad
BdyFrm	Cg	Disp	x	Vehicle CG displacement along vehicle-fixed x-axis	Computed	m
			y	Vehicle CG displacement along vehicle-fixed y-axis	0	m
			z	Vehicle CG displacement along vehicle-fixed z-axis	0	m

Signal				Description	Value	Units
		Vel	xdot	Vehicle CG velocity along vehicle-fixed x-axis	Computed	m/s
			ydot	Vehicle CG velocity along vehicle-fixed y-axis	0	m/s
			zdot	Vehicle CG velocity along vehicle-fixed z-axis	0	m/s
		Accel	ax	Vehicle CG acceleration along vehicle-fixed x-axis	Computed	gn
			ay	Vehicle CG acceleration along vehicle-fixed y-axis	0	gn
			az	Vehicle CG acceleration along vehicle-fixed z-axis	0	gn
	Forces	Body	Fx	Net force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Net force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Net force on vehicle CG along vehicle-fixed z-axis	0	N
		Ext	Fx	External force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	External force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	External force on vehicle CG along vehicle-fixed z-axis	0	N
		Drag	Fx	Drag force on vehicle CG along vehicle-fixed x-axis	Computed	N
			Fy	Drag force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Drag force on vehicle CG along vehicle-fixed z-axis	0	N
		Grvty	Fx	Gravity force on vehicle CG along vehicle-fixed x-axis	Computed	N

Signal				Description	Value	Units
			Fy	Gravity force on vehicle CG along vehicle-fixed y-axis	0	N
			Fz	Gravity force on vehicle CG along vehicle-fixed z-axis	Computed	N
	Pwr	PwrExt		Applied external power	Computed	W
		Drag		Power loss due to drag	Computed	W

xdot — Vehicle longitudinal velocity
scalar

Vehicle total longitudinal velocity, $\dot{x}$, in m/s.

Dependencies

To create 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 create 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
`scalar`

Vehicle body mass, *m*, in kg.

`Rolling resistance coefficient, a` — Rolling
`scalar`

Steady-state rolling resistance coefficient, *a*, in N.

`Rolling and driveline resistance coefficient, b` — Rolling and driveline
`scalar`

Viscous driveline and rolling resistance coefficient, *b*, in N*s/m.

`Aerodynamic drag coefficient, c` — Drag
`scalar`

Aerodynamic drag coefficient, *c*, in N*s^2/m.

`Gravitational acceleration, g` — Gravity
`scalar`

Gravitational acceleration, *g*, in m/s^2.

`Initial velocity, xdot_o` — Velocity
`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.

See Also

Drive Cycle Source | Vehicle Body 1DOF Longitudinal | Vehicle Body 3DOF Longitudinal

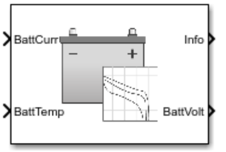
Introduced in R2017a

Energy Storage Blocks — Alphabetical List

Datasheet Battery

Lithium-ion, lithium-polymer, or lead-acid battery

Library: 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.

$$V_T = E_m - I_{batt}R_{int}$$
$$I_{batt} = \frac{I_{in}}{N_p}$$
$$V_{out} = N_s V_T$$
$$SOC = \frac{-1}{Cap_{batt}}\int_0^t I_{batt}dt$$

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_{int}	Battery internal resistance
N_s	Number of cells in series
N_p	Number of cells in parallel
V_{out}	Combined voltage of the battery network
V_T	Per module battery voltage
Cap_{batt}	Battery capacity

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	Units
BattCurr	Combined current flowing from the battery network	A
BattAmpHr	Normalized current flowing from the battery network	A*h
BattSoc	State-of-charge capacity	NA
BattVolt	Combined voltage of the battery network	V
BattPwr	Battery power	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

Block Parameter Initial battery capacity Option	Creates
`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
`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
1-by-N matrix

Battery temperature breakpoints for N temperatures, in K.

Battery capacity breakpoints 2, CapSOCBp — Breakpoints
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
scalar

Number of cells in series, dimensionless, N_s.

Number of cells in parallel, Np — Integer
scalar

Number of cells in parallel, dimensionless, N_p.

Initial battery capacity, BattCapInit — Capacity
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
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
`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 Einflusß 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.

See Also

Equivalent Circuit Battery | Estimation Equivalent Circuit Battery

Topics

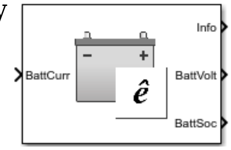
“Generate Parameter Data for Datasheet Battery Block”
Battery Modeling

Introduced in R2017a

Estimation Equivalent Circuit Battery

Resistor-capacitor (RC) circuit battery that creates lookup tables

Library: 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.

$$V_T = E_m - I_{batt} R_o - \sum_1^n V_n$$

$$V_n = \int_0^t \left[\frac{I_{batt}}{C_n} - \frac{V_n}{R_n C_n} \right] dt$$

$$SOC = \frac{-1}{C_{batt}} \int_0^t I_{batt} dt$$

$$I_{batt} = I_{in}$$

$$V_{out} = V_T$$

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
array

Open-circuit voltage table, E_m, in V. Function of SOC.

Series resistance table data, R0 — Resistance
array

Series resistance table, R_o, in ohms. Function of SOC.

`State of charge breakpoints, SOC_BP` — SOC breakpoints
`vector`

State-of-charge (SOC) breakpoints, dimensionless.

`Battery capacity, BattCap` — Capacity
`scalar`

Battery capacity, C_{batt}, in Ah.

`Initial battery capacity, BattCapInit` — Capacity
`scalar`

Initial battery capacity, C_{batto}, in Ah.

`Initial capacitor voltage, InitialCapVoltage` — Voltage
`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, Rn` — Lookup table
`array`

Network resistance table data for *n*-th RC pair, as a function of SOC, in ohms.

`Network capacitance table data, Cn` — Lookup table
`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
`scalar`

Upper voltage limit, in V.

`Lower Integrator Voltage Limit, Vl` — Minimum
`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.

See Also

Datasheet Battery | Equivalent Circuit Battery

Topics

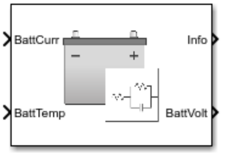
“Generate Parameter Data for Equivalent Circuit Battery Block”
Battery Modeling

Introduced in R2017a

Equivalent Circuit Battery

Resistor-capacitor (RC) circuit battery

Library: 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.

$$V_T = E_m - I_{batt} R_o - \sum_1^n V_n$$

$$V_n = \int_0^t \left[\frac{I_{batt}}{C_n} - \frac{V_n}{R_n C_n} \right] dt$$

$$SOC = \frac{-1}{C_{batt}} \int_0^t I_{batt} dt$$

$$I_{batt} = \frac{I_{in}}{N_p}$$

$$V_{out} = N_s V_T$$

Positive current indicates battery discharge. Negative current indicates battery charge.

To calculate the battery power, the block uses this equation.

$$P_{batt} = I_{batt}{}^2 R_0 + \sum_1^n \frac{V_n{}^2}{R_n}$$

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}	Resistive battery power loss
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	Units
`BattCurr`	Combined current flowing from the battery network	A
`BattSoc`	State-of-charge capacity	NA

Signal	Description	Units
`BattVolt`	Combined voltage of the battery network	V
`BattPwr`	Battery power	W
`BattPwrLoss`	Battery power loss	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
`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
`vector`

State-of-charge (SOC) breakpoints, dimensionless.

`Temperature breakpoints, Temperature_BP` — Battery
`vector`

Battery temperature breakpoints, K.

`Battery capacity table, BattCap` — Capacity
`array`

Battery capacity, C_{batt}, in Ah. Function of battery temperature.

`Initial capacitor voltage, InitialCapVoltage` — Voltage
`vector`

Initial capacitor voltage, in V. Dimension of vector must equal the **Number of series RC pairs**.

`Initial battery capacity, BattCapInit` — Capacity
`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
`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
`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
`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
`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
`scalar`

Upper voltage limit, in V.

`Lower integrator voltage limit, Vl` — Minimum
`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.

See Also

Datasheet Battery | Estimation Equivalent Circuit Battery

Topics

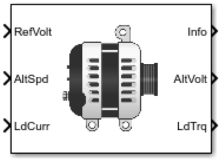
"Generate Parameter Data for Equivalent Circuit Battery Block"
Battery Modeling

Introduced in R2017a

Reduced Lundell Alternator

Reduced Lundell (claw-pole) alternator with an external voltage regulator

Library: 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.

Equations

The Reduced Lundell Alternator block implements equations for the electrical, control, and mechanical systems that 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}	Motor shaft torque

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	$v_f = R_f i_f + L_f \frac{di_f}{dt}$

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	$I_f(s) = \frac{V_f(s)}{(R_f + sL_f)}$
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	$T(s) = \frac{1}{\tau s + 1} \rightarrow G(s)Gc(s) = \frac{1}{\tau s}$ $G_C(s) = K_g\ (K_p + \frac{K_i}{s})$ $G(s)G_C(s) = \frac{K_v \omega}{(R_f + sL_f)} K_g\ (K_p + \frac{K_i}{s})$ $K_p = L_f\ , K_i = R_f\ , and\ K_g = \frac{2\pi f}{K_v \omega}$

To calculate torques, the block uses these equations.

Calculation	Equations
Electrical torque	$\tau_{elec} = (K_v i_f \omega) i_{load}$

Calculation	Equations
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	$\tau_{mech} = \tau_{elec} + \tau_{friction} + \tau_{windage} + \tau_{start}$

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.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Units
FldVolt	Field winding voltage	A
FldFlux	Field flux	Wb

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
scalar

Voltage constant, in V/rad/s.

Field winding resistance, Rf — Resistance
scalar

Field winding resistance, in ohm.

Field winding inductance, Lf — Inductance
scalar

Field winding inductance, in H.

Stator winding resistance, Rs — Resistance
scalar

Stator winding resistance, in ohm.

Diode voltage drop, Vd — Voltage
scalar

Diode voltage drop, in V.

Voltage Regulator

`Regulator bandwidth, Fv` — Bandwidth
`scalar`

The regulator bandwidth, in Hz.

`Current filter bandwidth, Fc` — Bandwidth
`scalar`

The current filter bandwidth, in Hz.

`Field voltage max, Vfmax` — Maximum field voltage
`scalar`

The maximum field voltage, in V.

`Field voltage min, Vfmin` — Minimum field voltage
scalar

The minimum field voltage, in V.

Mechanical Losses

`Coulomb friction, Kc` — Friction
`scalar`

Coulomb friction, in N.m.

`Viscous friction, Kb` — Friction
`scalar`

Viscous friction, in N.m/rad/s.

`Windage, Kw` — Windage
`scalar`

Windage, in N.m/rad^2/s^2.

References

[1] Krause, P. C. *Analysis of Electric Machinery*. New York: McGraw-Hill, 1994.

See Also

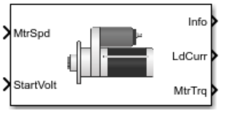
Starter

Introduced in R2017a

Starter

Starter as a DC motor

Library: 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.

Equations

The block implements equations that 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

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:

$$V_a = L_a \frac{di_a}{dt} + R_a i_a + EMF$$

The starter motor current load is the sum of the field winding current and armature winding current:

$$i_{load} = i_f + i_a$$

The starter motor shaft torque is the product of the armature current, field current, and mutual inductance:

$$T_{mech} = i_a i_f L_{af}$$

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:

$$T_{mech} = K_t i_a$$

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:

$$\omega > -\frac{R_{ser}}{L_{af}}$$

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

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**

Motor Type	Enables Motor Parameter
	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
`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
`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
`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
`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
`scalar`

Mutual inductance, in H.

Dependencies

To enable this parameter, select `Separately Excited DC Motor` for the **Motor Type** parameter.

`Initial armature and field current, Iaf` — Current
`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
`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
`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
`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
`scalar`

Initial armature current, in A.

Dependencies

To enable this parameter, select `Permanent Magnet Excited DC Motor` for the **Motor Type** parameter.

Series Excited DC Motor

`Total resistance, Rser` — Resistance
`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
`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

`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

`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.

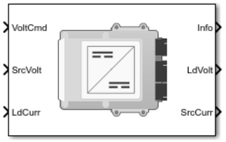
See Also

Reduced Lundell Alternator

Introduced in R2017a

Bidirectional DC-DC

DC-to-DC converter that supports bidirectional boost and buck
Library: 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.

Parameter Option	Description
`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.
`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	$Pwr_{Loss} = \frac{100 - Eff}{Eff} \cdot \left\| Ld_{Volt} \cdot Ld_{Amp} \right\|$
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	$Src_{Pwr} = Src_{Amp} \cdot Src_{Volt}$

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

`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
`scalar`

Converter response time, τ, in s.

`Converter response initial voltage, Vinit` — Voltage
`scalar`

Initial load voltage of the DC-to-DC converter, V_{init}, in V.

Converter power limit, Plimit — Power
`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 dataTabulated 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
`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
1-by-M matrix

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
1-by-N matrix

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
1-by-M matrix

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
1-by-N matrix

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 Mload voltages, in %.

Dependencies

To enable this parameter, for **Parameterize losses by**, select `Tabulated efficiency data`.

See Also

Equivalent Circuit Battery | Estimation Equivalent Circuit Battery

Topics

Battery Modeling

Introduced in R2017b

Propulsion Blocks — Alphabetical List

Boost Drive Shaft

Boost drive shaft speed

Library: 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	$\frac{d\omega}{dt} = \frac{1}{J_{shaft}}\left(\eta_{mech}\tau_{turb} + \tau_{comp} + \tau_{ext}\right)$ with initial speed ω_0
Speed constraint	$\omega_{min} \leq \omega \leq \omega_{max}$
Power loss	$\dot{W}_{loss} = \omega\tau_{turb}\left(1 - \eta_{mech}\right)$

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	Variable	Units
`DriveshftSpd`	Shaft speed	ω	rad/s
`MechPwrLoss`	Mechanical power loss	$\dot{W}_{loss}$	W
`ExtTrq`	Applied external torque	τ_{ext}	N.m

`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 input`

Dependencies

- To enable this parameter, select a `Turbocharger` configuration.
- To create the `Trq` port, select `External torque input`.

`Shaft inertia, J_shaft` — Inertia
`scalar`

Shaft inertia, J_{shaft}, in kg*m^2.

`Initial shaft speed, w_0` — Speed
`scalar`

Initial drive shaft speed, ω_0, in rad/s.

Min shaft speed, w_min — Speed
scalar

Minimum drive shaft speed, ω_{min}, in rad/s.

Max shaft speed, w_max — Speed
scalar

Maximum drive shaft speed, ω_{max}, in rad/s.

Turbine mechanical efficiency, eta_mech — Efficiency
scalar

Mechanical efficiency of turbine η_{max}.

Dependencies

To enable this parameter, select the Turbocharger or Turbine only configuration.

See Also

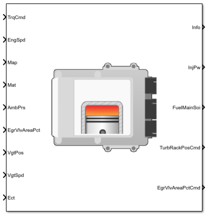
Compressor | Turbine

Introduced in R2017a

CI Controller

Compression-ignition controller that includes air mass flow, torque, and EGR estimation

Library: 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:

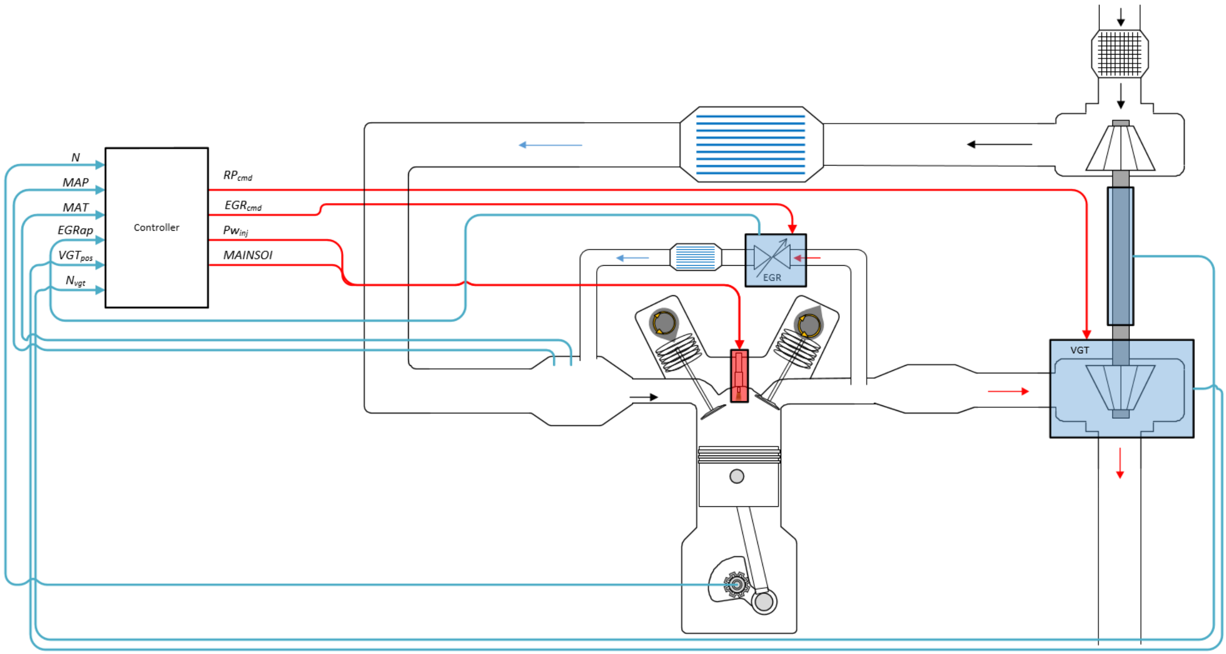
- The `Controller` subsystem — Determines the commands based on tables that are functions of commanded torque and measured engine speed.

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.

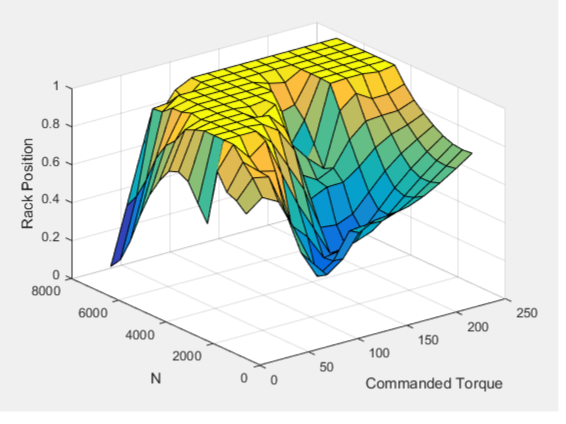
The controller commands the EGR valve area percent and VGT rack position. Changing the VGT rack position modifies the turbine flow characteristics. At low-requested torques, the rack position can reduce the exhaust back pressure, resulting in a low turbocharger speed and boost pressure. When the commanded 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.

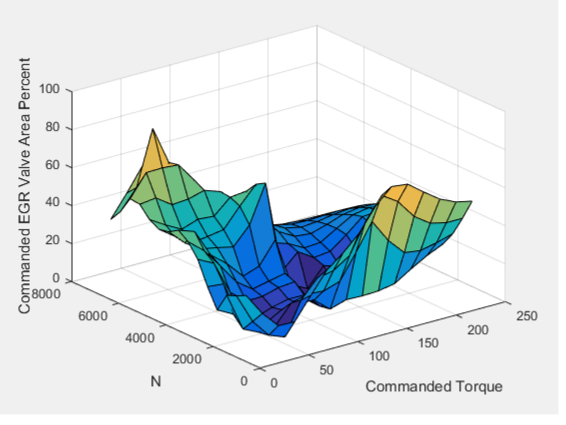


The commanded exhaust gas recirculation (EGR) valve area percent lookup table is a function of commanded torque and engine speed

$$EGR_{cmd} = f_{EGRcmd}(Trq_{cmd}, N)$$

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.



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.

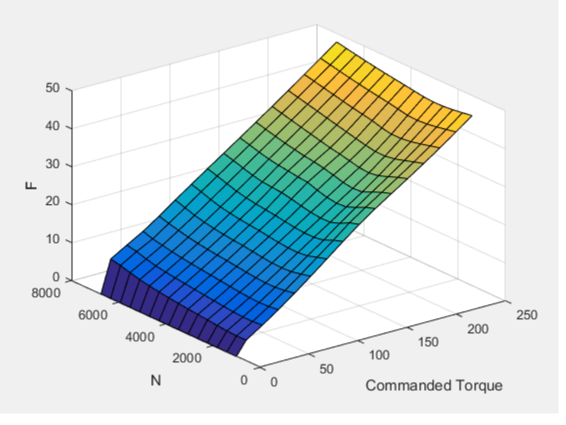
Pw_{inj}	Fuel injector pulse-width
S_{inj}	Fuel injector slope
$F_{cmd,tot}$	Commanded total fuel mass per injection
$MAINSOI$	Main start-of-injection timing
N	Engine speed

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.

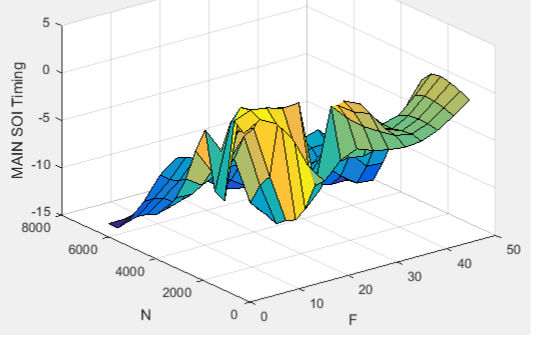


The main start-of-injection (SOI) timing lookup table is a function of commanded fuel mass and engine speed

$$MAINSOI = f(F_{cmd,tot}, N)$$

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.



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

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.

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.

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.

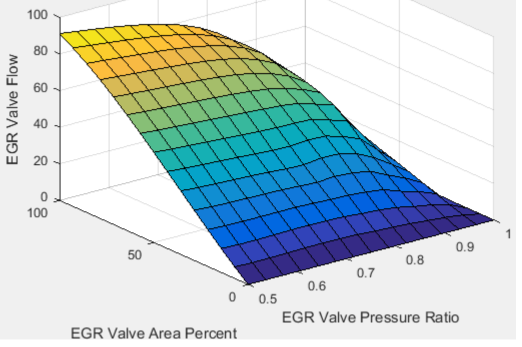
$$\dot{m}_{egr,est} = \dot{m}_{egr,std} \frac{P_{exh,est}}{P_{std}} \sqrt{\frac{T_{std}}{T_{exh,est}}}$$

- 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

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:

$$N_{vgtcorr} = \frac{N_{vgt}}{\sqrt{T_{exh,est}}}$$

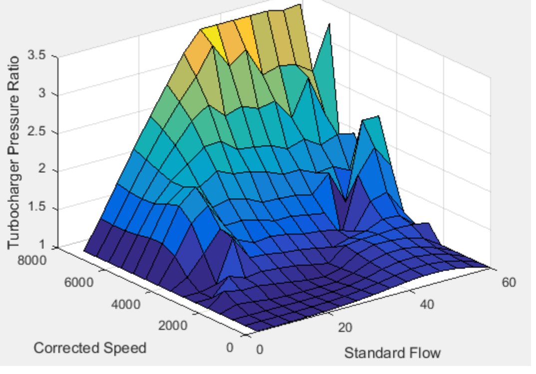
The equations use these variables.

$\dot{m}_{egr,est}$	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:

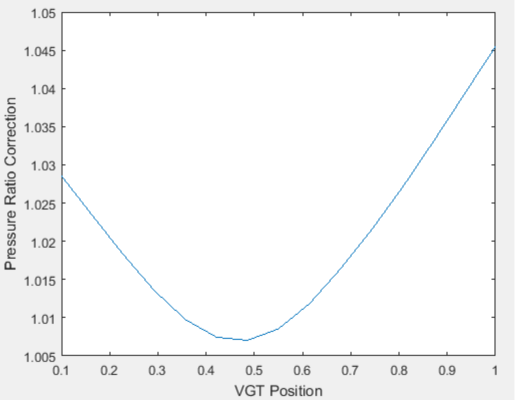
- The turbocharger pressure ratio, corrected for variable geometry turbocharger (VGT) speed, is a lookup table that is a function of the standard air mass flow and corrected turbocharger speed, $Pr_{turbo} = f(\dot{m}_{airstd}, N_{vgtcorr})$, where:
  - Pr_{turbo} is the turbocharger pressure ratio, 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.



To calculate the engine torque, you can configure the CI controller to use either of these torque models.

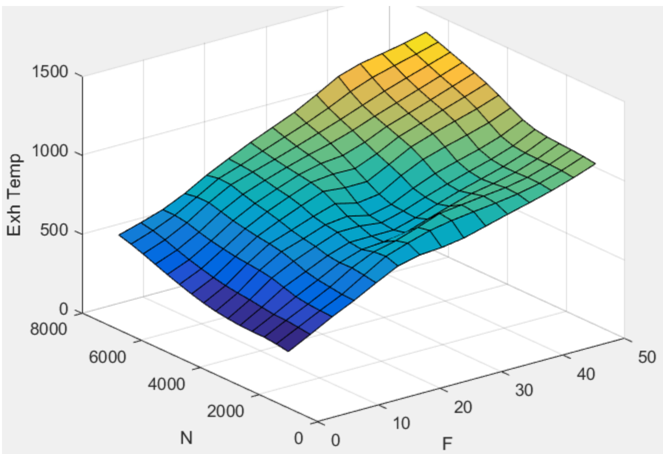
Brake Torque Model	Description
"CI Engine Torque Structure Model"	Model accounts for the reduction in engine torque as these engine conditions vary from nominal: • Fuel injection timing • Intake manifold gas temperature and pressure • Unburned cylinder air mass
"CI Engine Simple Torque Model"	For the simple engine torque calculation, the CI engine uses a torque lookup table map that is a function of engine speed and injected fuel mass.

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.



The measured engine speed and fuel injector pulse-width determine the commanded fuel mass flow rate:

$$\dot{m}_{fuel,cmd} = \frac{N S_{inj} Pw_{inj} N_{cyl}}{Cps\left(\frac{60s}{min}\right)\left(\frac{1000mg}{g}\right)}$$

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.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Description	Variable	Units
`InjPw`	Fuel injector pulse-width	Pw_{inj}	ms

Signal	Description	Variable	Units
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
EstIntkPortFlw	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

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

Configuration

`Torque estimation model` — Select torque estimation model
`Torque Structure` (default) | `Simple Torque Lookup`

To calculate the engine torque, you can configure the CI controller to use either of these torque models.

Brake Torque Model	Description
"CI Engine Torque Structure Model"	Model accounts for the reduction in engine torque as these engine conditions vary from nominal: • Fuel injection timing • Intake manifold gas temperature and pressure • Unburned cylinder air mass
"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.

Dependencies

The table summarizes the parameter dependencies.

Torque 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** **Inner torque fuel mass per injection breakpoints, f_tq_inr_f_bpt** **Inner torque speed breakpoints, f_tq_inr_n_bpt** **Main start of injection timing modifier on torque, f_tq_mainsoi_mod** **Main start of injection timing modifier breakpoints, f_tq_mainsoi_bpt** **Intake manifold gas temperature modifier on torque, f_tq_mat_mod** **Intake manifold gas temperature modifier breakpoints, f_tq_mat_bpt** **Intake manifold gas pressure modifier on torque, f_tq_map_mod** **Intake manifold gas pressure modifier breakpoints, f_tq_map_bpt** **Unburned air mass per cylinder modifier on torque, f_tq_apc_mod** **Unburned air mass per cylinder modifier breakpoints, f_tq_apc_bpt**

Torque Model	Enables Parameters on Estimation > Torque Tab
`Simple Torque Lookup`	**Torque table, f_tq_nf** **Torque table load breakpoints, f_tq_nf_f_bpt** **Torque table speed breakpoints, f_tq_nf_n_bpt**

Controls

Air

EGR valve area percent, f_egrcmd — Lookup table

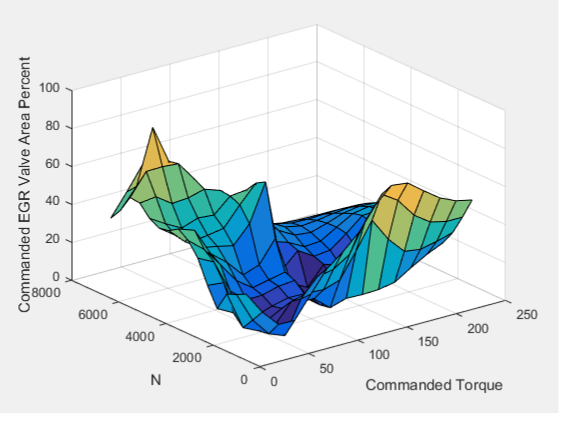
array

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
vector

Commanded torque breakpoints, in N.m.

Speed breakpoints, f_egr_n_bpt — Breakpoints
vector

Speed breakpoints, in rpm.

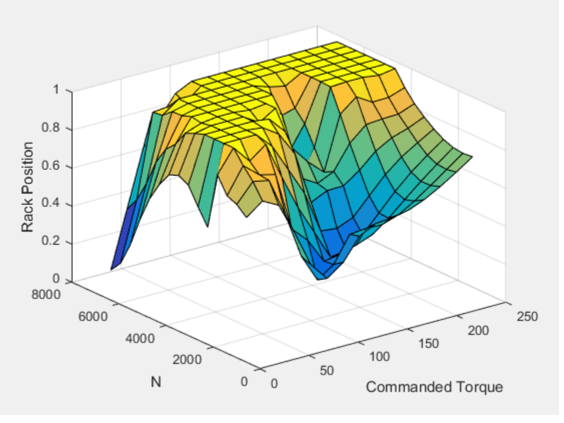
VGT rack position table, f_rpcmd — Lookup table
array

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
vector

Breakpoints, in N.m.

`Speed breakpoints, f_rp_n_bpt` — Breakpoints
`vector`

Breakpoints, in rpm.

Fuel

`Injector slope, Sinj` — Slope
`scalar`

Fuel injector slope, S_{inj} , in mg/ms.

`Stoichiometric air-fuel ratio, afr_stoich` — Ratio
`scalar`

Stoichiometric air-fuel ratio, AFR_{stoich}.

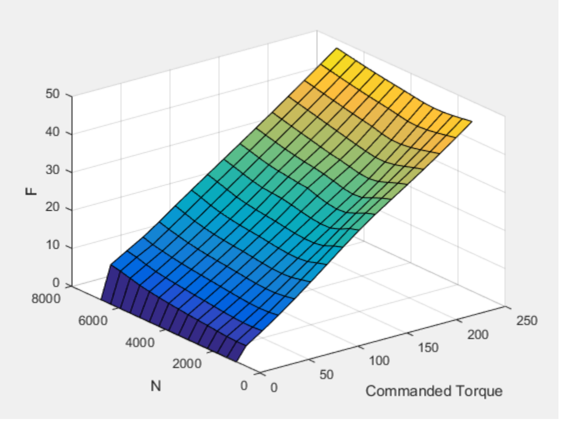
`Fuel mass per injection table, f_fcmd_tot` — Lookup table
`array`

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.



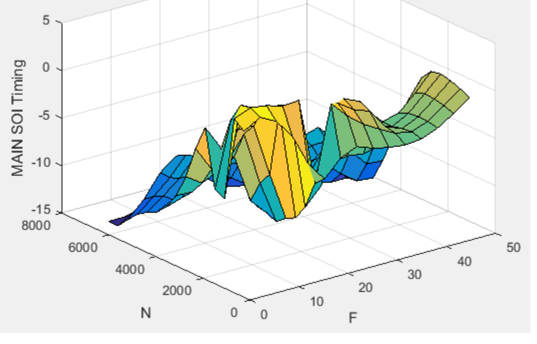
`Fuel main injection timing table, f_main_soi` — Lookup table
`array`

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 breakponts, f_main_soi_f_bpt` — Breakpoints
`vector`

Fuel main injection timing fuel breakpoints, in mg per injection.

`Fuel main injection timing speed breakponts, f_main_soi_n_bpt` — Breakpoints
`vector`

Fuel main injection timing speed breakpoints, in rpm.

`Commanded torque breakpoints, f_f_tot_tq_bpt` — Breakpoints
`vector`

Commanded torque breakpoints, in N·m.

`Speed breakpoints, f_f_tot_n_bpt` — Breakpoints
`vector`

Speed breakpoints, in rpm.

Idle Speed

`Base idle speed, N_idle` — Speed
`scalar`

Base idle speed, N_{idle}, in rpm.

`Enable torque command limit, Trq_idlecmd_enable` — Torque
`scalar`

Torque to enable the idle speed controller, $Trq_{idlecmd,enable}$, in N.m.

`Maximum torque command, Trq_idlecmd_max` — Torque
`scalar`

Maximum idle controller commanded torque, $Trq_{idlecmd,max}$, in N.m.

`Proportional gain, Kp_idle` — PI Controller
`scalar`

Proportional gain for idle speed control, $K_{p,idle}$, in N.m/rpm.

`Integral gain, Ki_idle` — PI Controller
`scalar`

Integral gain for idle speed control, $K_{i,idle}$, in N.m/(rpm*s).

Estimation

Air

`Number of cylinders, NCyl` — Engine cylinders
`scalar`

Number of engine cylinders, N_{cyl} .

`Crank revolutions per power stroke, Cps` — Revolutions per stroke
`scalar`

Crankshaft revolutions per power stroke, Cps , in rev/stroke.

`Total displaced volume, Vd` — Volume
`scalar`

Displaced volume, V_d , in m^3.

`Ideal gas constant air, Rair` — Constant
`scalar`

Ideal gas constant, R_{air} , in J/(kg*K).

`Air standard pressure, Pstd` — Pressure
`scalar`

Standard air pressure, P_{std} , in Pa.

`Air standard temperature, Tstd` — Temperature
`scalar`

Standard air temperature, T_{std} , in K.

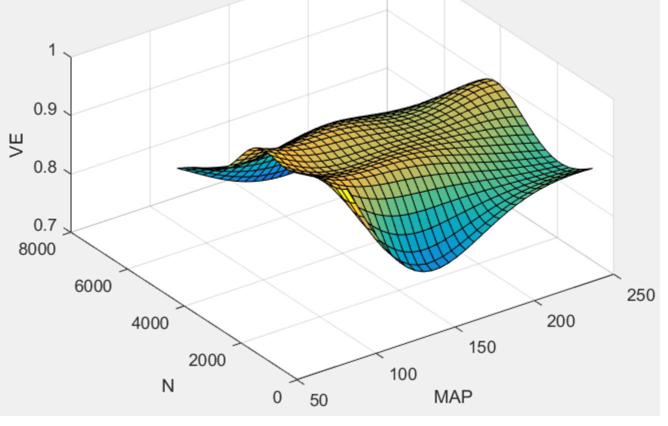
Speed density volumetric efficiency, f_nv — Lookup table
array

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
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.

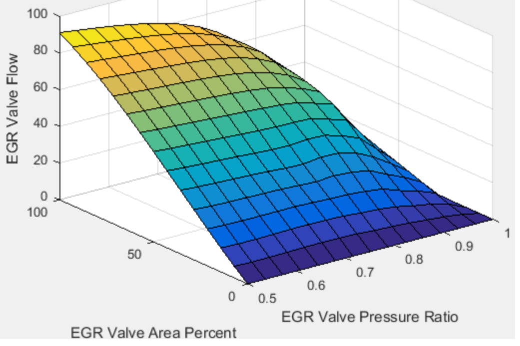
EGR valve standard flow calibration, f_egr_stdflow — Lookup table
array

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.

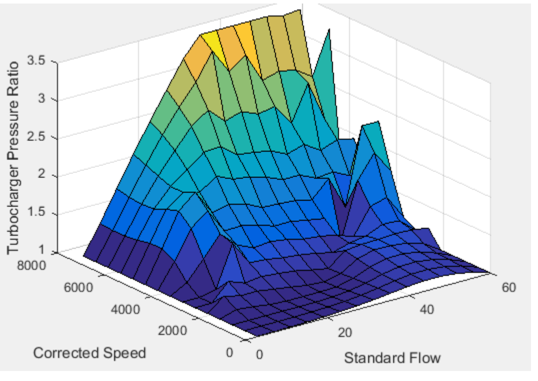
EGR valve standard flow area percent breakpoints, f_egr_stdflow_egrap_bpt — Breakpoints
vector

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.

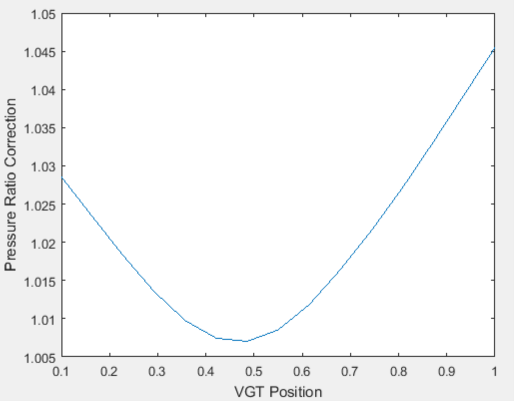
Turbocharger pressure ratio corrected speed breakpoints, f_turbo_pr_corrspd_bpt — Breakpoints
vector

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

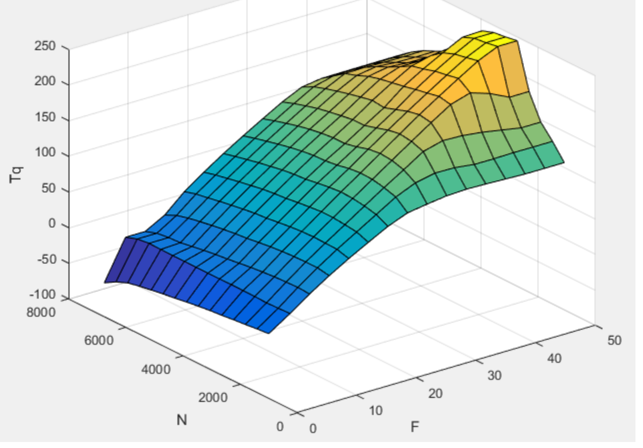
Turbocharger pressure ratio VGT position correction breakpoints, dimensionless.

Torque

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 the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table fuel mass per injection breakpoints, f_tq_nf_f_bpt` — Breakpoints

`vector`

Torque table fuel mass per injection breakpoints, in mg per injection.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table speed breakpoints, f_tq_nf_n_bpt` — Breakpoints

`vector`

Engine speed breakpoints, in rpm.

Dependencies

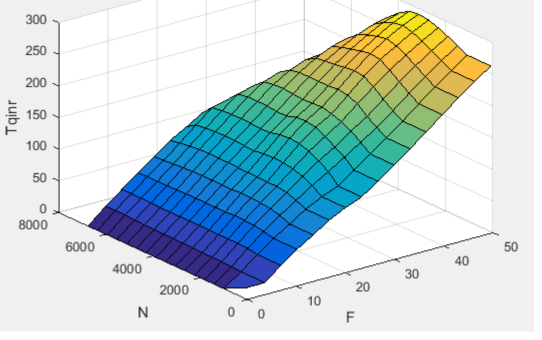
To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Inner torque table, f_tq_inr` — Lookup table

`array`

The inner torque lookup table, f_{Tqinr}, is a function of engine speed and injected fuel mass, $Tq_{inr} = f_{Tqinr}(F,N)$, where:

- Tq_{inr} is inner torque based on gross indicated mean effective pressure, in N.m.
- F is injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



Dependencies

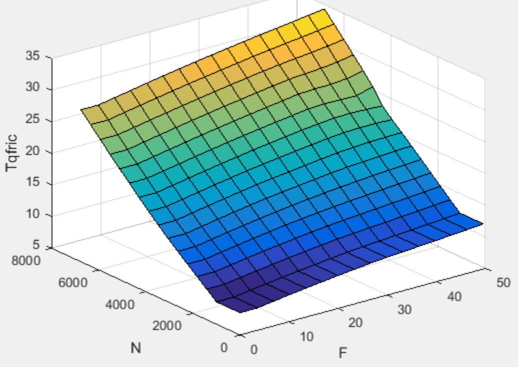
To enable this parameter, for **Torque model**, select `Torque Structure`.

`Friction torque table, f_tq_fric` — Lookup table

`array`

The friction torque lookup table, f_{Tfric}, is a function of engine speed and injected fuel mass, $T_{fric} = f_{Tfric}(F,N)$, where:

- T_{fric} is friction torque offset to inner torque, 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 `Torque Structure`.

`Engine temperature modifier on friction torque, f_fric_temp_mod` — Lookup table
`vector`

Engine temperature modifier on friction torque, $f_{fric,temp}$, dimensionless.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Engine temperature modifier breakpoints, f_fric_temp_bpt` — Breakpoints
`vector`

Engine temperature modifier breakpoints, in K.

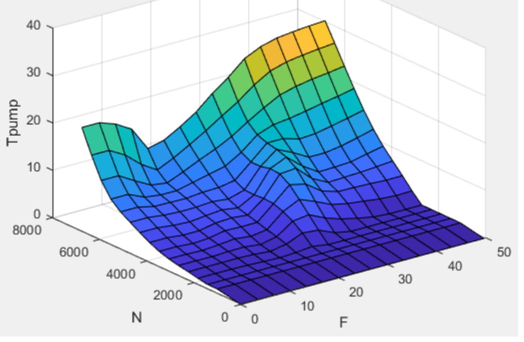
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Pumping torque table, f_tq_pump` — Lookup table
`array`

The pumping torque lookup table, f_{Tpump}, is a function of engine speed and injected fuel mass, $T_{pump}=f_{Tpump}(F,N)$, where:

- T_{pump} is pumping torque, 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 `Torque Structure`.

Inner torque fuel mass per injection breakpoints, f_tq_inr_f_bpt — Breakpoints

`vector`

Inner torque fuel mass per injection breakpoints, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Inner torque speed breakpoints, f_tq_inr_n_bpt — Breakpoints

`vector`

Inner torque speed breakpoints.

Dependencies

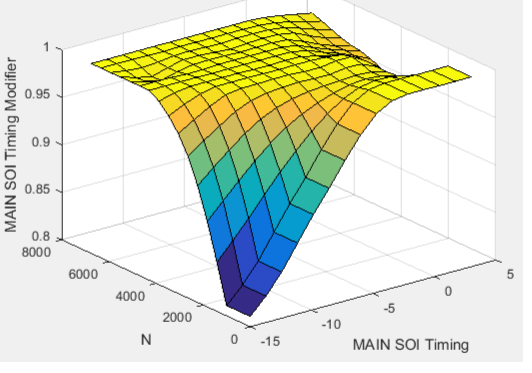
To enable this parameter, for **Torque model**, select `Torque Structure`.

Main start of injection timing modifier on torque, f_tq_mainsoi_mod — Lookup table

`array`

The main start-of-injection (MAINSOI) torque modifier lookup table is a function of MAINSOI and engine speed $Tmod_{mainsoi} = f_{mainsoi}(MAINSOI, N)$, where:

- $Tmod_{mainsoi}$ is the torque modifier due to MAINSOI torque loss.
- *MAINSOI* is the main start-of-injection timing, in degrees crank angle after top dead center (degATDC).
- *N* is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Main start of injection timing modifier breakpoints, f_tq_mainsoi_bpt` — Breakpoints
`vector`

Main start of injection timing modifier breakpoints, in degrees crank angle after top dead center (degATDC).

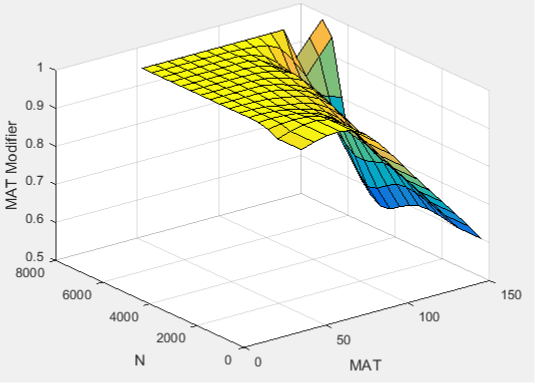
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Intake manifold gas temperature modifier on torque, f_tq_mat_mod` — Lookup table
`array`

The intake manifold gas temperature (MAT) torque modifier lookup table is a function of MAT and engine speed, $Tmod_{mat} = f_{mat}(MAT, N)$, where:

- $Tmod_{mat}$ is the torque modifier due to MAT torque loss.
- *MAT* is the measured intake manifold gas pressure, in C.
- *N* is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas temperature modifier breakpoints, f_tq_mat_bpt — Breakpoints

vector

Intake manifold gas temperature modifier breakpoints, in °C.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

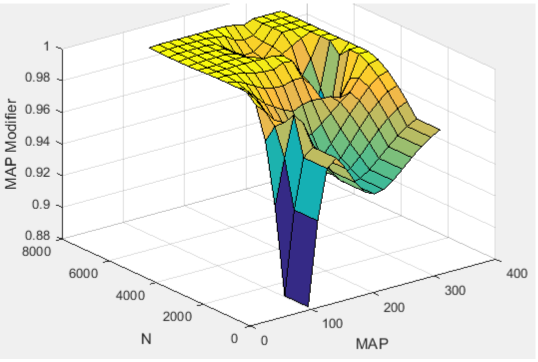
Intake manifold gas pressure modifier on torque, f_tq_map_mod — Lookup table

array

The intake manifold absolute pressure (MAP) torque modifier lookup table is a function of MAP and engine speed, $Tmod_{map} = f_{map}(MAP, N)$, where:

- $Tmod_{map}$ is the torque modifier due to MAP torque loss.
- *MAP* is the measured intake manifold absolute pressure, in kPa.

- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas pressure modifier breakpoints, f_tq_map_bpt — Breakpoints

`vector`

Intake manifold gas pressure modifier breakpoints, in kPa.

Dependencies

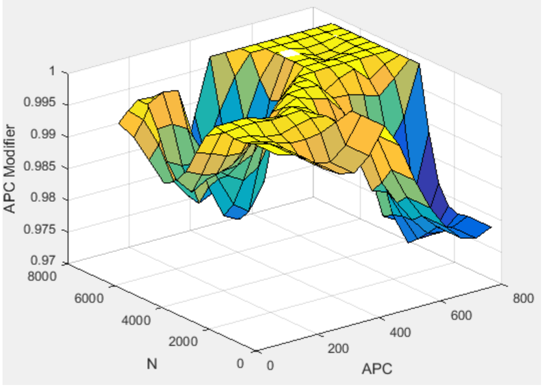
To enable this parameter, for **Torque model**, select `Torque Structure`.

Unburned air mass per cylinder modifier on torque, f_tq_apc_mod — Lookup table

`array`

The unburned air per cylinder (APC) torque modifier lookup table is a function of APC and engine speed, $Tmod_{apc} = f_{apc}(APC,N)$, where:

- $Tmod_{apc}$ is the torque modifier due to APC torque loss.
- APC is the unburned air per cylinder, in mg.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Unburned air mass per cylinder modifier breakpoints, f_tq_apc_bpt` — Breakpoints

`vector`

Unburned air mass per cylinder modifier breakpoints, in mg.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Exhaust

`Exhaust temperature table, f_t_exh` — Lookup table

`array`

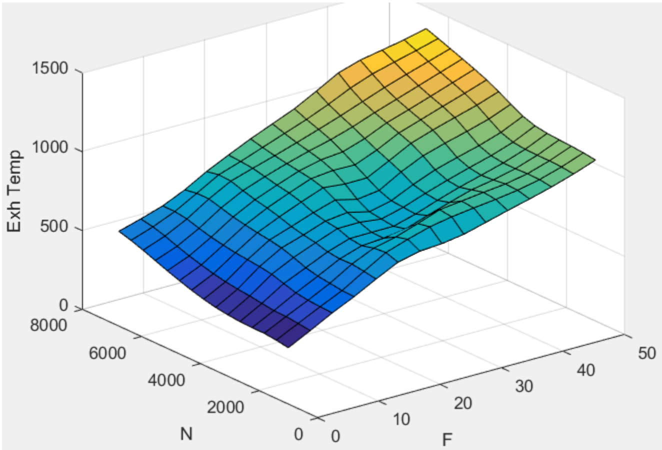
The lookup table for the exhaust temperature is a function of injected fuel mass and engine speed

$$T_{exh} = f_{Texh}(F,N)$$

where:

- T_{exh} is exhaust temperature, in K.
- F is injected fuel mass, in mg per injection.

- *N* is engine speed, in rpm.



`Fuel mass per injection breakpoints, f_t_exh_f_bpt` — Breakpoints
`vector`

Engine load breakpoints used for exhaust temperature lookup table.

`Speed breakpoints, f_t_exh_n_bpt` — Breakpoints
`vector`

Engine speed breakpoints used for exhaust temperature lookup table, in rpm.

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

[2] Sequenz, Heiko. *Emission Modeling and Model-Based Optimisation of the Engine Control*. VDI Fortschrittsberichte, 8. VDI Verlag , Düsseldorf, 2013.

See Also

CI Core Engine | Mapped CI Engine

Topics

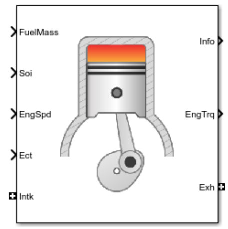
"Engine Calibration Maps"
"Generate Mapped CI Engine from a Spreadsheet"

Introduced in R2017a

CI Core Engine

Compression-ignition engine from intake to exhaust port

Library: 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
- Fuel flow
- Air 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 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 CI controller to use either of these torque models.

Brake Torque Model	Description
"CI Engine Torque Structure Model"	Model accounts for the reduction in engine torque as these engine conditions vary from nominal: • Fuel injection timing • Intake manifold gas temperature and pressure • Unburned cylinder air mass
"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

To calculate the engine fuel mass flow, the CI Core Engine block uses fuel mass flow delivered by the injectors and the engine airflow.

$$\dot{m}_{fuel} = \frac{N \cdot N_{cyl}}{Cps\left(\frac{60s}{\min}\right)\left(\frac{1000mg}{g}\right)} \sum m_{fuel,inj}$$

The equation uses these variables.

$\dot{m}_{fuel}$	Engine 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

Air-Fuel Ratio

To calculate the air-fuel (AFR) ratio, the CI Core Engine and SI Core Engine blocks implement this equation.

$$AFR = \frac{\dot{m}_{air}}{\dot{m}_{fuel}}$$

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.

$$EGR_{pct} = 100 \frac{\dot{\mathrm{m}}_{intk,b}}{\dot{\mathrm{m}}_{intk}} = 100 y_{intk,b}$$

The equations use these variables.

AFR	Air-fuel ratio
$\dot{m}_{intk}$	Engine air mass flow
$\dot{m}_{fuel}$	Fuel mass flow
$y_{intk,b}$	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

Ports

Input

`FuelMass` — Fuel injector pulse-width
`vector`

Fuel mass per injection, $m_{fuel,inj}$, in mg/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.

`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`	Air mass flow entering and exiting the engine from the intake ports to the exhaust ports.	$\dot{m}_{intk}$	kg/s
`IntkAirMassFlw`	Total engine air mass flow at intake ports, including EGR flow.	$\dot{m}_{port}$	kg/s
`NrmlzdAirChrg`	Engine load (that is, normalized cylinder air mass) at arbitrary cam phaser angles, 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
`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
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

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 CI controller to use either of these torque models.

Brake Torque Model	Description
"CI Engine Torque Structure Model"	Model accounts for the reduction in engine torque as these engine conditions vary from nominal: • Fuel injection timing • Intake manifold gas temperature and pressure • Unburned cylinder air mass
"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.

Dependencies

The table summarizes the parameter dependencies.

Port Configuration	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 torque table, f_tq_pump** **Inner torque fuel mass per injection breakpoints, f_tq_inr_f_bpt** **Inner torque speed breakpoints, f_tq_inr_n_bpt** **Main start of injection timing modifier on torque, f_tq_mainsoi_mod** **Main start of injection timing modifier breakpoints, f_tq_mainsoi_bpt** **Intake manifold gas temperature modifier on torque, f_tq_mat_mod** **Intake manifold gas temperature modifier breakpoints, f_tq_mat_bpt** **Intake manifold gas pressure modifier on torque, f_tq_map_mod** **Intake manifold gas pressure modifier breakpoints, f_tq_map_bpt** **Unburned air mass per cylinder modifier on torque, f_tq_apc_mod** **Unburned air mass per cylinder modifier breakpoints, f_tq_apc_bpt**

Port Configuration	Enables Parameters
`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
`scalar`

Number of engine cylinders, N_{cyl} .

`Crank revolutions per power stroke, Cps` — Revolutions per stroke
`scalar`

Crankshaft revolutions per power stroke, Cps , in rev/stroke.

`Total displaced volume, Vd` — Volume
`scalar`

Displaced volume, V_d , in m^3.

`Ideal gas constant air, Rair` — Constant
`scalar`

Ideal gas constant, R_{air} , in J/(kg*K).

`Air standard pressure, Pstd` — Pressure
`scalar`

Standard air pressure, P_{std} , in Pa.

`Air standard temperature, Tstd` — Temperature
`scalar`

Standard air temperature, T_{std} , in K.

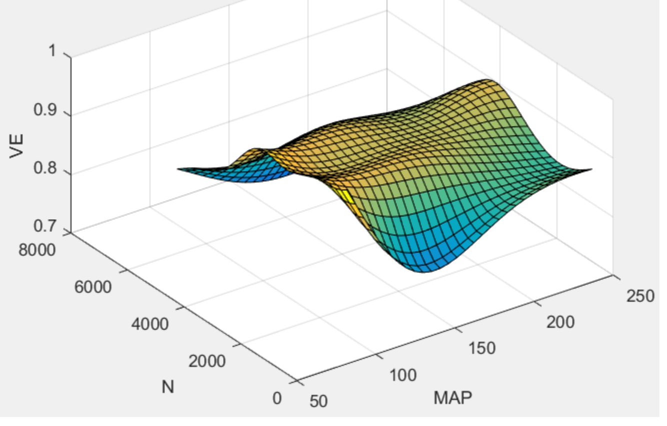
Speed-density volumetric efficiency, f_nv — Lookup table
array

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
array

Intake manifold pressure breakpoints for speed-density volumetric efficiency lookup table, in KPa.

Speed-density engine speed breakpoints, f_nv_n_bpt — Breakpoints
array

Engine speed breakpoints for speed-density volumetric efficiency lookup table, in rpm.

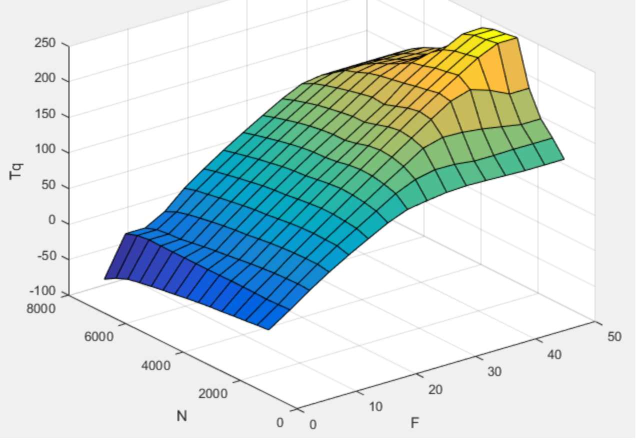
Torque

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 the **Torque model** parameter, select `Simple Torque Lookup`.

Torque table fuel mass per injection breakpoints, f_tq_nf_f_bpt — Breakpoints

vector

Torque table fuel mass per injection breakpoints, in mg per injection.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table speed breakpoints, f_tq_nf_n_bpt` — Breakpoints
`vector`

Engine speed breakpoints, in rpm.

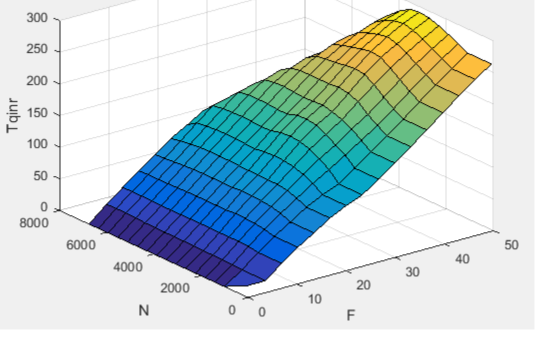
Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Inner torque table, f_tq_inr` — Lookup table
`array`

The inner torque lookup table, f_{Tqinr}, is a function of engine speed and injected fuel mass, $Tq_{inr} = f_{Tqinr}(F,N)$, where:

- Tq_{inr} is inner torque based on gross indicated mean effective pressure, in N.m.
- F is injected fuel mass, in mg per injection.
- N is engine speed, in rpm.



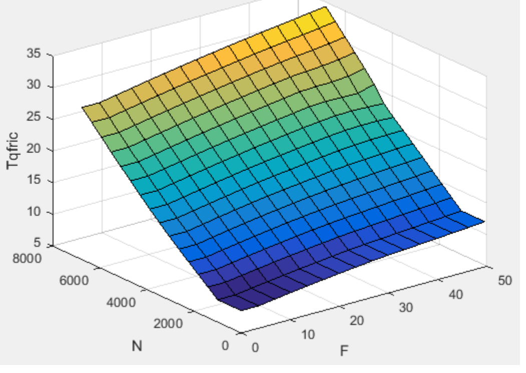
Dependencies

To enable this parameter, for **Torque model**, select `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 injected fuel mass, $T_{fric} = f_{Tfric}(F,N)$, where:

- T_{fric} is friction torque offset to inner torque, 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 `Torque Structure`.

Engine temperature modifier on friction torque, f_fric_temp_mod — Lookup table
vector

Engine temperature modifier on friction torque, $f_{fric,temp}$, dimensionless.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Engine temperature modifier breakpoints, f_fric_temp_bpt — Breakpoints
vector

Engine temperature modifier breakpoints, in K.

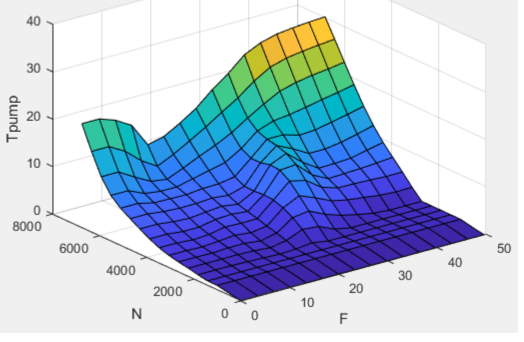
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

`Pumping torque table, f_tq_pump` — Lookup table
`array`

The pumping torque lookup table, f_{Tpump}, is a function of engine speed and injected fuel mass, T_{pump}=`f`$_{\texttt{Tpump}}$`(F,N)`, where:

- T_{pump} is pumping torque, 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 `Torque Structure`.

`Inner torque fuel mass per injection breakpoints, f_tq_inr_f_bpt` — Breakpoints
`vector`

Inner torque fuel mass per injection breakpoints, in mg per injection.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Inner torque speed breakpoints, f_tq_inr_n_bpt — Breakpoints
vector

Inner torque speed breakpoints.

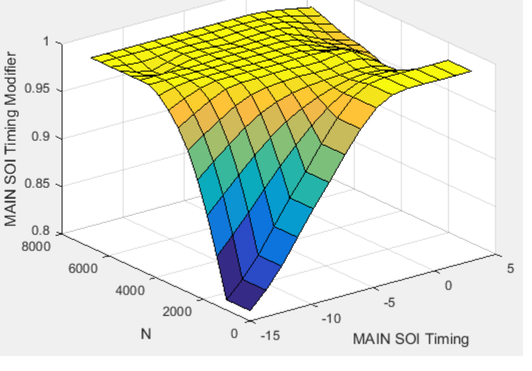
Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Main start of injection timing modifier on torque, f_tq_mainsoi_mod — Lookup table
array

The main start-of-injection (MAINSOI) torque modifier lookup table is a function of MAINSOI and engine speed $Tmod_{mainsoi} = f_{mainsoi}(MAINSOI, N)$, where:

- $Tmod_{mainsoi}$ is the torque modifier due to MAINSOI torque loss.
- $MAINSOI$ is the main start-of-injection timing, in degrees crank angle after top dead center (degATDC).
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Main start of injection timing modifier breakpoints, f_tq_mainsoi_bpt — Breakpoints
vector

Main start of injection timing modifier breakpoints, in degrees crank angle after top dead center (degATDC).

Dependencies

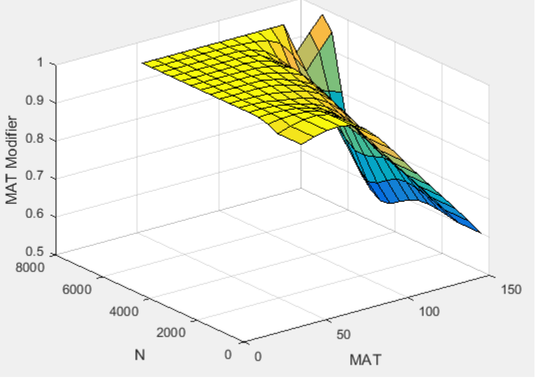
To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas temperature modifier on torque, f_tq_mat_mod — Lookup table

`array`

The intake manifold gas temperature (MAT) torque modifier lookup table is a function of MAT and engine speed, $Tmod_{mat} = f_{mat}(MAT, N)$, where:

- $Tmod_{mat}$ is the torque modifier due to MAT torque loss.
- *MAT* is the measured intake manifold gas pressure, in C.
- *N* is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas temperature modifier breakpoints, f_tq_mat_bpt — Breakpoints

`vector`

Intake manifold gas temperature modifier breakpoints, in °C.

Dependencies

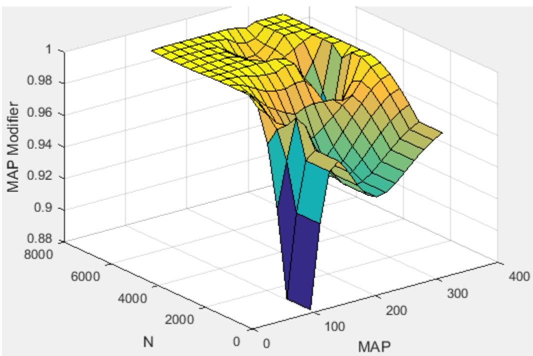
To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas pressure modifier on torque, f_tq_map_mod — Lookup table

`array`

The intake manifold absolute pressure (MAP) torque modifier lookup table is a function of MAP and engine speed, $Tmod_{map} = f_{map}(MAP, N)$, where:

- $Tmod_{map}$ is the torque modifier due to MAP torque loss.
- MAP is the measured intake manifold absolute pressure, in kPa.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Intake manifold gas pressure modifier breakpoints, f_tq_map_bpt — Breakpoints

`vector`

Intake manifold gas pressure modifier breakpoints, in kPa.

Dependencies

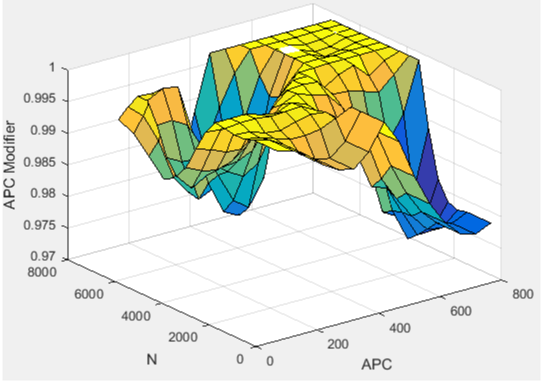
To enable this parameter, for **Torque model**, select `Torque Structure`.

Unburned air mass per cylinder modifier on torque, f_tq_apc_mod — Lookup table

array

The unburned air per cylinder (APC) torque modifier lookup table is a function of APC and engine speed, $Tmod_{apc} = f_{apc}(APC,N)$, where:

- $Tmod_{apc}$ is the torque modifier due to APC torque loss.
- APC is the unburned air per cylinder, in mg.
- N is engine speed, in rpm.



Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Unburned air mass per cylinder modifier breakpoints, f_tq_apc_bpt — Breakpoints

vector

Unburned air mass per cylinder modifier breakpoints, in mg.

Dependencies

To enable this parameter, for **Torque model**, select `Torque Structure`.

Exhaust

Exhaust temperature table, f_t_exh — Lookup table

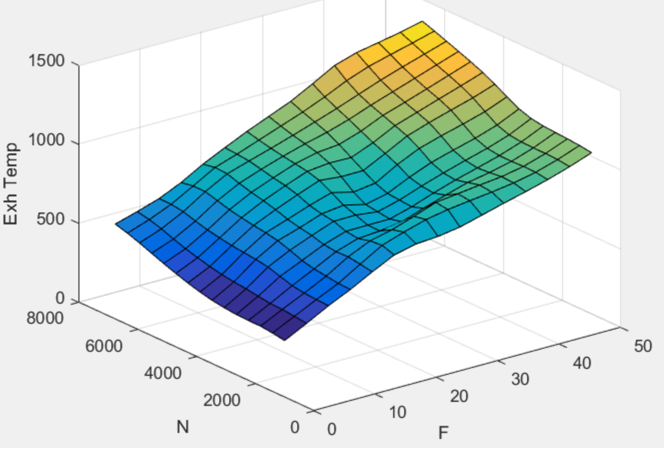
array

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.



Fuel mass per injection breakpoints, f_t_exh_f_bpt — Breakpoints
array

Engine load breakpoints used for exhaust temperature lookup table, in mg.

Speed breakpoints, f_t_exh_n_bpt — Breakpoints
array

Engine speed breakpoints used for exhaust temperature lookup table, in rpm.

Exhaust gas specific heat at constant pressure, cp_exh — Specific heat
scalar

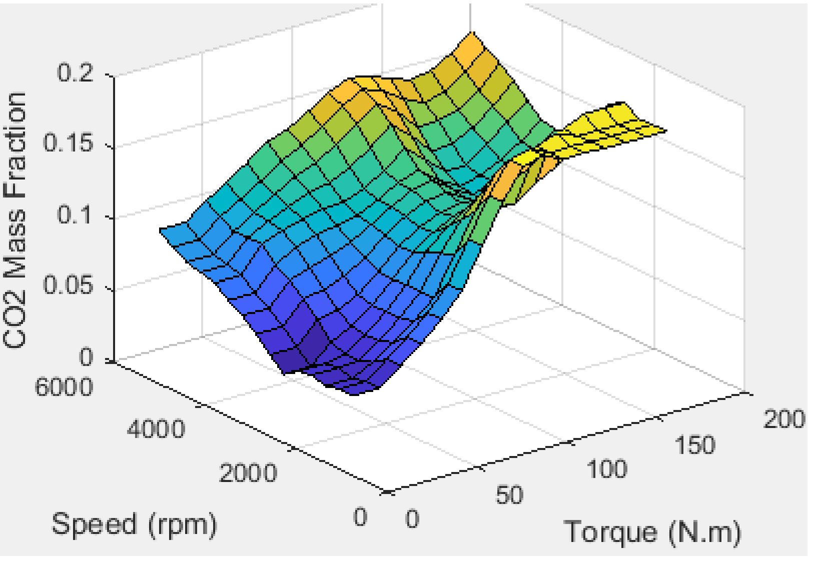
Exhaust gas-specific heat, Cp_{exh}, in J/(kg*K).

`CO2 mass fraction table, f_CO2_frac` — Carbon dioxide (CO_2) emission lookup table

`array`

The 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

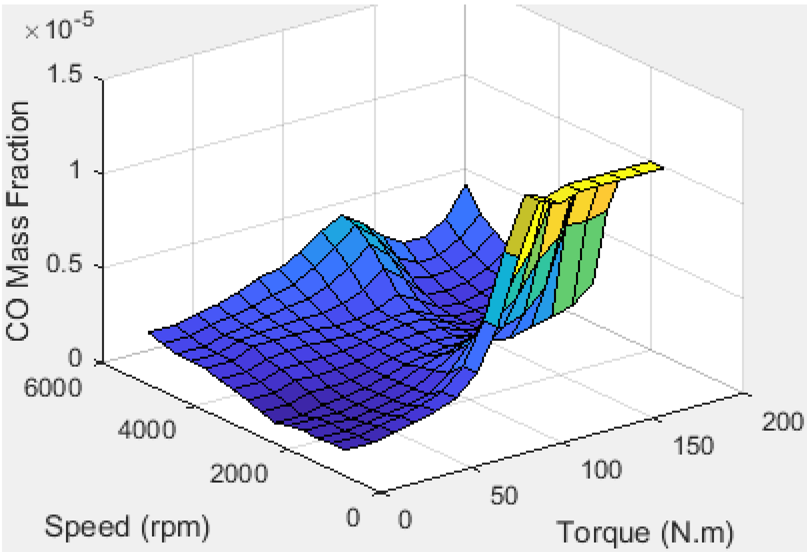
To enable this parameter, on the **Exhaust** tab, select **CO2**.

`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* = 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

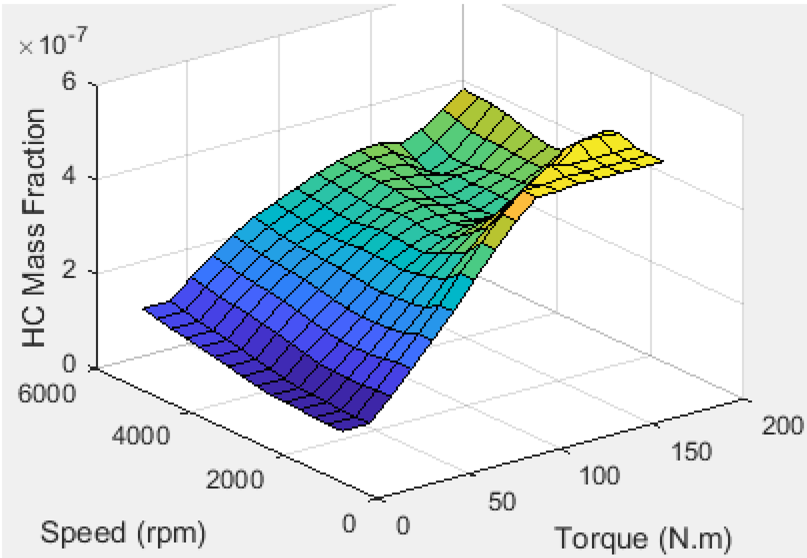
To enable this parameter, on the **Exhaust** tab, select **CO**.

`HC mass fraction table, f_HC_frac` — Hydrocarbon (HC) emission lookup table

`array`

The CI Core Engine HC emission mass fraction lookup table is a function of engine torque and engine speed, *HC Mass Fraction* = ƒ(*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

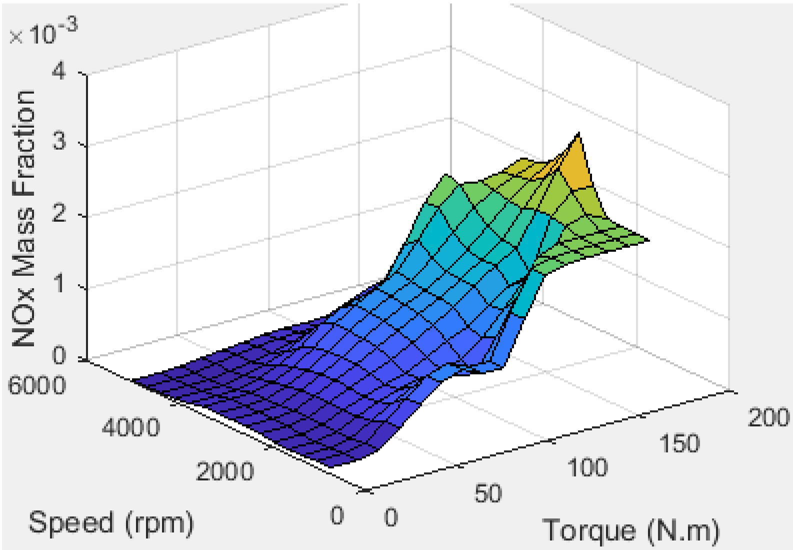
To enable this parameter, on the **Exhaust** tab, select **HC**.

`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

`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
`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

`Stoichiometric air-fuel ratio, afr_stoich` — Air-fuel ratio
`scalar`

Air-fuel ratio, AFR .

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

[2] Sequenz, Heiko. *Emission Modelling and Model-Based Optimisation of the Engine Control*. VDI Fortschrittsberichte, 8. Düsseldorf: VDI Verlag, 2013.

See Also

CI Controller | Mapped CI Engine

Topics

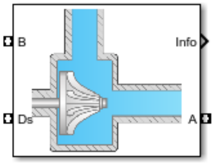
"CI Core Engine Air Mass Flow and Torque Production"
"Engine Calibration Maps"

Introduced in R2017a

Compressor

Compressor for boosted engines

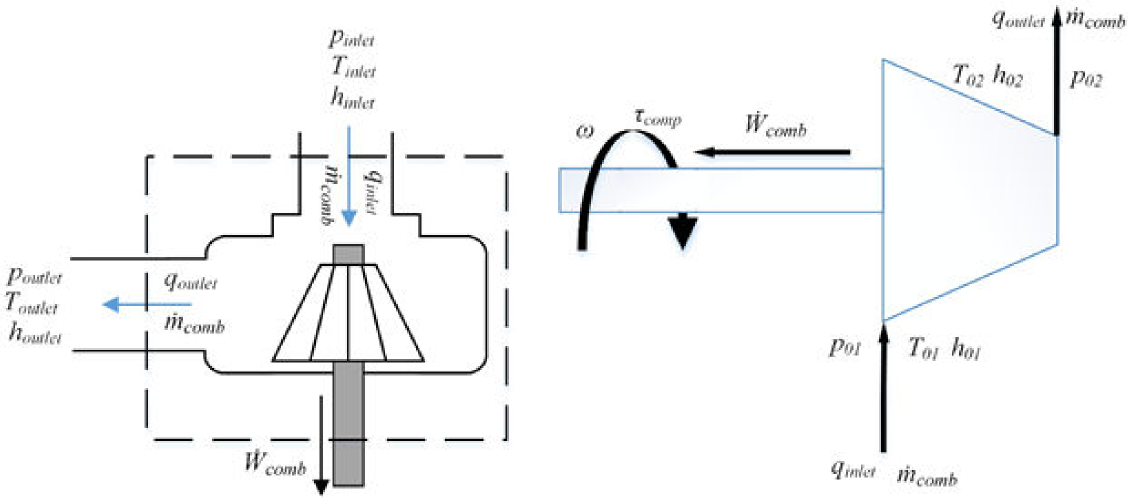
Library: Propulsion / Combustion Engine Components / Boost



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.

The mass flows from the inlet control volume to the outlet control volume.



Thermodynamics

The block uses these equations to model the thermodynamics.

Calculation	Equations
Forward mass flow	$\dot{m}_{comp} > 0$ $p_{01} = p_{inlet}$ $p_{02} = p_{outlet}$ $T_{01} = T_{inlet}$ $h_{01} = h_{inlet}$

Calculation	Equations
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 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 2-D lookup table
$\dot{m}_{corr,tbl}$	Corrected mass flow rate 2-D lookup table
$\omega_{corr,bpts1}$	Corrected speed breakpoints
$p_{r,bpts2}$	Pressure ratio breakpoints

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.

Signal	Description	Variable	Units
`CmprsOutletTemp`	Temperature exiting the compressor	T_{02}	K
`DriveshftPwr`	Drive shaft power	$\dot{W}_{comp}$	W
`DriveshftTrq`	Drive shaft torque	τ_{comp}	N.m
`CmprsMassFlw`	Mass flow rate through compressor	$\dot{m}_{comp}$	kg/s
`PrsRatio`	Pressure ratio	p_r	N/A
`DriveshftCorrSpd`	Corrected drive shaft speed	ω_{corr}	rad/s
`CmprsEff`	Compressor isentropic efficiency	η_{comp}	N/A
`CorrMassFlw`	Corrected mass flow rate	$\dot{m}_{corr}$	kg/s

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.

  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

Performance Tables

`Corrected mass flow rate table, mdot_corr_tbl` — 2-D lookup table
`array`

Corrected mass flow rate 2-D lookup table, $\dot{m}_{corr,tbl}$, in kg/s.

`Efficiency table, eta_comp_tbl` — 2-D lookup table
array

Efficiency 2-D lookup table, $\eta_{comb,tbl}$.

`Corrected speed breakpoints, w_corr_bpts1` — Breakpoints
`array`

Corrected drive shaft speed breakpoints, $\omega_{corr,bpts1}$, in rad/s.

`Pressure ratio breakpoints, Pr_bpts2` — Breakpoints
array

Pressure ratio breakpoints, $p_{r,bpts2}$.

`Reference temperature, T_ref` — Lookup table
`array`

Lookup table reference temperature, T_{ref} , in K.

`Reference pressure, P_ref` — Lookup table
`array`

Lookup table reference pressure, P_{ref} , in Pa.

Gas Properties

`Ideal gas constant, R` — Constant
`scalar`

Ideal gas constant, R , in J/(kg*K).

`Specific heat at constant pressure, cp` — Specific heat
`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.

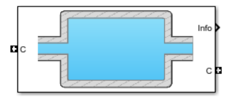
See Also

Boost Drive Shaft | Turbine

Introduced in R2017a

Control Volume System

Constant volume open thermodynamic system with heat transfer
Library: 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:

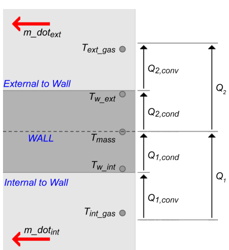
$$\frac{dy_{vol,j}}{dt} = \frac{RT_{vol}}{P_{vol}V_{ch}}\left(\sum \dot{m}_i y_{i,j} + y_{vol,j}\sum \dot{m}_i\right)$$

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}.

$$Q_1 = Q_{1,conv} = Q_{1,cond}$$

$$Q_{1,conv} = h_{int}\left(x_{int}\right) \bullet A_{int\_conv} \bullet \left(T_{int\_gas} - T_{w\_int}\right)$$

$$Q_{1,cond} = k_{int} \bullet \frac{A_{int\_cond}}{D_{int\_cond}} \bullet \left(T_{w\_int} - T_{mass}\right)$$

The block implements these equations to calculate the heat transfer, Q_2, from the external wall depth, D_{ext_cond} to the external gas.

$$Q_2 = Q_{2,conv} = h_{ext}\left(x_{ext}\right) \bullet A_{ext\_conv} \bullet \left(T_{w\_ext} - T_{ext\_gas}\right)$$

$$Q_{2,cond} = k_{ext} \bullet \frac{A_{ext\_cond}}{D_{ext\_cond}} \bullet \left(T_{mass} - T_{w\_ext}\right)$$

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.

$$\dot{m}_{int\_gas} = \frac{1}{2}\sum\left|\dot{m}_i\right|$$

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

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

Signal			Description	Units
		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

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
scalar

Chamber volume, V_{ch}, in m^3.

Initial chamber pressure, Pinit — Pressure
scalar

Initial chamber pressure, P_{vol}, in Pa.

Initial chamber temperature, Tinit — Temperature
scalar

Initial chamber temperature, T_{vol}, in K.

Ideal gas constant, R — Ideal gas constant
scalar

Ideal gas constant, R, in J/(kg*K).

Specific heat capacity, cp — Specific heat
scalar

Specific heat capacity, c_p, in J/(kg*K).

Heat Transfer

Heat transfer rate, q_he — Rate
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

`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)

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

`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

`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

`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

`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

`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

`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

`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
`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
`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
`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
`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
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
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.

See Also

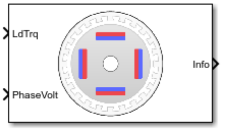
Constant Volume Pneumatic Chamber | Two-Way Connection | Flow Restriction | Heat Exchanger

Introduced in R2017a

Interior PMSM

Three-phase interior permanent magnet synchronous motor with sinusoidal back electromotive force

Library: Propulsion / Electric Motors

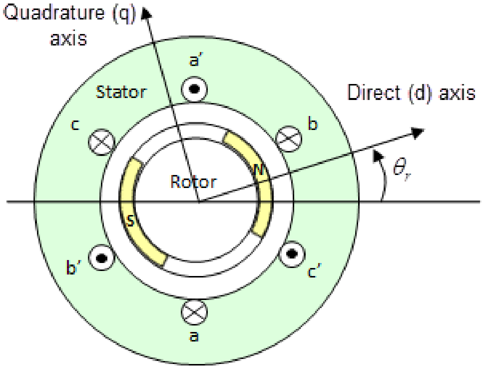


Description

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.

Motor Construction

This figure shows the motor construction with a single pole pair on the rotor.



The rotor magnetic field due to the permanent magnets creates a sinusoidal rate of change of flux with rotor angle.

For the axes convention, the *a*-phase and permanent magnet fluxes are aligned when rotor angle θ_r is zero.

Three-Phase Sinusoidal Model Electrical System

The block implements these equations, expressed in the rotor flux reference frame (dq frame). All quantities in the rotor 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 rotor position due to the saliency of the rotor.

The equations use these variables.

L_q, L_d	q- and d-axis inductances
R	Resistance of the stator windings
i_q, i_d	q- and d-axis currents
v_q, v_d	q- and d-axis voltages
ω_m	Angular mechanical velocity of the rotor
ω_e	Angular electrical velocity of the rotor
λ_{pm}	Permanent magnet flux linkage
P	Number of pole pairs
T_e	Electromagnetic torque
Θ_e	Electrical angle

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	Rotor shaft static friction torque
ω_m	Angular mechanical velocity of the rotor

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
`vector`

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

Parameters

Port Configuration — Select port configuration
Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Ports
Torque	LdTrq PhaseVolt Info
Speed	Spd PhaseVolt Info

Stator phase resistance, Rs — Resistance
scalar

Stator phase resistance, R_s, in ohm.

D and Q axis inductances, Ldq — Inductance
vector

D and Q axis inductances, L_d, L_q, in H.

Permanent magnet flux, lambda_pm — Flux
scalar

Permanent magnet flux linkage, λ_{pm}, in Wb.

Number of pole pairs, P — Pole pairs
scalar

Motor pole pairs, P.

Initial dq current, idq0 — Current
vector

Initial q- and d-axis currents, i_q, i_d, in A.

`Initial mechanical position, theta_init` — Angle
`scalar`

Initial rotor angular position, θ_{m0}, in rad.

`Initial mechanical speed, omega_init` — Speed
`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
`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] 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.

See Also

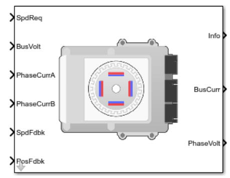
Flux-Based PMSM | Induction Motor | Interior PM Controller | Interior PMSM | Mapped Motor | Surface Mount PMSM

Introduced in R2017a

Interior PM Controller

Torque-based, field-oriented controller for an internal permanent magnet synchronous motor

Library: Propulsion / Electric Motor Controllers

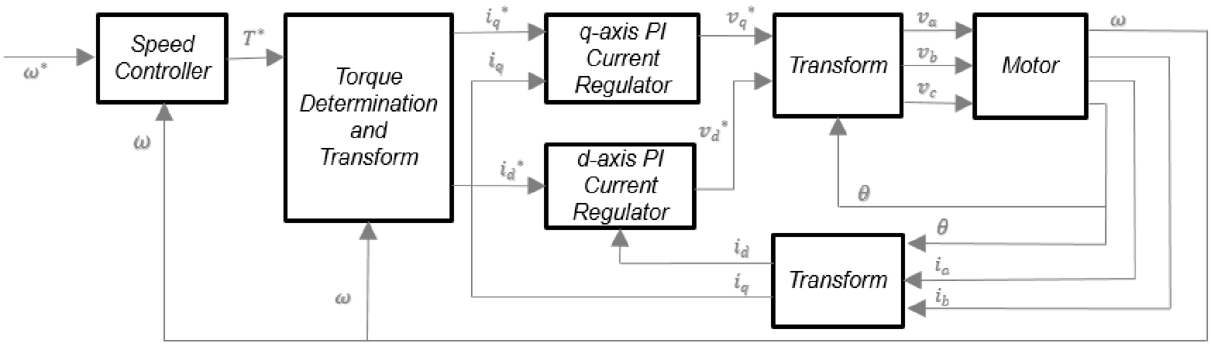


Description

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.



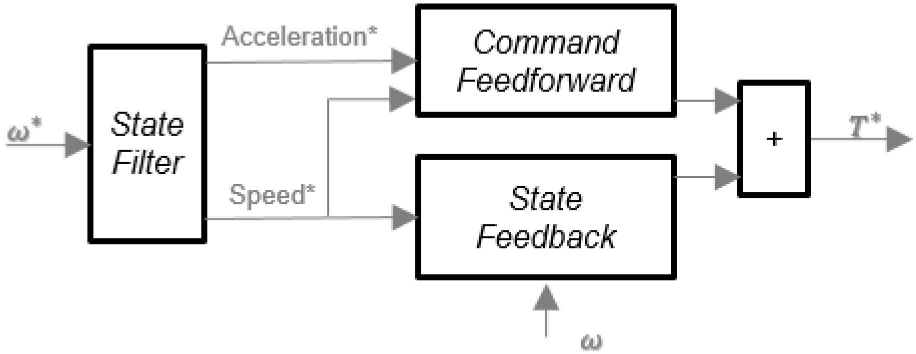
The block implements equations that use these variables.

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.



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 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

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	$K_{sa} = \frac{J_p \left(p_1 p_2 + p_2 p_3 + p_3 p_1\right) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$
Speed regulator double integral gain	$K_{isa} = \frac{-J_p \left(p_1 + p_2 + p_3\right) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$

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

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	$\omega_{base} = \frac{v_{max}}{\sqrt{\left(L_q i_q\right)^2 + \left(L_d i_d + \lambda_{pm}\right)^2}}$
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	$i_{max}{}^2 = i_{d\_\max}^2 + i_{q\_\max}^2$
Maximum line to neutral voltage	$v_{max} = \frac{v_{bus}}{\sqrt{3}}$
d-axis phase current MTPA table	$I_m = \frac{2T_{max}}{3P\lambda_{pm}}$ $i_{d\_mtpa} = \frac{\lambda_{pm}}{4\left(L_q - L_d\right)} - \sqrt{\frac{\lambda_{pm}^2}{16\left(L_q - L_d\right)^2} + \frac{I_m^2}{2}}$
q-axis phase current MTPA table	$i_{q\_mtpa} = \sqrt{I_m^2 - \left(i_{mtpa}\right)^2}$
Torque MTPA breakpoints	$T_{mtpa} = \frac{3}{2} P \left(\lambda_{pm} i_q + \left(L_d - L_q\right) i_d i_q\right)$

Calculation	Equations
Field weakening, using the speed-based voltage limits	$\left(L_q i_q\right)^2 + \left(L_d i_d + \lambda_{pm}\right)^2 \leq \frac{v_{max}^2}{\omega_e^2}$ $i_q = \sqrt{i_{max}^2 - i_d^2}$ $\left(L_d^2 - L_q^2\right) i_d^2 + 2\lambda_{pm} L_d i_d + \lambda_{pm} + L_q^2 i_{max}^2 - \frac{v_{max}^2}{\omega_e^2} = 0$ $i_{dfw} = \frac{-\lambda_{pm} L_d + \sqrt{\left(\lambda_{pm} L_d\right)^2 - \left(L_d^2 - L_q^2\right)\left(\lambda_{pm}^2 + L_q^2 i_{max}^2 - \frac{v_{max}^2}{\omega_e^2}\right)}}{\left(L_d^2 - L_q^2\right)}$ $T_{fw} = \frac{3}{2} P \left(\lambda_{pm} i_{qfw} + \left(L_d - L_q\right) i_{dfw} i_{qfw}\right)$

Calculation	Equations
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 $T_{fw} < T_{ref}$ $i_{dref} = i_{d_{fw}}$ $i_{qref} = i_{q_{fw}}$ Else $i_{dref} = i_{d_{fw}}$ $i_{qref} = \dfrac{T_{ref}}{\frac{3}{2}P\left(\lambda_{pm} + \left(L_d - L_q\right)i_{dfw}\right)}$ 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	$L_d \frac{di_d}{dt} = v_d - R_s i_d + p\omega_m L_q i_q$ $L_d \frac{di_q}{dt} = v_q - R_s i_q - p\omega_m L_d i_d - p\omega_m \lambda_{pm}$

Calculation	Equations
Current regulator gains	$\omega_b = 2\pi EV_{current}$ $K_{p\_d} = L_d\omega_b$ $K_{p\_q} = L_q\omega_b$
Transfer functions	$K_i = R_s\omega_b$ $\frac{i_d}{i_{dref}} = \frac{\omega_b}{s+\omega_b}$ $\frac{i_q}{i_{qref}} = \frac{\omega_b}{s+\omega_b}$

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).	$x_a = x_\alpha$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$
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

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 Parameters

`Stator resistance, Rs` — Resistance

`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

`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
`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
`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
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
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

`scalar`

Maximum torque, in N.m.

Dependencies

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

`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**

Derived Parameter on Id and Iq Calculation tab		Depends On: Parameter	Depends On: Tab
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
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

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**

Parameter	Dependency	
	Parameter	Tab
	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
`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
`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
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

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 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
`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
`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
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
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
`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 time constant, Ksf**	**Speed Controller**

`Sample time for the motion control, Tsm` — Time
`scalar`

Sample time for the motion controller, in s.

Dependencies

The parameter is enabled when the **Control Type** parameter is set to `Speed Control`.

Parameter	Used to Derive	
	Parameter	Tab
Sample time for the motion control, Tsm	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa**	**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	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$	**Sample time for the motion control, Tsm** **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 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**

Derived Parameter on Speed Controller tab		Depends On	
		Parameter	Tab
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
T_{sm}	Motion controller sample time
EV_{sf}	State filter bandwidth
EV_{motion}	Motion controller bandwidth

`Proportional gain, ba` — Derived

`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**

Parameter	Dependency	
	Parameter	Tab
	Bandwidth of the motion controller, EV_motion **Sample time for the motion control, Tsm**	**Speed Controller**

`Angular gain, Ksa` — Derived

`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 **Sample time for the motion control, Tsm**	**Speed Controller**

`Rotational gain, Kisa` — Derived

`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 **Sample time for the motion control, Tsm**	**Speed Controller**

`Speed time constant, Ksf` — Derived

`scalar`

Derived speed time constant, in 1/s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Speed 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

`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

`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

`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
`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
1-by-M matrix

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

1-by-N matrix

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

M-by-N matrix

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

1-by-M matrix

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

1-by-N matrix

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
`M`-by-`N` matrix

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.

See Also

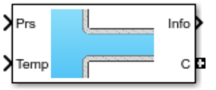
Flux-Based PM Controller | IM Controller | Interior PMSM | Surface Mount PM Controller

Introduced in R2017a

Flow Boundary

Flow boundary for ambient temperature and pressure

Library: 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

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

`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
scalar

Constant pressure, *P*, in Pa.

Dependencies

To enable this parameter, select Constant for the **Pressure and temperature source** parameter.

Temperature, Tcnst — Constant
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, J/(kg(K)
scalar

Specific heat at constant pressure, in J/(kg*K).

References

[1] Heywood, John B. *Internal Combustion Engine Fundamentals*. New York: McGraw-Hill, 1988.

See Also

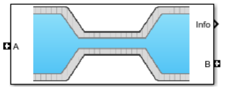
Compressor | Flow Restriction | Turbine

Introduced in R2017a

Flow Restriction

Isentropic ideal gas flow through an orifice

Library: 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	$\dot{m}_{orf} = \Gamma \cdot \Psi\left(P_{ratio}\right)$ $P_{ratio} = \dfrac{P_{downstr}}{P_{upstr}}$ $\Gamma = \dfrac{A_{eff} \cdot P_{upstr}}{\sqrt{R \cdot T_{upstr}}}$ $P_{cr} = \left(\dfrac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$ $\Psi = \begin{cases} \sqrt{\gamma\left(\dfrac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} & P_{ratio} < P_{cr} \\ \sqrt{\dfrac{2\gamma}{\gamma-1}\left(P_{ratio}^{\frac{2}{\gamma}} - P_{ratio}^{\frac{\gamma+1}{\gamma}}\right)} & P_{cr} \le P_{ratio} \le P_{lim} \\ \dfrac{P_{ratio}-1}{P_{lim}-1}\sqrt{\dfrac{2\gamma}{\gamma-1}\left(P_{lim}^{\frac{2}{\gamma}} - P_{lim}^{\frac{\gamma+1}{\gamma}}\right)} & P_{lim} < P_{ratio} \end{cases}$
Constituent Mass Flow Rates	$\dot{m}_i = \dot{m}_{orf}\, y_{upstr,i}$
Constant Orifice Area	$A_{eff} = A_{orf\_cnst} \cdot Cd_{cnst}$
External Input Orifice Area	$A_{eff} = A_{orf\_ext} \cdot Cd_{ext}$

Calculation	Equations
Throttle Body Geometry	$\theta_{thr} = Pct_{thr} \cdot \frac{90}{100}$ $A_{eff\_thr} = \frac{\pi}{4} D_{thr}{}^2 C_{d\_thr}(\theta_{thr})$

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

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

Signal			Description	Units
		UpstrmTemp	Upstream temperature	K
	OrfMassFlw		Mass flow rate through orifice	kg/s
	SpeciesMassFlow	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
Area	FlwArea		Cross-sectional flow area	m^2
	EffctArea		Effective orifice cross-sectional area	m^2

Signal		Description	Units
	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

scalar

Ratio of specific heats, γ.

Ideal gas constant, R — Constant

scalar

Ideal gas constant, R , in J/(kg*K).

Pressure ratio linearize limit, Plim — Limit

scalar

Pressure ratio limit to avoid singularities as the pressure ratio approaches 1, P_{lim} .

Area

`Constant area value, Aorf_cnst` — Area
`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
`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
`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
`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
`array`

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
`array`

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.

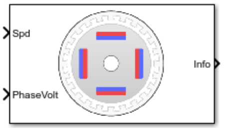
See Also

Control Volume System | Heat Exchanger

Introduced in R2017a

Flux-Based PMSM

Flux-based permanent magnet synchronous motor
Library: Propulsion / Electric Motors



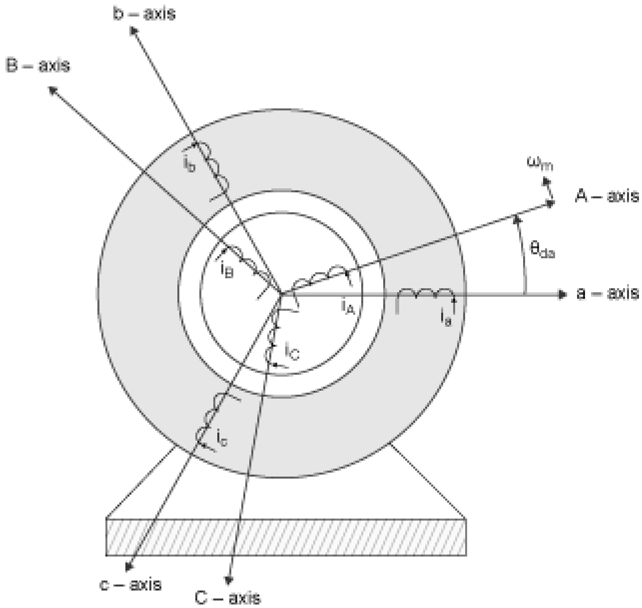
Description

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.

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	$v_d = \frac{d\psi_d}{dt} + R_s i_d - \omega_e \psi_q$
q- and *d*-axis current	$v_q = \frac{d\psi_q}{dt} + R_s i_q + \omega_e \psi_d$
Electromechanical torque	$i_d = f(\psi_d, \psi_q)$ $i_q = g(\psi_d, \psi_q)$

$$T_e = 1.5P[\psi_d i_q - \psi_q i_d]$$

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).	$x_d = x_\alpha \cos\theta_e + x_\beta \sin\theta_e$ $x_q = -x_\alpha \sin\theta_e + x_\beta \cos\theta_e$

Transform	Description	Equations
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

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
`vector`

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	*d*-axis current	i_d	A
IqSync	*q*axis current	i_q	A
VdSync	*d*-axis voltage	v_d	V
VqSync	*q*-axis 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

Parameters

Port Configuration — Select port configuration

Torque (default) | Speed

This table summarizes the port configurations.

Port Configuration	Creates Ports
Torque	LdTrq PhaseVolt Info
Speed	Spd PhaseVolt Info

Stator phase resistance, Rs — Resistance
scalar

Stator phase resistance, R_s, in ohm.

Vector of d-axis flux, flux_d — Flux
vector

d-axis flux, Ψ_d, in Wb.

Vector of q-axis flux, flux_q — Flux
vector

q-axis flux, Ψ_q, in Wb.

Corresponding d-axis current, id — Current
vector

d-axis current, i_d, in A.

Corresponding q-axis current, iq — Current
vector

q-axis current, i_q, in A.

Number of pole pairs, P — Pole pairs
scalar

Motor pole pairs, *P*.

Initial flux, fluxdq0 — Flux
vector

Initial *d*- and *q*-axis flux, Ψ_{q0} and Ψ_{d0}, in Wb.

Initial mechanical position, theta_init — Angle
scalar

Initial rotor angular position, θ_{m0}, in rad.

Initial mechanical speed, omega_init — Speed
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
`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.

See Also

Flux-Based PM Controller | Induction Motor | Interior PMSM | Mapped Motor | Surface Mount PMSM

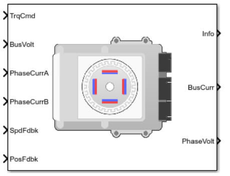
Topics

"Generate Parameters for Flux-Based Blocks"

Introduced in R2017b

Flux-Based PM Controller

Controller for a flux-based permanent magnet synchronous motor
Library: Propulsion / Electric Motor Controllers

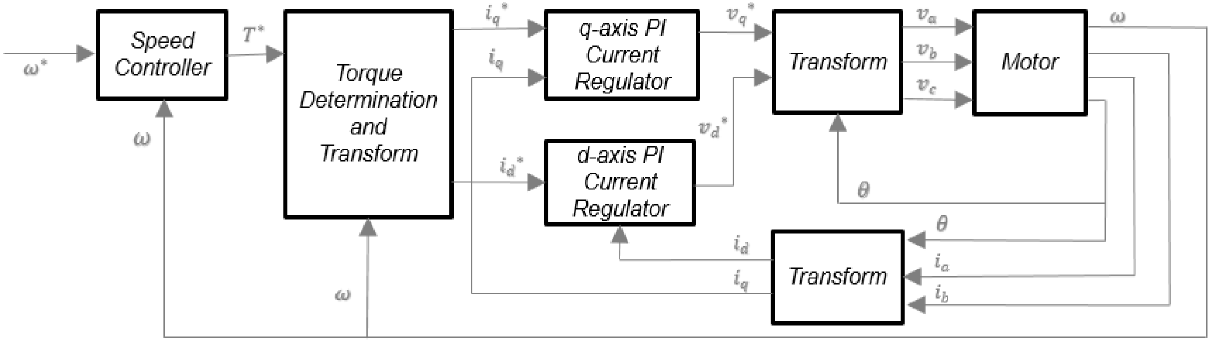


Description

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.



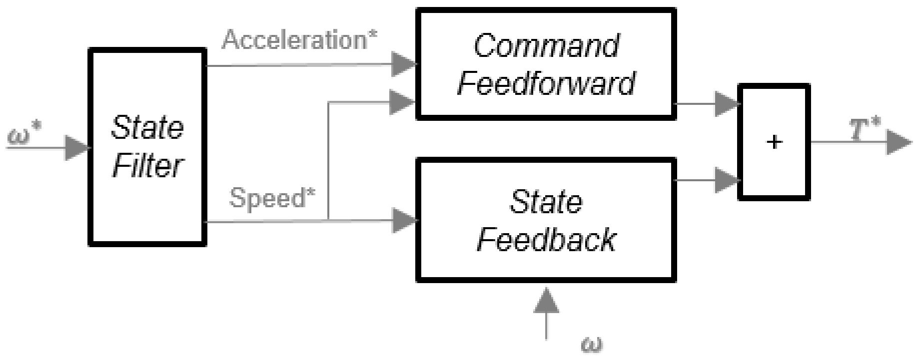
The block implements equations using these variables.

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.



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

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
ω^*_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

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.

$$T_{cmd\_ff} = J_p \dot{\omega}_m + F_v \omega_m + F_s \frac{\omega_m}{|\omega_m|}$$

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

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

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).	$x_a = x_\alpha$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$

Transform	Description	Equations
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.

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 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

Signal	Description	Units
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 Parameters

Number of pole pairs, PolePairs — Poles
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
scalar

Torque control sample time, T_{st}, in s.

D-axis proportional gain, Kp_d — Gain
scalar

d-axis proportional gain, Kp_d, in V/A.

Q-axis proportional gain, Kp_q — Gain
scalar

q-axis proportional gain, Kp_q, in V/A.

D-axis integral gain, Ki_d — Gain
scalar

d-axis integral gain, Ki_d, in V/A*s.

Q-axis integral gain, Ki_q — Gain
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

Sample time for the motion control, Tsm — Time
scalar

Sample time for the motion controller, T_{sm}, in s.

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

Speed time constant, Ksf — Time
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
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
`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
`scalar`

Inertia compensation, in kg*m^2.

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

`Static friction, Fs` — Friction
`scalar`

Static friction, in N.m.

Dependencies

To enable this parameter, for the **Control Type** parameter, select `Speed Control`.

`Viscous damping compensation, Fv` — Dampint
`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.
`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

`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

1-by-M matrix

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

1-by-N matrix

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

M-by-N matrix

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

1-by-M matrix

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

1-by-N matrix

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
`M`-by-`N` matrix

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.

See Also

Flux-Based PMSM | IM Controller | Interior PM Controller | Surface Mount PM Controller

Topics

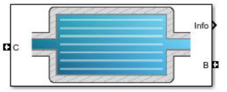
“Generate Parameters for Flux-Based Blocks”

Introduced in R2017b

Heat Exchanger

Intercooler or exhaust gas recirculation (EGR) cooler

Library: 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 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.

$$T_{dnstr} = T_{upstr} - \varepsilon\left(T_{upstr} - T_{cool}\right)$$
$$q_{ht} = \dot{m}c_p\left(T_{upstr} - T_{dnstr}\right)$$

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	$\dot{m} \geq 0$	$T_{upstr} = T_{flw,in}$ $T_{in} = T_{upstr}$ $T_{out} = T_{dnstr}$ $q_{out} = \dot{m}c_p T_{dnstr}$

Fluid Flow	Mass Flow Rate	Temperatures and Heat Flow
Reverse — From outlet volume to engine flow component	$\dot{m} < 0$	$T_{upstr} = T_{vol,out}$ $T_{in} = T_{dnstr}$ $T_{out} = T_{vol,out}$ $h_{in} = c_p T_{dnstr}$ $q_{out} = \dot{m} h_{vol,out}$

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, select `External input` for the **Effectiveness model** parameter.

`CoolTemp` — Cooling medium temperature
scalar

Cooling medium temperature, $T_{cool,input}$.

Dependencies

To create this port, select `External input` for the **Cooling medium temperature input** parameter.

Output

`Info` — Bus signal
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

`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.
- Selecting 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.
- Selecting Constant enables the **Cooling medium temperature, T_cool_cnst** parameter.

Image type — Icon color

Intercooler (default) | EGR cooler

Block icon color:

- Intercooler for blue, to indicate an intercooler
- EGR cooler for red, to indicate exhaust-gas-recirculation (EGR) cooling

`Heat exchanger effectiveness, ep_cnst` — Effectiveness
`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
`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
`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.

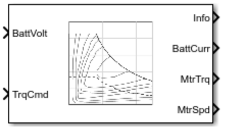
See Also

Control Volume System | Flow Restriction

Introduced in R2017a

Mapped Motor

Mapped motor and drive electronics operating in torque-control mode
Library: Propulsion / Electric Motors



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:

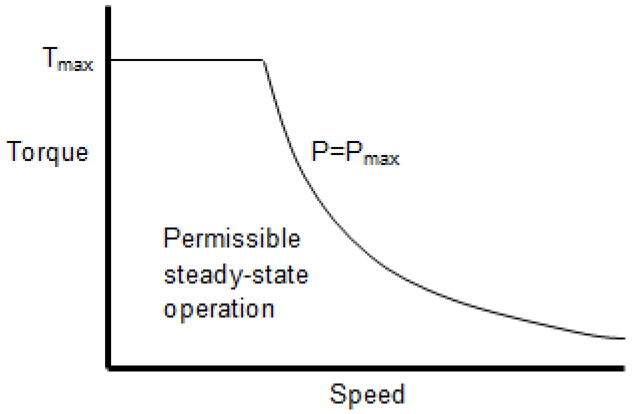
- Port configuration — Input torque or speed
- Electrical torque range — Torque speed envelope or maximum motor power and torque
- Electrical loss — Single operating point, measured efficiency, or measured loss

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.

Setting	Block Implementation
`Tabulated efficiency data`	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.

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.

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

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

Bus signal containing these block calculations.

Signal	Description	Units
`MechPwr`	Mechanical power	W
`PwrLoss`	Internal inverter and motor power loss	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

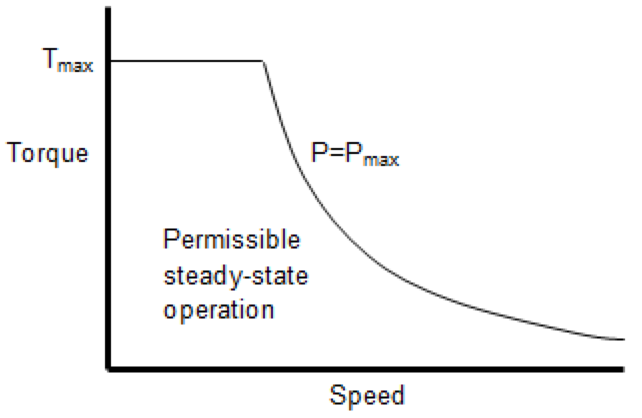
Electrical Torque

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
`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
`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
`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
`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
`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`

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.

Setting	Block Implementation
`Tabulated efficiency data`	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.

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.

`Motor and drive overall efficiency, eff` — Efficiency
`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
`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
`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
`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
`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

`[1 x 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 `Tabulated loss data` or `Tabulated efficiency data`

`Vector of torques (T) for tabulated losses, T_eff_bp` — Breakpoints

`[1 x 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 `Tabulated loss data` or `Tabulated efficiency data`

`Corresponding losses, losses_table` — Table

`[m x n] array`

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 `[mxn]` 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 efficiency, efficiency_table` — Table

`[m x n] 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 [mxn] 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.

Mechanical

Rotational inertia, J — Inertia

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

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

scalar

Rotor speed at the start of the simulation, in rad/s.

Dependencies

To create this parameter, for the **Port configuration** parameter, select Torque.

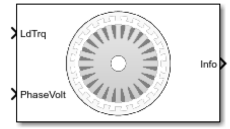
See Also

Flux-Based PMSM | Induction Motor | Interior PMSM | Surface Mount PMSM

Introduced in R2017a

Induction Motor

Three-phase induction motor
Library: Propulsion / Electric Motors

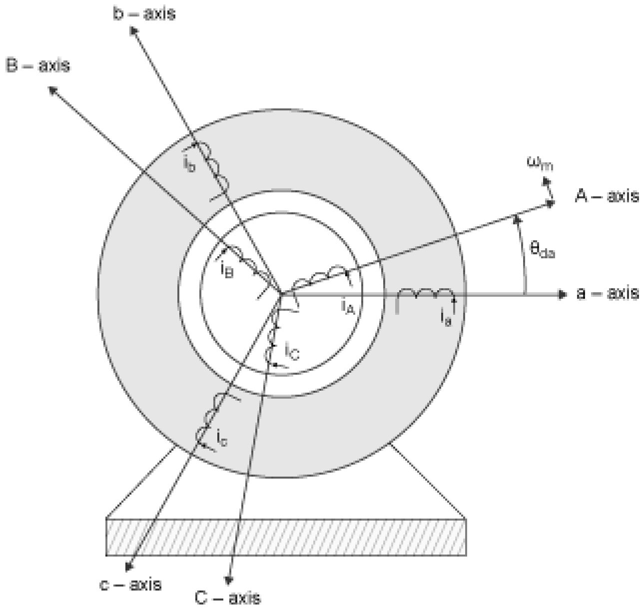


Description

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.

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	$$\frac{d}{dt}\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\end{bmatrix}=\begin{bmatrix}v_{sd}\\ v_{sq}\end{bmatrix}-R_s\begin{bmatrix}i_{sd}\\ i_{sq}\end{bmatrix}-\omega_{da}\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\end{bmatrix}$$ $$\frac{d}{dt}\begin{bmatrix}\lambda_{rd}\\ \lambda_{rq}\end{bmatrix}=\begin{bmatrix}v_{rd}\\ v_{rq}\end{bmatrix}-R_r\begin{bmatrix}i_{rd}\\ i_{rq}\end{bmatrix}-\omega_{dA}\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix}\begin{bmatrix}\lambda_{rd}\\ \lambda_{rq}\end{bmatrix}$$ $$\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\\ \lambda_{rd}\\ \lambda_{rq}\end{bmatrix}=\begin{bmatrix}L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix}\begin{bmatrix}i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix}$$
Current	$$\begin{bmatrix}i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix}=\left(\frac{1}{L_m^2-L_rL_s}\right)\begin{bmatrix}-L_r & 0 & L_m & 0\\ 0 & -L_r & 0 & L_m\\ L_m & 0 & -L_s & 0\\ 0 & L_m & 0 & -L_s\end{bmatrix}\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\\ \lambda_{rd}\\ \lambda_{rq}\end{bmatrix}$$
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
ω_{em}	Electrical rotor speed
ω_{slip}	Electrical rotor slip speed
ω_{syn}	Synchronous rotor speed
ω_{da}	dq stator electrical speed with respect to the rotor a-axis
ω_{dA}	dq stator electrical speed with respect to the rotor A-axis
Θ_{da}	dq stator electrical angle with respect to the rotor a-axis
Θ_{dA}	dq stator electrical angle with respect to the rotor A-axis
L_q, L_d	q- and d-axis inductances
L_s	Stator inductance
L_r	Rotor inductance
L_m	Magnetizing inductance
L_{ls}	Stator leakage inductance
L_{lr}	Rotor leakage inductance
v_{sq}, v_{sd}	Stator q- and d-axis voltages
i_{sq}, i_{sd}	Stator q- and d-axis currents
λ_{sq}, λ_{sd}	Stator q- and d-axis flux
i_{rq}, i_{rd}	Rotor q- and d-axis currents
λ_{rq}, λ_{rd}	Rotor q- and d-axis flux
v_a, v_b, v_c	Stator voltage phases a, b, c
i_a, i_b, i_c	Stator currents phases a, b, c
R_s	Resistance of the stator windings
R_r	Resistance of the rotor windings
P	Number of pole pairs
T_e	Electromagnetic torque

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	Rotor shaft static friction torque
ω_m	Angular mechanical velocity of the rotor

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
`vector`

Stator terminal voltages, V_a, V_b, and V_c, in V.

Output

`Info` — Bus signal
bus

Bus signal containing 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
`IdSta`	Direct axis current	i_{sd}	A
`IqSta`	Quadrature axis current	i_{sq}	A
`VdSta`	Direct axis voltage	v_{sd}	V
`VqSta`	Quadrature axis voltage	v_{sq}	V
`MtrSpd`	Angular velocity of the rotor	ω_m	rad/s
`MtrPos`	Rotor angular position	θ_m	rad
`MtrTrq`	Electromagnetic torque	T_e	N.m

Parameters

Configuration

`Port configuration` — Select port configuration
`Torque` (default) | `Speed`

This table summarizes the port configurations.

Port Configuration	Creates Ports

`Torque`	`PhaseV`
	
	`Info`
	
	`LdTrq`

`Speed`	`PhaseV`
	
	`Info`
	
	`Spd`

`Stator resistance and leakage inductance, Zs` — Resistance and inductance
`vector`

Stator resistance, R_S, in ohms and leakage inductance, L_{ls}, in H.

`Rotor resistance and leakage inductance, Zr` — Resistance and inductance
`vector`

Rotor resistance, R_r, in ohms and leakage inductance, L_{lr}, in H.

`Magnetizing inductance, Lm` — Inductance
`scalar`

Magnetizing inductance, L_m, in H.

`Number of pole pairs, P` — Pole pairs
`scalar`

Motor pole pairs, P.

`Initial mechanical position, theta_init` — Angular position
`scalar`

Initial rotor angular position, θ_{m0}, in rad.

`Initial mechanical speed, omega_init` — Angular speed
`scalar`

Initial angular velocity of the rotor, ω_{m0}, in rad/s.

Dependencies

To enable this parameter, select `Torque` for the **Port configuration**.

`Physical inertia, viscous damping, static friction, mechanical` — Inertia, damping, friction
`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 `Torque` for the **Port configuration**.

References

[1] Mohan, Ned. *Advanced Electric Drives: Analysis, Control and Modeling Using Simulink*. Minneapolis, MN: MNPERE, 2001.

See Also

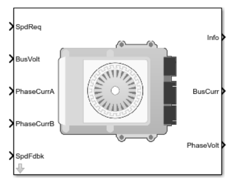
Flux-Based PMSM | IM Controller | Interior PMSM | Mapped Motor | Surface Mount PMSM

Introduced in R2017a

IM Controller

Internal torque-based, field-oriented controller for an induction motor with an optional outer-loop speed controller

Library: Propulsion / Electric Motor Controllers

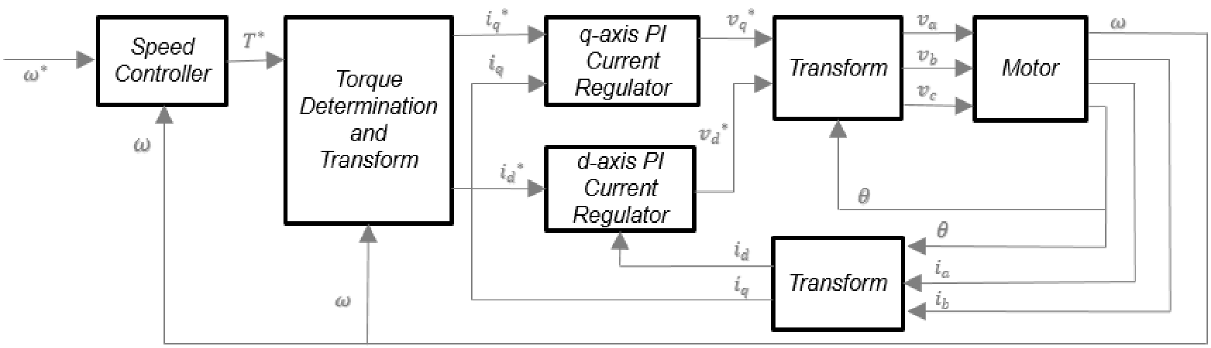


Description

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.



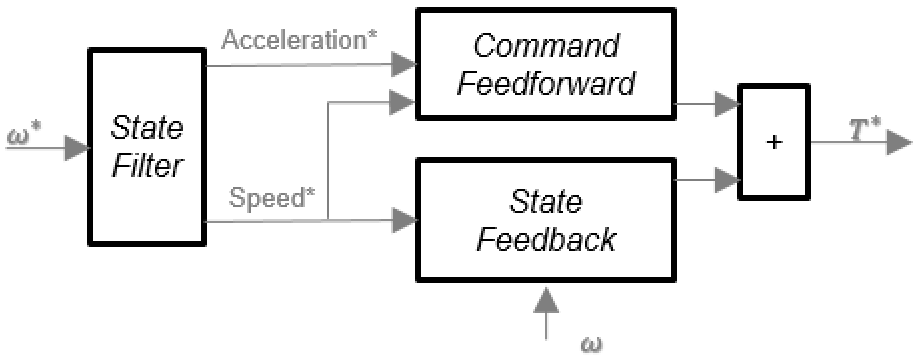
The block implements equations that use these variables.

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.



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 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

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	$K_{sa} = \frac{J_p \left(p_1 p_2 + p_2 p_3 + p_3 p_1\right) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$
Speed regulator double integral gain	$K_{isa} = \frac{-J_p \left(p_1 + p_2 + p_3\right) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$

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

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	$i_{qref} = \dfrac{T_{cmd}}{i_{sq\_0} \cdot P \cdot \left(\dfrac{L^2_m}{L_r}\right)}$
	 `If` $\lvert\omega_e\rvert \le \omega_{rated}$
	 $i_{dref} = i_{sd\_0}$
	 `Else`
	 $i_{dref} = \dfrac{i_{sd\_0}}{\lvert\omega_e\rvert}$
	 `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).	$x_a = x_\alpha$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$
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	$Ld_{Pwr} = v_a i_a + v_b i_b + v_c i_c$
Source power	$Src_{Pwr} = Ld_{Pwr} + Pwr_{Loss}$
DC bus current	$i_{bus} = \frac{Src_{Pwr}}{v_{bus}}$
Estimated rotor torque	$MtrTrq_{est} = P\lambda_{rd} i_{sq} \frac{L_m}{L_r}$
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	$Pwr_{Loss} = f(\omega_m, MtrTrq_{est})$

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.
`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
`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
`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
`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
`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
`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
`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
`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
`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

`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

`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
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**

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**

`Q-axis rated current, Isq_0` — Derived

`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**

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**

`Torque at rated current, Tem` — Derived
`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
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
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 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
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
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
`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
`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 time constant, Ksf**	**Speed Controller**

`Sample time for the motion control, Tsm` — Time
`scalar`

Sample time for the motion controller, in s.

Dependencies

The parameter is enabled when the **Control Type** parameter is set to `Speed Control`.

Parameter	Used to Derive	
	Parameter	Tab
Sample time for the motion control, Tsm	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa**	**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	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$	**Sample time for the motion control, Tsm** **Bandwidth of the motion controller, EV_motion** **Bandwidth of the state filter, EV_sf**	**Speed Controller**
Angular gain, Ksa	$K_{sa} = \frac{J_p \left(p_1 p_2 + p_2 p_3 + p_3 p_1\right) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$	**Sample time for the torque control, Tst**	**Current Controller**
Rotational gain, Kisa	$K_{isa} = \frac{-J_p \left(p_1 + p_2 + p_3\right) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$	**Physical inertia, viscous damping, static friction, Mechanical**	**Motor Parameters**
Speed 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
T_{sm}	Motion controller sample time
EV_{sf}	State filter bandwidth
EV_{motion}	Motion controller bandwidth

Proportional gain, ba — Derived
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 **Sample time for the motion control, Tsm**	**Speed Controller**

Angular gain, Ksa — Derived
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 **Sample time for the motion control, Tsm**	**Speed Controller**

`Rotational gain, Kisa` — Derived
`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 **Sample time for the motion control, Tsm**	**Speed Controller**

`Speed time constant, Ksf` — Derived
`scalar`

Derived speed time constant, in 1/s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	Tab
Speed 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

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

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

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
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
1-by-M matrix

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
1-by-N matrix

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
M-by-N matrix

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
1-by-M matrix

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

1-by-N matrix

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

M-by-N matrix

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.

See Also

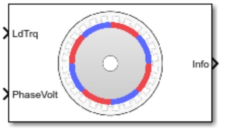
Flux-Based PM Controller | Induction Motor | Interior PM Controller | Surface Mount PM Controller

Introduced in R2017a

Surface Mount PMSM

Three-phase exterior permanent magnet synchronous motor with sinusoidal back electromotive force

Library: Propulsion / Electric Motors

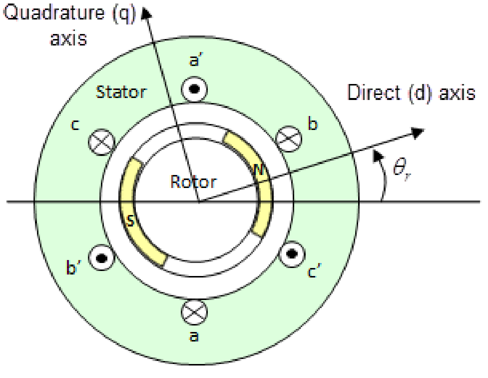


Description

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.

Motor Construction

This figure shows the motor construction with a single pole pair on the rotor.



The rotor magnetic field due to the permanent magnets creates a sinusoidal rate of change of flux with rotor angle.

For the axes convention, the *a*-phase and permanent magnet fluxes are aligned when rotor angle θ_r is zero.

Three-Phase Sinusoidal Model Electrical System

The block implements these equations, expressed in the rotor flux reference frame (dq frame). All quantities in the rotor 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 rotor position due to the saliency of the rotor magnets. For the surface mount PMSM,

$$L_d = L_q \, .$$

The equations use these variables.

L_q, L_d	q- and d-axis inductances
R	Resistance of the stator windings
i_q, i_d	q- and d-axis currents
v_q, v_d	q- and d-axis voltages
ω_m	Angular mechanical velocity of the rotor
ω_e	Angular electrical velocity of the rotor
λ_{pm}	Permanent magnet flux linkage
P	Number of pole pairs
T_e	Electromagnetic torque
Θ_e	Electrical angle

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	Rotor shaft static friction torque
ω_m	Angular mechanical velocity of the rotor

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
`vector`

Stator terminal voltages, V_a, V_b, and V_c, in V.

Output

`Info` — Bus signal
bus

Bus signal containing 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

Parameters

`Port Configuration` — Select port configuration
`Torque` (default) | `Speed`

This table summarizes the port configurations.

Port Configuration	Creates Ports
Torque	PhaseVolt Info LdTrq
Speed	PhaseVolt Info Spd

Stator phase resistance, Rs — Resistance
scalar

Stator phase resistance, R_s, in ohm.

Armature inductance, Ldq_ — Inductance
vector

Armature inductance, L_d, L_q, in H.

Permanent magnet flux, lambda_pm — Flux
scalar

Permanent magnet flux linkage, λ_{pm}, in Wb.

Number of pole pairs, P — Pole pairs
scalar

Motor pole pairs, P.

Initial dq current, idq0 — Current
vector

Initial q- and d-axis currents, i_q, i_d, in A.

Initial mechanical position, theta_init — Angle
scalar

Initial rotor angular position, θ_{m0}, in rad.

Initial mechanical speed, omega_init — Speed
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
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] 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.

See Also

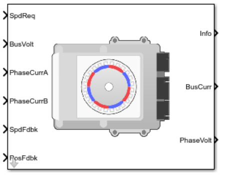
Flux-Based PMSM | Induction Motor | Interior PMSM | Mapped Motor | Surface Mount PM Controller

Introduced in R2017a

Surface Mount PM Controller

Torque-based, field-oriented controller for a surface mount permanent magnet synchronous motor

Library: Propulsion / Electric Motor Controllers

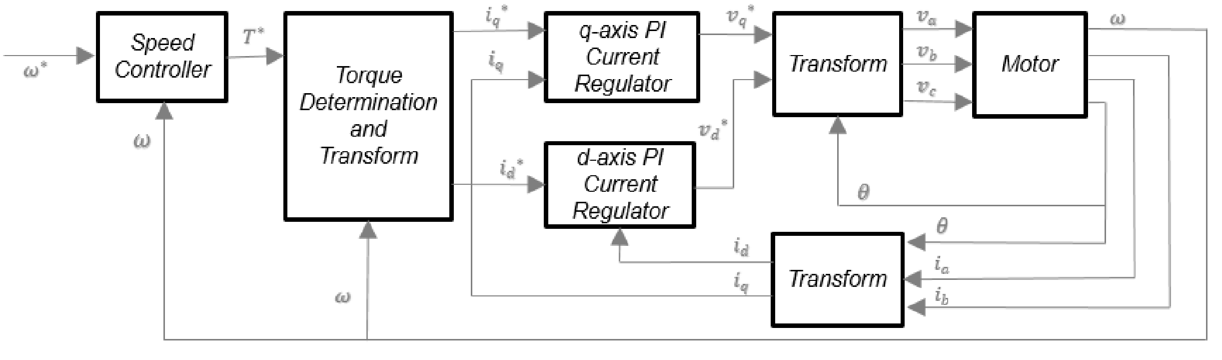


Description

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.



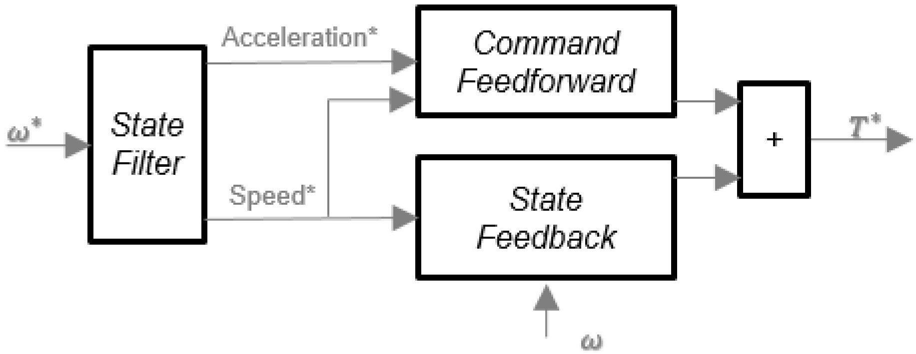
The block implements equations that use these variables.

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.



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 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

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	$K_{sa} = \frac{J_p\left(p_1 p_2 + p_2 p_3 + p_3 p_1\right) - 3J_p + 2b_a T_{sm}}{T_{sm}^2}$
Speed regulator double integral gain	$K_{isa} = \frac{-J_p\left(p_1 + p_2 + p_3\right) + 3J_p - b_a T_{sm} - K_{sa} T_{sm}^2}{T_{sm}^3}$

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

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` $\lvert\omega_e\rvert \le \omega_{base}$
	$i_{qref} = i_{q\_tmp}$
	`Else`
	$i_{qfw} = sqrt(\min(0, \frac{1}{L_q}(\left(\frac{v_{max}}{\omega_e}\right)^2 - \left(\lambda_{pm}\right)^2))$
	`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	$L_d \frac{di_d}{dt} = v_d - R_s i_d + p\omega_m L_q i_q$ $L_d \frac{di_q}{dt} = v_q - R_s i_q - p\omega_m L_d i_d - p\omega_m \lambda_{pm}$
Current regulator gains	$\omega_b = 2\pi EV_{current}$ $K_{p\_d} = L_d \omega_b$ $K_{p\_q} = L_q \omega_b$ $K_i = R_s \omega_b$

Calculation	Equations
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).	$x_a = x_\alpha$ $x_b = -\frac{1}{2}x_\alpha + \frac{\sqrt{3}}{2}x_\beta$ $x_c = -\frac{1}{2}x_\alpha - \frac{\sqrt{3}}{2}x_\beta$
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	$i_{bus} = \dfrac{Src_{Pwr}}{v_{bus}}$
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	$Pwr_{Loss} = \dfrac{100 - Eff}{Eff} \cdot Ld_{Pwr}$
Power loss for single efficiency load to source	$Pwr_{Loss} = \dfrac{100 - Eff}{100} \cdot \lvert Ld_{Pwr} \rvert$
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
`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
`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
`scalar`

Permanent magnet flux, λ_{pm}, in Wb.

`Number of pole pairs, PolePairs` — Poles
`scalar`

Motor pole pairs, P.

`Physical inertia, viscous damping, static friction, Mechanical` — Inertia, damping, friction
`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
`scalar`

Maximum torque, in N.m.

Current Controller

`Bandwidth of the current regulator, EV_current` — Bandwidth
`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
`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 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
`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
`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

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

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
`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 time constant, Ksf**	**Speed Controller**

`Sample time for the motion control, Tsm` — Time
`scalar`

Sample time for the motion controller, in s.

Dependencies

The parameter is enabled when the **Control Type** parameter is set to `Speed Control`.

Parameter	Used to Derive	
	Parameter	Tab
Sample time for the motion control, Tsm	**Proportional gain, ba** **Angular gain, Ksa** **Rotational gain, Kisa**	**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	$b_a = \frac{J_p - J_p p_1 p_2 p_3}{T_{sm}}$	**Sample time for the motion control, Tsm** **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 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**

Derived Parameter on Speed Controller tab		Depends On	
		Parameter	Tab
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
T_{sm}	Motion controller sample time
EV_{sf}	State filter bandwidth
EV_{motion}	Motion controller bandwidth

`Proportional gain, ba` — Derived

`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**

Parameter	Dependency	
	Parameter	Tab
	Bandwidth of the motion controller, EV_motion **Sample time for the motion control, Tsm**	**Speed Controller**

`Angular gain, Ksa` — Derived

`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 **Sample time for the motion control, Tsm**	**Speed Controller**

`Rotational gain, Kisa` — Derived

`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 **Sample time for the motion control, Tsm**	**Speed Controller**

`Speed time constant, Ksf` — Derived
`scalar`

Derived speed time constant, in 1/s.

Dependencies

This table summarizes the parameter dependencies.

Parameter	Dependency	
	Parameter	**Tab**
Speed 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
`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
`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
`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
`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
1-by-M matrix

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
1-by-N matrix

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
M-by-N matrix

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
1-by-M matrix

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
1-by-N matrix

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
`M`-by-`N` matrix

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.

See Also

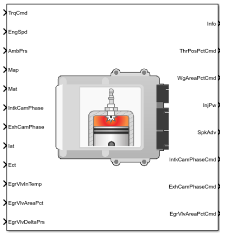
Flux-Based PM Controller | IM Controller | Interior PM Controller | Surface Mount PMSM

Introduced in R2017a

SI Controller

Spark-ignition engine controller that uses the driver torque request

Library: 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.

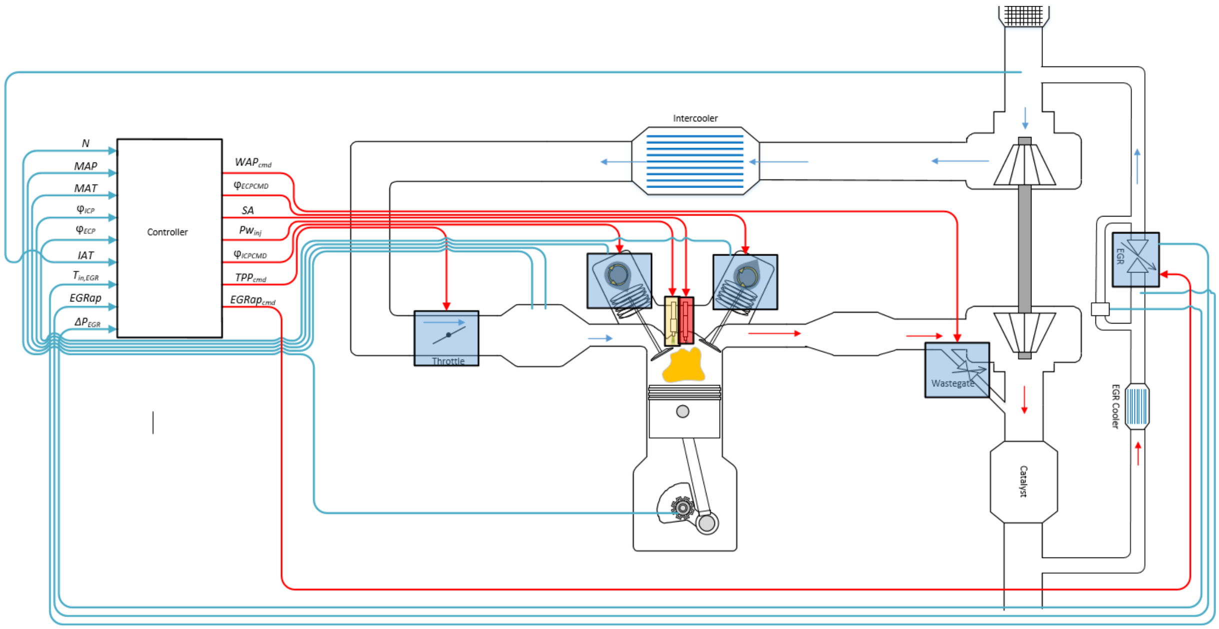
The block uses the commanded torque and engine speed to determine these open-loop actuator commands:

- 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

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.

$$\varphi_{ICPCMD} = f_{ICPCMD}\left(L_{est}, N\right)$$

$$\varphi_{ECPCMD} = f_{ECPCMD}\left(L_{est}, N\right)$$

The block calculates the desired engine load using this equation.

$$L_{est} = \frac{CpsR_{air}T_{std}\dot{m}_{air,est}}{P_{std}V_{d}N}$$

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

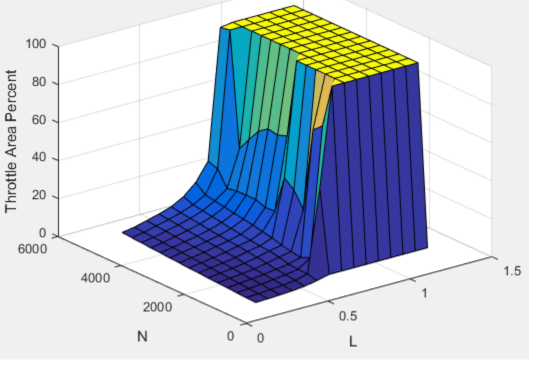
The controller subsystem uses these lookup tables for the air calculations.

- 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.

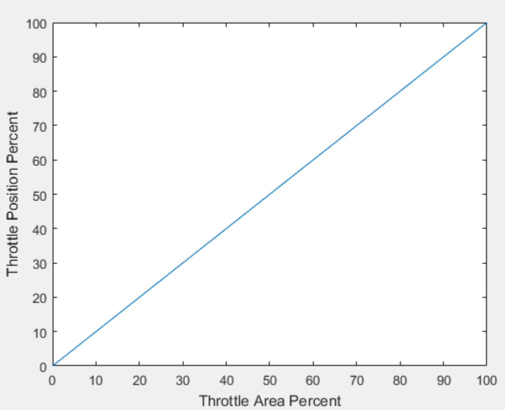
- To account for the non-linearity of the throttle position to throttle area, the throttle position percent lookup table linearizes the open-loop air mass flow control.

  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.

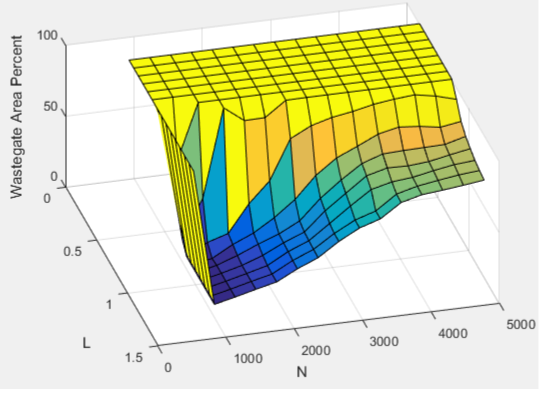


- The wastegate area percent command lookup table, f_{WAPcmd}, is a function of the commanded engine load and engine speed

$$WAP_{cmd} = f_{WAPcmd}\left(L_{cmd}, N\right)$$

where:

- WAP_{cmd} is wastegate area percentage command, in percent.
- L_{cmd}=L is commanded engine load, dimensionless.
- N is engine speed, in rpm.

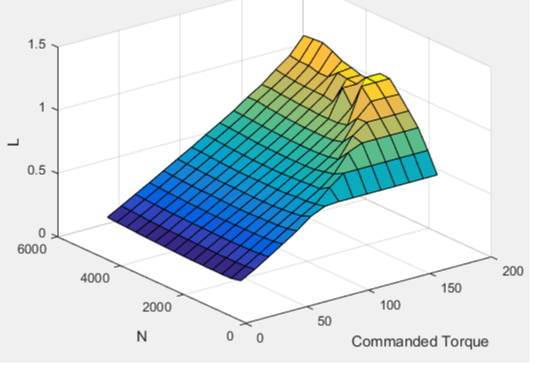


- The commanded engine load lookup table, f_{Lcmd}, is a function of the commanded torque and engine speed

  $$L_{cmd} = f_{Lcmd}(T_{cmd}, N)$$

  where:

  - L_{cmd}=L is commanded engine load, dimensionless.
  - T_{cmd} is commanded torque, in N.m.
  - N is engine speed, in rpm.

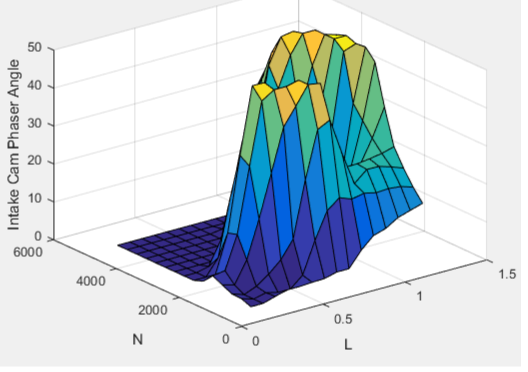
  

- The intake cam phaser angle command lookup table, f_{ICPCMD}, is a function of the engine load and engine speed

  $$\varphi_{ICPCMD} = f_{ICPCMD}(L_{est}, N)$$

  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.

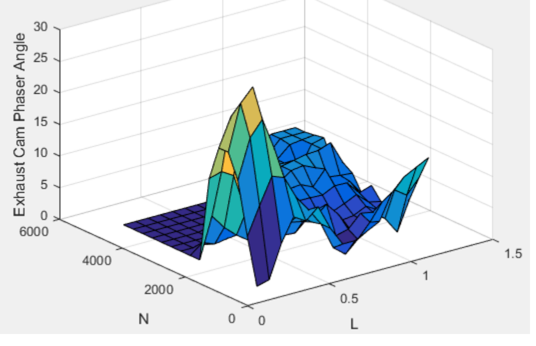


- The exhaust cam phaser angle command lookup table, f_{ECPCMD}, is a function of the engine load and engine speed

$$\varphi_{ECPCMD} = f_{ECPCMD}(L_{est}, N)$$

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 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	$\dot{m}_{EGRstd,cmd} = \dot{m}_{EGR,cmd} \frac{P_{std}}{P_{in,EGR}} \sqrt{\frac{T_{in,EGR}}{T_{std}}}$ $\dot{m}_{EGRstd,max} = f_{EGRstd,max} \left(\frac{P_{out,EGR}}{P_{in,EGR}} \right)$ $\dot{m}_{EGR,cmd} = EGR_{pct,cmd} \dot{m}_{intk,est}$

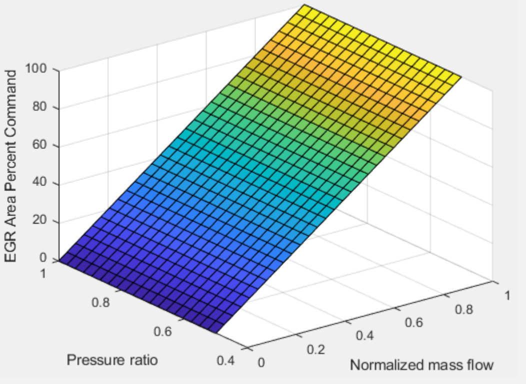
<table>
<tr><td>Lookup table</td><td>

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.



</td></tr>
</table>

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

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.

$$\lambda_{cmd} = \frac{AFR_{cmd}}{AFR_{stoich}}$$

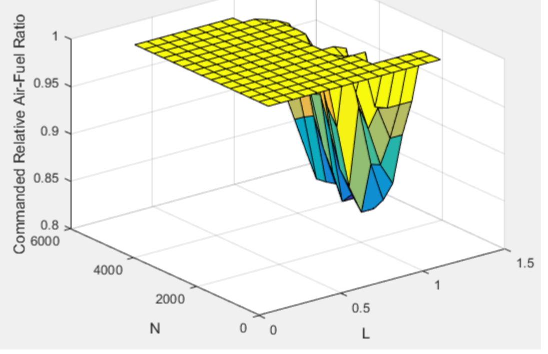
$$AFR_{cmd} = \frac{\dot{m}_{air,est}}{\dot{m}_{fuel,cmd}}$$

The commanded lambda, λ_{cmd}, lookup table is a function of estimated engine load and measured engine speed

$$\lambda_{cmd} = f_{\lambda cmd}\left(L_{est}, N\right)$$

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.

$$Pw_{inj} = \begin{cases} \dfrac{\dot{m}_{fuel,cmd} Cps(\frac{60s}{min})\left(\frac{1000mg}{g}\right)\left(\frac{1000g}{kg}\right)}{NS_{inj} N_{cyl}} & \text{when } \; Trq_{cmd} > 0 \\ 0 & \text{when } \; Trq_{cmd} \leq 0 \end{cases}$$

The equations use these variables.

λ_{cmd}	Lambda command, relative AFR
L_{est}	Estimated engine load, based on normalized cylinder air mass
N	Engine speed
Trq_{cmd}	Commanded engine torque
AFR_{stoich}	Stoichiometric fuel AFR

AFR_{cmd}	Commanded AFR
$\dot{m}_{air,est}$	Estimated engine air mass flow
$\dot{m}_{fuel,cmd}$	Commanded fuel mass flow
N_{cyl}	Number of engine cylinders
S_{inj}	Fuel injector slope
Pw_{inj}	Fuel injector pulse-width
$f_{\lambda cmd}$	Relative AFR lookup table

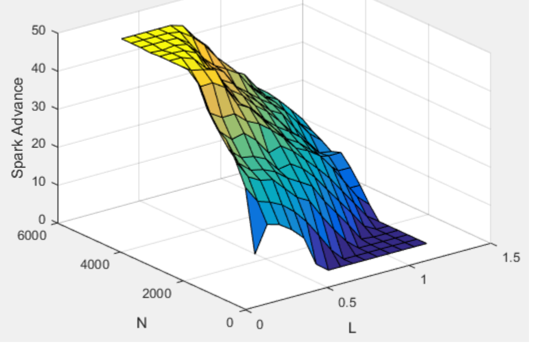
Spark advance is the crank angle before top dead center (BTDC) of the power stroke when the spark is delivered. The spark advance has an impact on engine efficiency, torque, exhaust temperature, knock, and emissions.

The spark advance lookup table is a function of estimated load and engine speed.

$$SA = f_{SA}\left(L_{est}, N\right)$$

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

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

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

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

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.
"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.

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

$$\dot{m}_{air,std} = \dot{m}_{air,est}\frac{P_{std}}{P_{amb}}\sqrt{\frac{IAT}{T_{std}}}$$

$$P_{in,EGR} = P_{out,EGR} + \Delta P_{EGR}$$

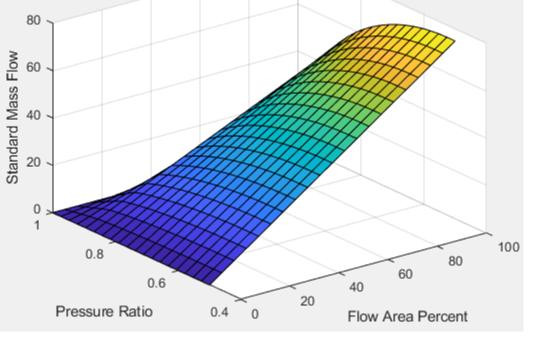
$$\dot{m}_{EGR,est} = \dot{m}_{EGR,std}\frac{P_{in,EGR}}{P_{std}}\sqrt{\frac{T_{std}}{T_{in,EGR}}}$$

- 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.

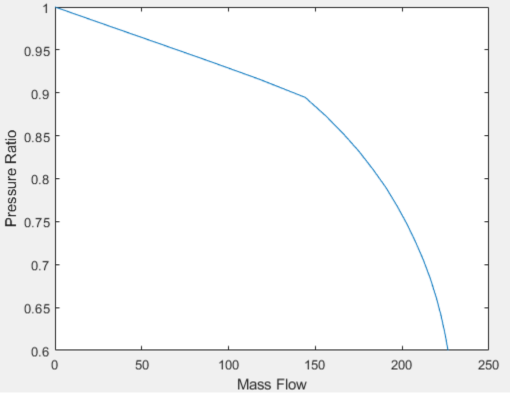


- The pressure ratio is a function of the standard mass flow

$$\frac{P_{out,EGR}}{P_{amb}} = f_{intksys,pr}(\dot{m}_{air,std})$$

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

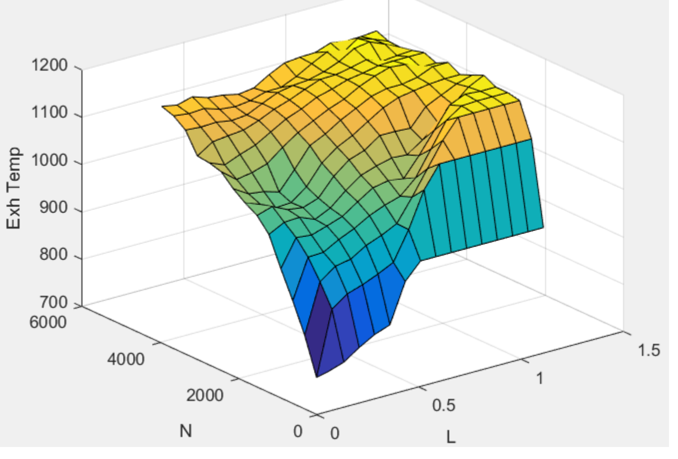
ΔP_{EGR}	Pressure difference at EGR valve inlet and outlet
$T_{in,EGR}$, $T_{out,EGR}$	Temperature at EGR valve inlet and outlet, respectively
$P_{in,EGR}$, $P_{out,EGR}$	Pressure at EGR valve inlet and outlet, respectively

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 pressure MAP, 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.

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

Signal	Description	Variable	Units
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
EstEngTrq	Estimated engine torque	Trq_{est}	N.m
EstNrmlzdAirCharg	Estimated normalized cylinder air mass	N/A	N/A
EstIntkPortFlw	Estimated air mass flow rate	$\dot{m}_{air,est}$	kg/s
EstExhManGasTemp	Estimated exhaust manifold gas temperature	$T_{exh,est}$	K

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.

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

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.
"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**

Torque Estimation Model	Enables Parameters on Estimation > Torque Tab
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

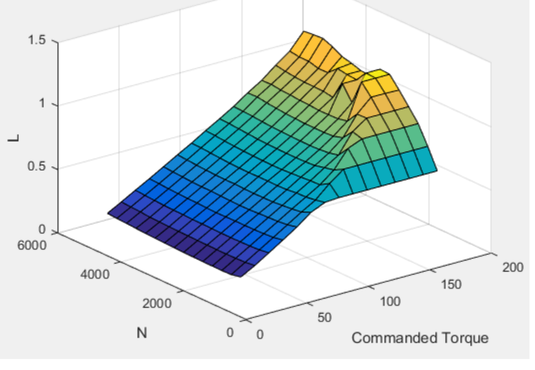
array

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
`array`

Torque command breakpoints, in N.m.

`Speed breakpoints, f_lcmd_n_bpt` — Breakpoints
`array`

Speed breakpoints, in rpm.

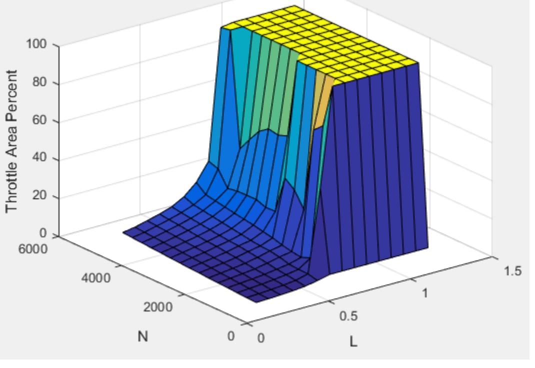
`Throttle area percent, f_tap` — Lookup table, %
`array`

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
`array`

Throttle area percent load breakpoints, dimensionless.

Throttle area percent speed breakpoints, f_tap_n_bpt — Breakpoints
array

Throttle area percent speed breakpoints, in rpm.

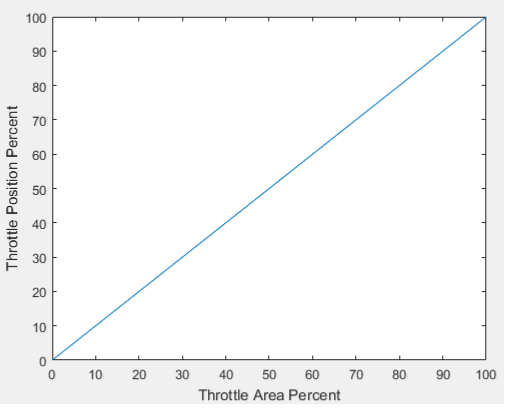
Throttle area percent to position percent table, f_tpp — Lookup table
array

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
array

Throttle area percent to position percent area breakpoints, dimensionless.

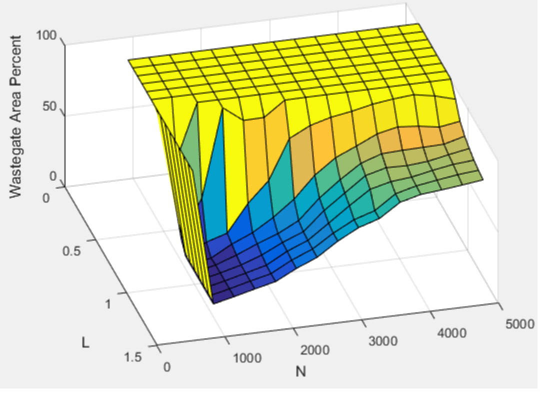
Wastegate area percent, f_wap — Lookup table, %
array

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
array

Load breakpoints, dimensionless.

Speed breakpoints, f_wap_n_bpt — Breakpoints, rpm
array

Speed breakpoints, in rpm.

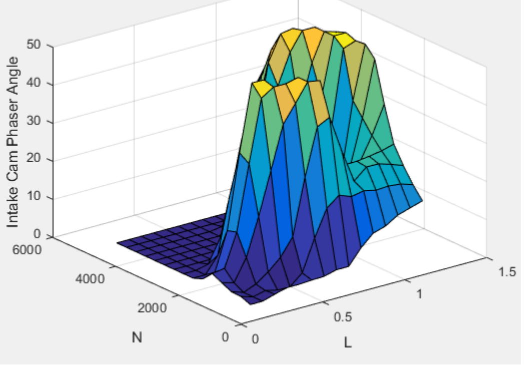
Intake cam phaser angle, f_icp — Lookup table
array

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.



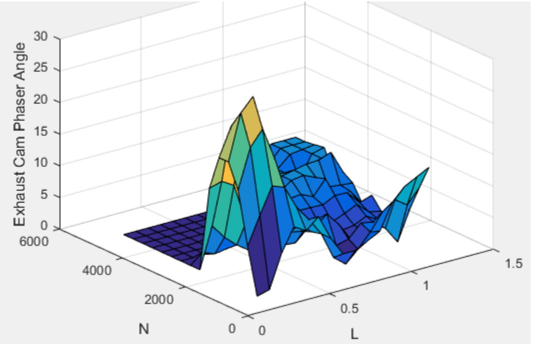
`Exhaust cam phaser angle, f_ecp` — Lookup table
`array`

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
`array`

Load breakpoints, dimensionless.

Speed breakpoints, `f_cp_n_bpt` — Breakpoints
`array`

Speed breakpoints, in rpm.

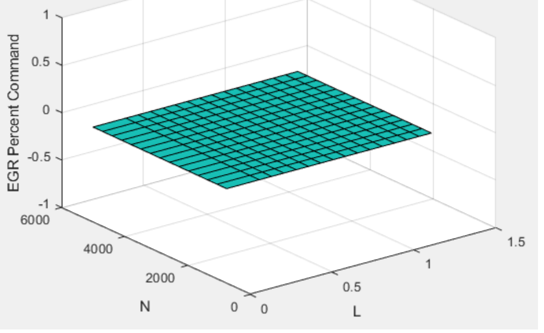
Commanded EGR percent, `f_egrpct_cmd` — Lookup table
`array`

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
vector

Engine load breakpoints, L, dimensionless.

Speed breakpoints, f_egrpct_n_bpt — Breakpoints
vector

Engine speed breakpoints, N, in rpm.

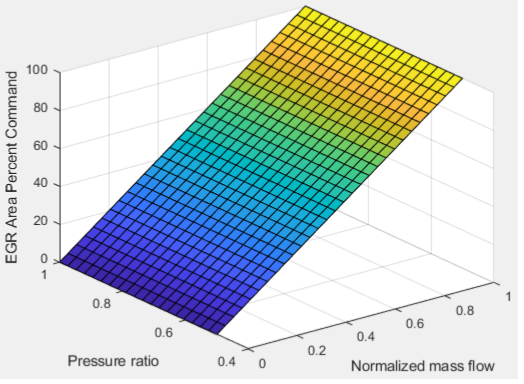
EGR valve area percent, f_egr_areapct_cmd — Lookup table
array

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
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
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
scalar

Fuel injector slope, S_{inj}, in mg/ms.

Stoichiometric air-fuel ratio, `afr_stoich` — Ratio
`scalar`

Stoichiometric air-fuel ratio, AFR_{stoich}.

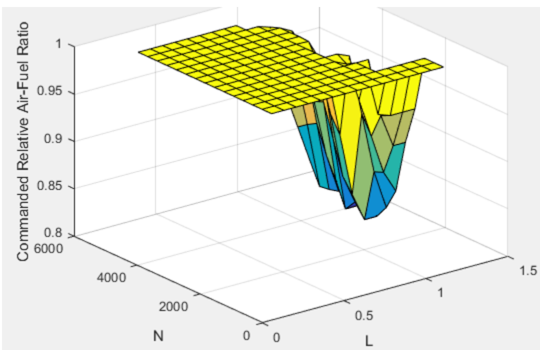
Relative air-fuel ratio lambda, `f_lam` — Air-fuel-ratio (AFR) lookup table
`array`

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.



Load breakpoints, `f_lam_ld_bpt` — Breakpoints
`array`

Load breakpoints, dimensionless.

Speed breakpoints, `f_lam_n_bpt` — Breakpoints
`array`

Speed breakpoints, in rpm.

Spark

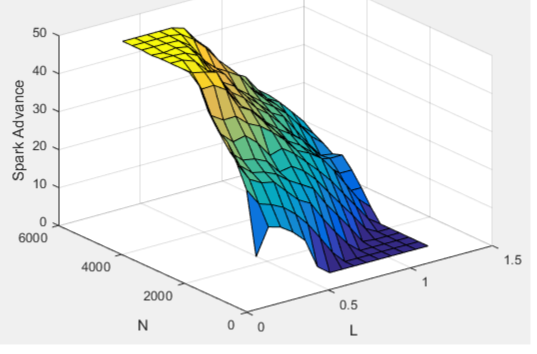
`Spark advance table, f_sa` — Lookup table
`array`

The spark advance lookup table is a function of estimated load and engine speed.

$$SA = f_{SA}\left(L_{est}, N\right)$$

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
`array`

Load breakpoints, dimensionless.

`Speed breakpoints, f_sa_n_bpt` — Breakpoints
`array`

Speed breakpoints, in rpm.

Idle Speed

`Target idle speed, N_idle` — Speed
`scalar`

Target idle speed, N_{idle}, in rpm.

`Enable torque command limit, Trq_idlecmd_enable` — Torque
`scalar`

Torque to enable the idle speed controller, $Trq_{idlecmd,enable}$, in N.m.

`Maximum torque command, Trq_idlecmd_max` — Torque
`scalar`

Maximum idle controller commanded torque, $Trq_{idlecmd,max}$, in N.m.

`Proportional gain, Kp_idle` — PI Controller
`scalar`

Proportional gain for idle speed control, $K_{p,idle}$, in N.m/rpm.

`Integral gain, Ki_idle` — PI Controller
`scalar`

Integral gain for idle speed control, $K_{i,idle}$, in N.m/(rpm*s).

Estimation

Air

`Number of cylinders, NCyl` — Engine cylinders
`scalar`

Number of engine cylinders, N_{cyl} .

`Crank revolutions per power stroke, Cps` — Revolutions per stroke
`scalar`

Crankshaft revolutions per power stroke, Cps , in rev/stroke.

`Total displaced volume, Vd` — Volume
`scalar`

Displaced volume, V_d , in m^3.

Ideal gas constant air, Rair — Constant
scalar

Ideal gas constant, R_{air} , in J/(kg*K).

Air standard pressure, Pstd — Pressure
scalar

Standard air pressure, P_{std} , in Pa.

Air standard temperature, Tstd — Temperature
scalar

Standard air temperature, T_{std} , in K.

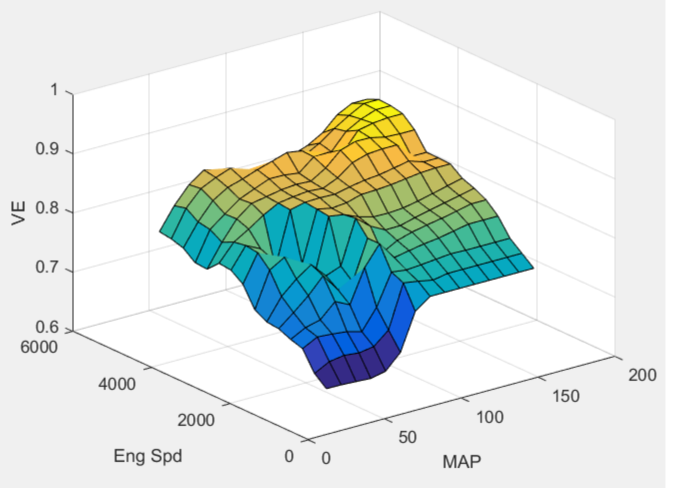
Speed-density volumetric efficiency, f_nv — Lookup table
array

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

`array`

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

`array`

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`.

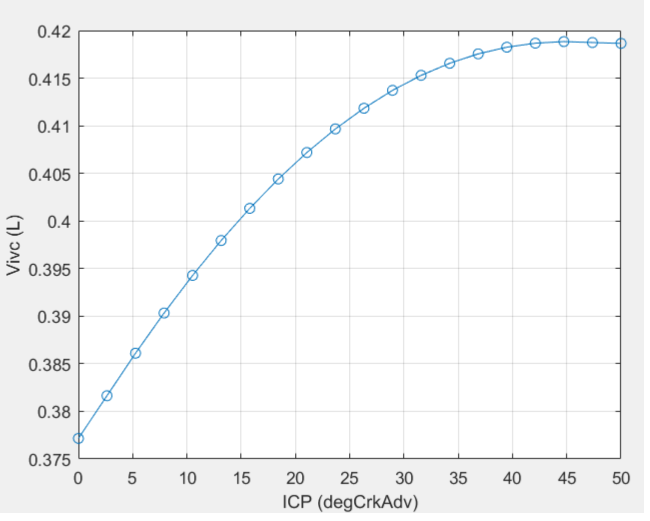
`Cylinder volume at intake valve close table, f_vivc` — 2-D lookup table
`array`

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
`array`

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
array

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`.

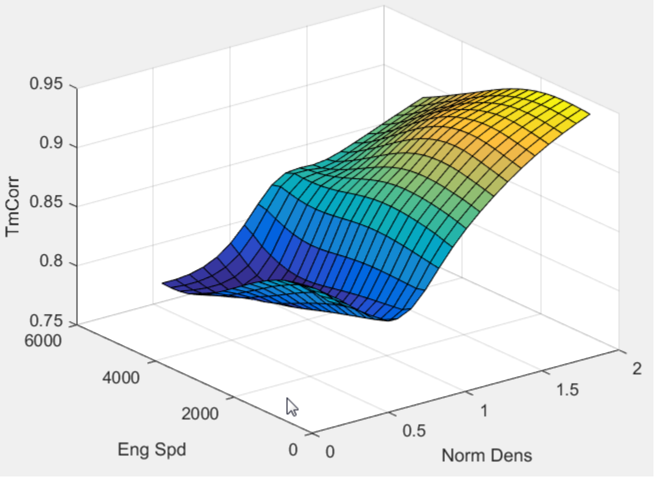
Cylinder trapped mass correction factor, f_tm_corr — Lookup table
array

The trapped mass correction factor table, f_{TMcorr}, is a function of the normalized density and engine speed

$$TM_{corr} = f_{TMcorr}(\rho_{norm}, N)$$

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

`array`

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

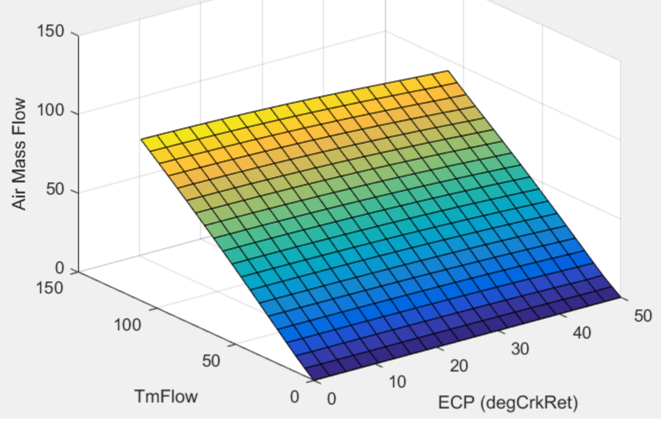
`array`

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
`array`

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
`array`

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`.

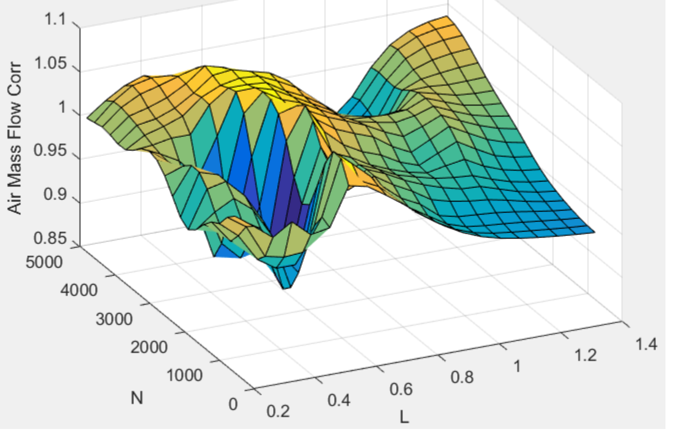
`Air mass flow correction factor, f_mdot_air_corr` — Lookup table
`array`

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
array

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
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
scalar

EGR flow time constant, τ_{EGR}, in s.

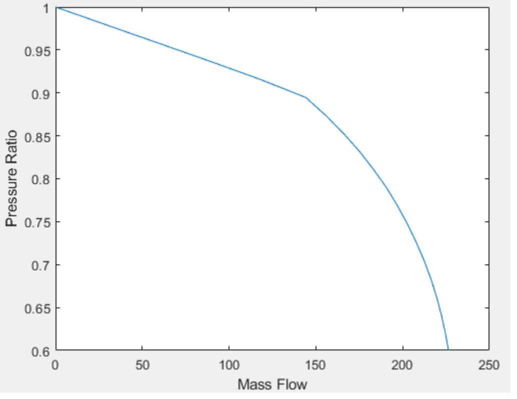
Intake system pressure ratio table, f_intksys_stdflow_pr — Table
array

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.
- $\dfrac{P_{out,EGR}}{P_{amb}}$ is pressure ratio, dimensionless.



Standard mass flow rate breakpoints for intake pressure ratio, f_intksys_stdflow_bpt — Breakpoints
vector

Standard mass flow, $\dot{m}_{air,std}$, in g/s.

EGR valve standard mass flow rate, f_egr_stdflow — Table
array

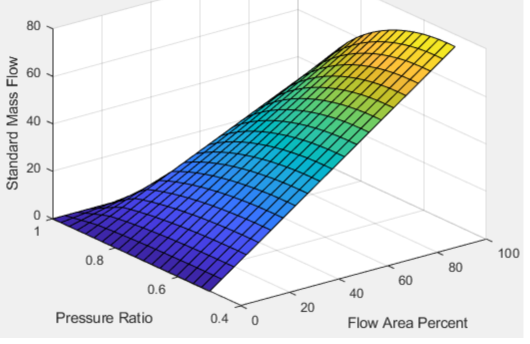
The EGR valve standard mass flow lookup table is a function of EGR valve area percent and the pressure ratio

$$\dot{m}_{EGR,std} = f_{EGR,std}\left(EGRap, \frac{P_{out,EGR}}{P_{in,EGR}}\right)$$

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
`vector`

EGR valve flow area percent, *EGRap*, in percent.

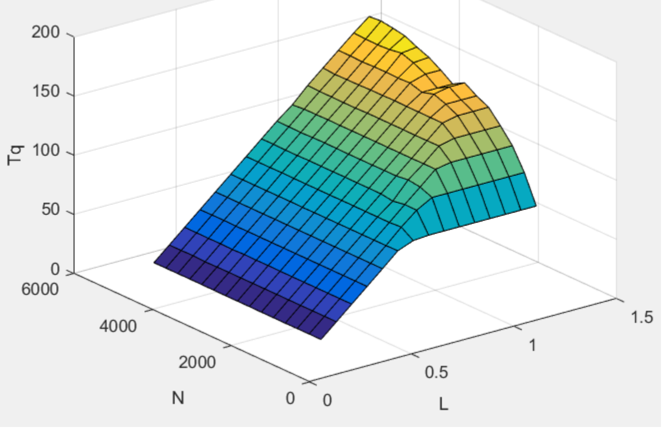
Torque

`Torque table, f_tq_nl` — Lookup table
`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.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table load breakpoints, f_tq_nl_l_bpt` — Breakpoints
`array`

Engine load breakpoints, 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
`array`

Engine speed breakpoints, in rpm.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

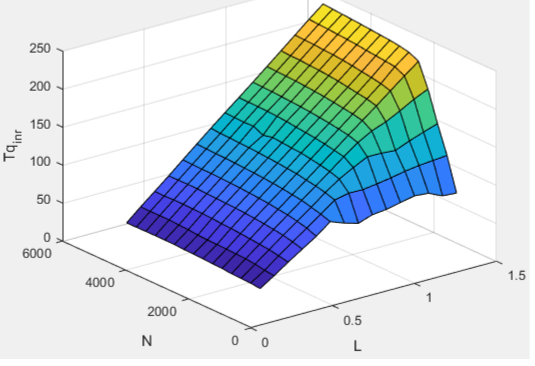
`Inner torque table, f_tq_inr` — Lookup table

`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

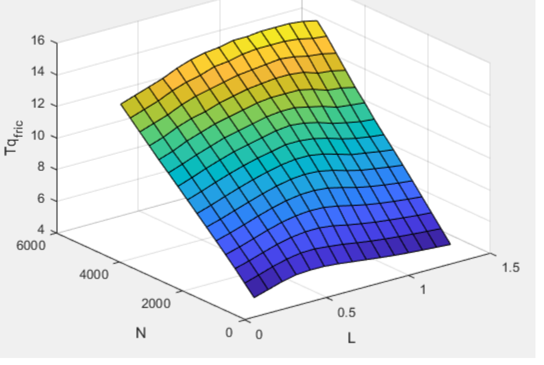
`array`

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

`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

`vector`

Engine temperature modifier breakpoints, in K.

Dependencies

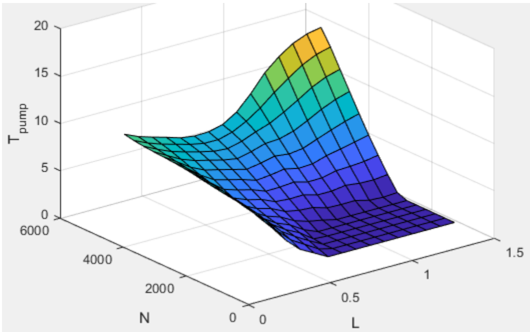
To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`Pumping torque table, f_tq_pump` — Lookup table

`array`

The pumping torque lookup table, f_{Tpump}, is a function of engine speed and injected fuel mass, $T_{pump}=f_{Tpump}(L,N)$, where:

- T_{pump} is pumping torque, 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`.

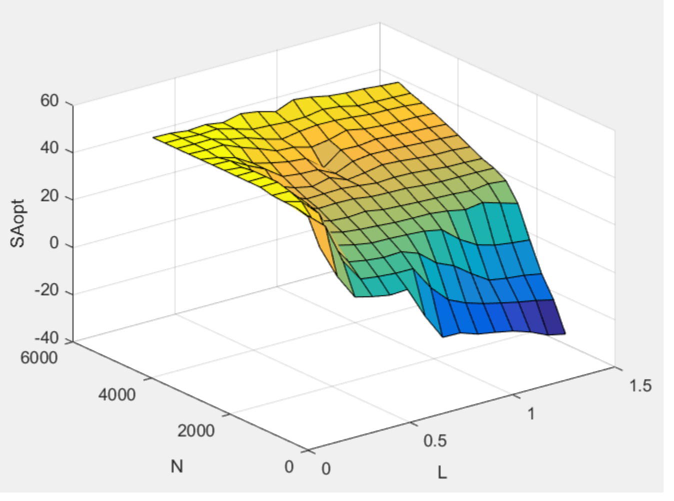
`Optimal spark table, f_sa_opt` — Lookup table

`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
`array`

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
`array`

Inner torque speed breakpoints, in rpm.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

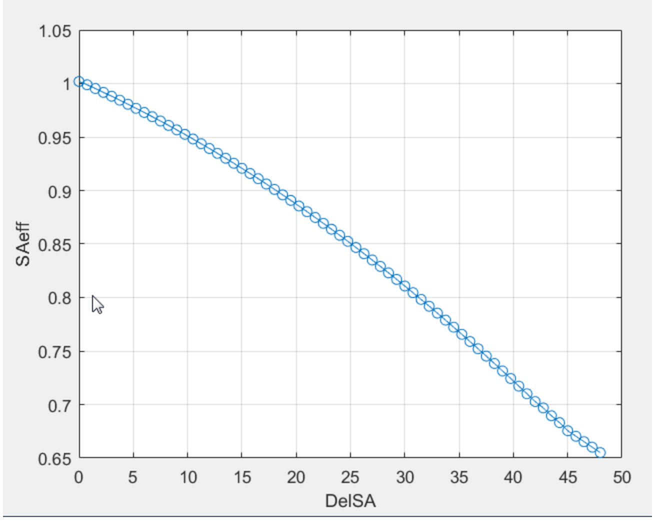
`Spark efficiency table, f_m_sa` — Lookup table
`array`

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.
- ΔSA 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
`scalar`

Spark retard from optimal inner torque timing breakpoints, in deg.

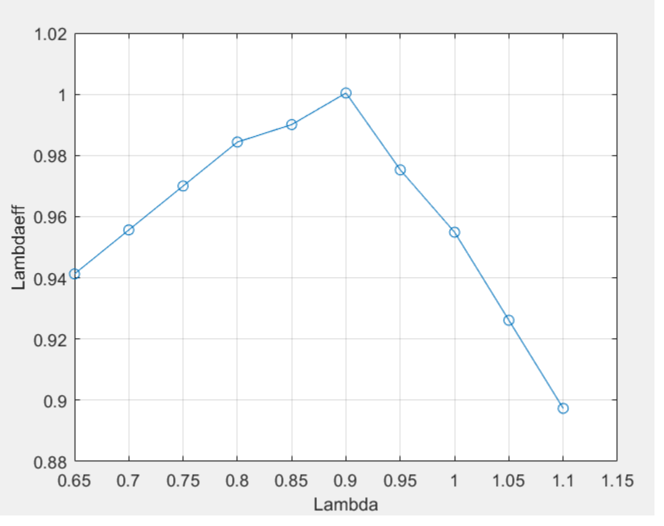
Dependencies

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
`array`

Lambda effect on inner torque lambda breakpoints, dimensionless.

Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

Exhaust

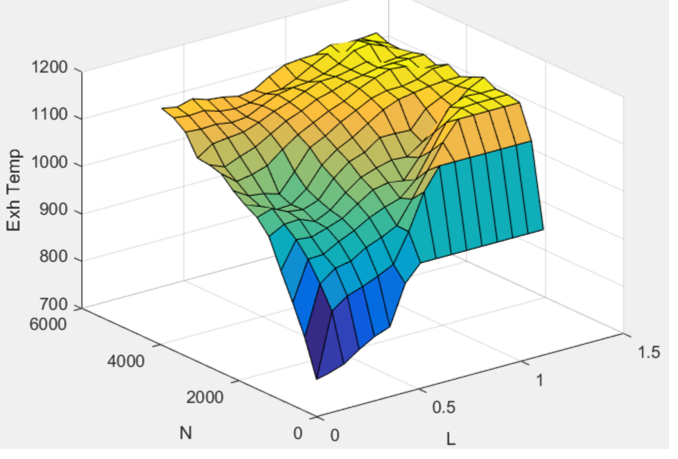
`Exhaust temperature table, f_t_exh` — Lookup table
`array`

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
`array`

Engine load breakpoints used for exhaust temperature lookup table.

`Speed breakpoints, f_t_exh_n_bpt` — Breakpoints
`array`

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.

See Also

Mapped SI Engine | SI Core Engine

Topics

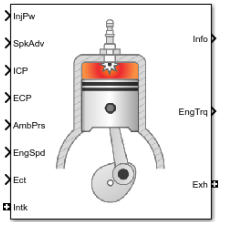
"Engine Calibration Maps"

Introduced in R2017a

SI Core Engine

Spark-ignition engine from intake to exhaust port

Library: 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.
"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.
"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.

$$\dot{m}_{fuel} = \frac{NS_{inj}Pw_{inj}N_{cyl}}{Cps\left(\frac{60s}{\min}\right)\left(\frac{1000mg}{g}\right)}$$

The equation uses these variables.

$\dot{m}_{fuel}$	Engine 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

Air-Fuel Ratio

To calculate the air-fuel (AFR) ratio, the CI Core Engine and SI Core Engine blocks implement this equation.

$$AFR = \frac{\dot{m}_{air}}{\dot{m}_{fuel}}$$

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.

$$EGR_{pct} = 100\frac{\dot{m}_{intk,b}}{\dot{m}_{intk}} = 100 y_{intk,b}$$

The equations use these variables.

AFR	Air-fuel ratio
$\dot{m}_{intk}$	Engine air mass flow
$\dot{m}_{fuel}$	Fuel mass flow
$y_{intk,b}$	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

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 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

Signal	Description	Variable	Units
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
EoPm	EO particulate matter emission mass flow rate	$y_{exh,PM}$	kg/s

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.

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

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.
"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 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**

Torque Model	Enables Parameters
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
scalar

Number of engine cylinders, N_{cyl} .

Crank revolutions per power stroke, Cps — Revolutions per stroke
scalar

Crankshaft revolutions per power stroke, Cps , in rev/stroke.

Total displaced volume, Vd — Volume
scalar

Displaced volume, V_d , in m^3.

Ideal gas constant air, Rair — Constant
scalar

Ideal gas constant, R_{air} , in J/(kg*K).

Air standard pressure, Pstd — Pressure
scalar

Standard air pressure, P_{std} , in Pa.

Air standard temperature, Tstd — Temperature
scalar

Standard air temperature, T_{std} , in K.

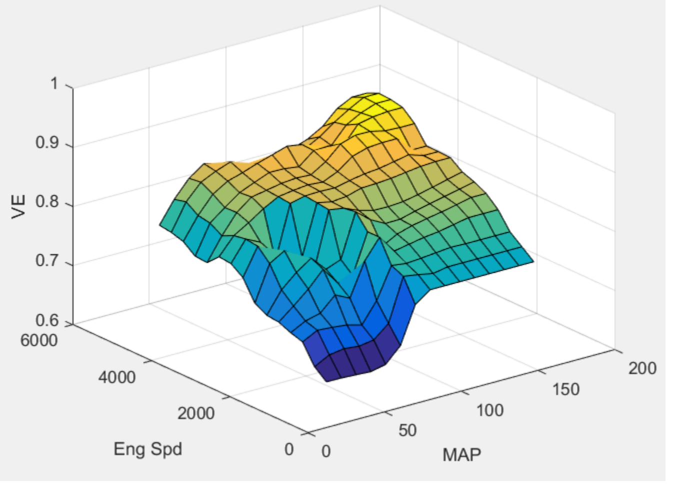
Speed-density volumetric efficiency, f_nv — Lookup table
array

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
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
`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`.

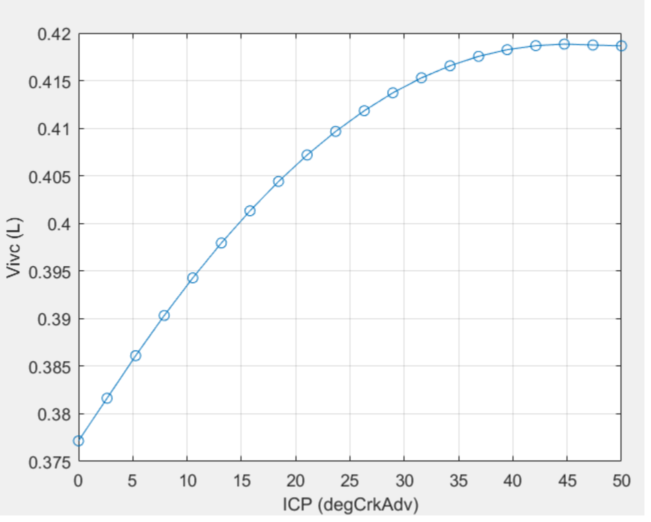
`Cylinder volume at intake valve close table, f_vivc` — 2-D lookup table
`array`

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
array

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`.

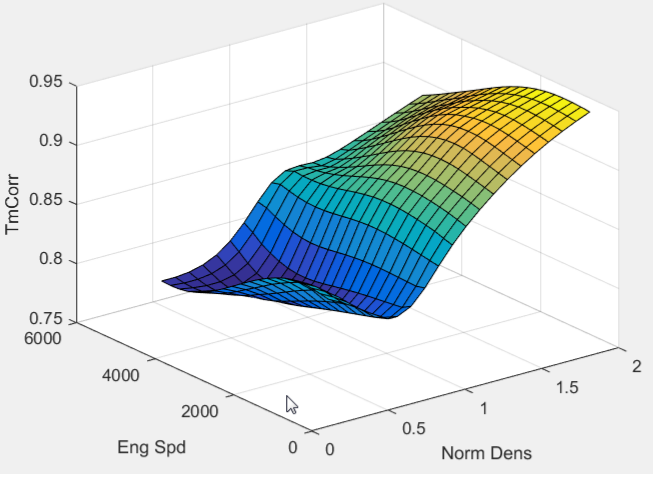
Cylinder trapped mass correction factor, f_tm_corr — Lookup table
array

The trapped mass correction factor table, f_{TMcorr}, is a function of the normalized density and engine speed

$$TM_{corr} = f_{TMcorr}(\rho_{norm}, N)$$

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
`array`

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
`array`

Engine speed breakpoints, in rpm.

Dependencies

To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

`Air mass flow, f_mdot_air` — Lookup table

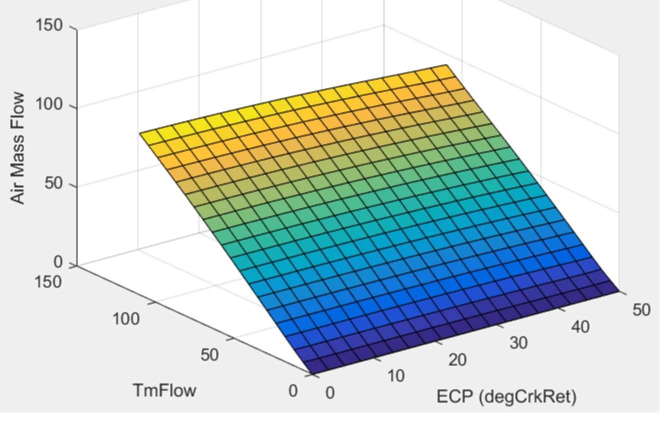
`array`

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
array

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
array

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`.

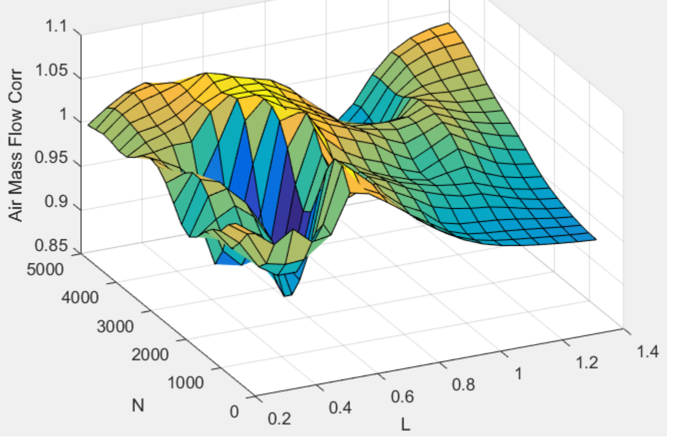
Air mass flow correction factor, f_mdot_air_corr — Lookup table
array

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

`array`

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

`array`

Engine speed breakpoints for air mass flow final correction, in rpm.

Dependencies

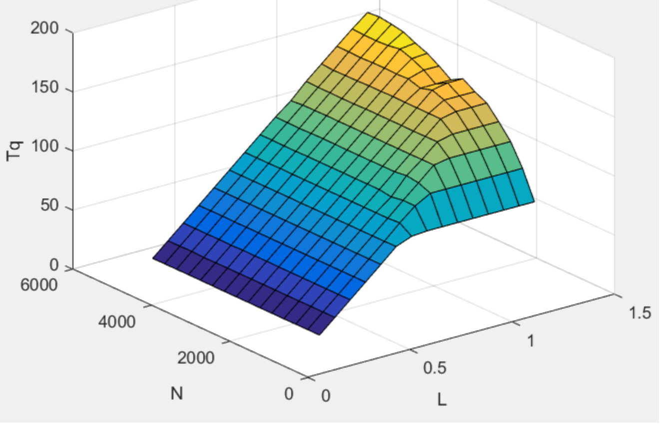
To enable this parameter, for the **Air mass flow model** parameter, select `Dual-Independent Variable Cam Phasing`.

Torque

`Torque table, f_tq_nl` — Lookup table
`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.



Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`Torque table load breakpoints, f_tq_nl_l_bpt` — Breakpoints
`array`

Engine load breakpoints, 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
`array`

Engine speed breakpoints, in rpm.

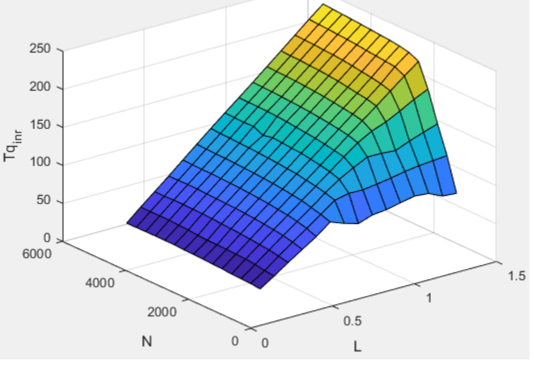
Dependencies

To enable this parameter, for the **Torque model** parameter, select `Simple Torque Lookup`.

`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

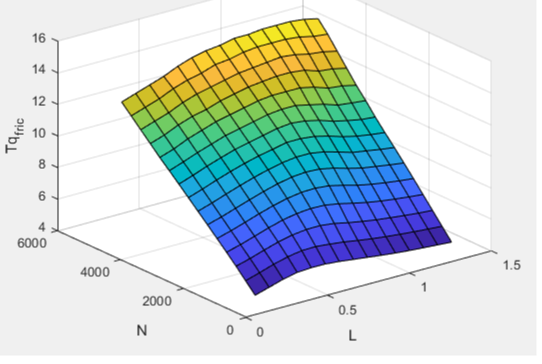
To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

`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
`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
vector

Engine temperature modifier breakpoints, in K.

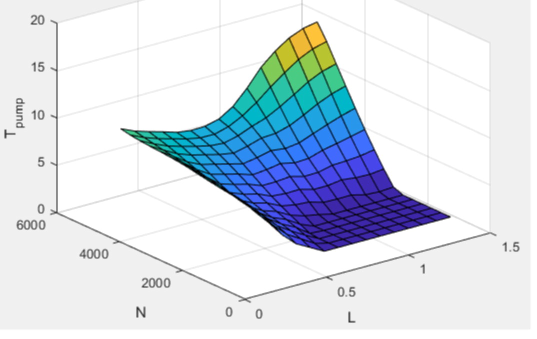
Dependencies

To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

Pumping torque table, f_tq_pump — Lookup table
array

The pumping torque lookup table, f_{Tpump}, is a function of engine speed and injected fuel mass, $T_{pump}=f_{Tpump}(L,N)$, where:

- T_{pump} is pumping torque, in N.m.
- L is engine load, as a normalized cylinder air mass, dimensionless.
- N is engine speed, in rpm.



Dependencies

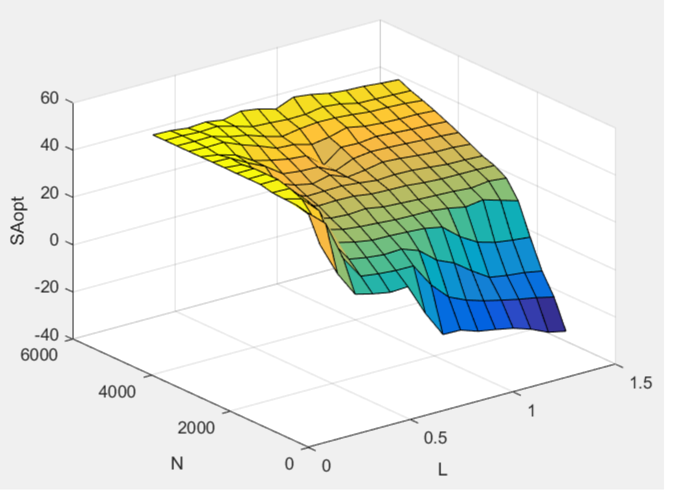
To enable this parameter, for the **Torque model** parameter, select `Torque Structure`.

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

`array`

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

`array`

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

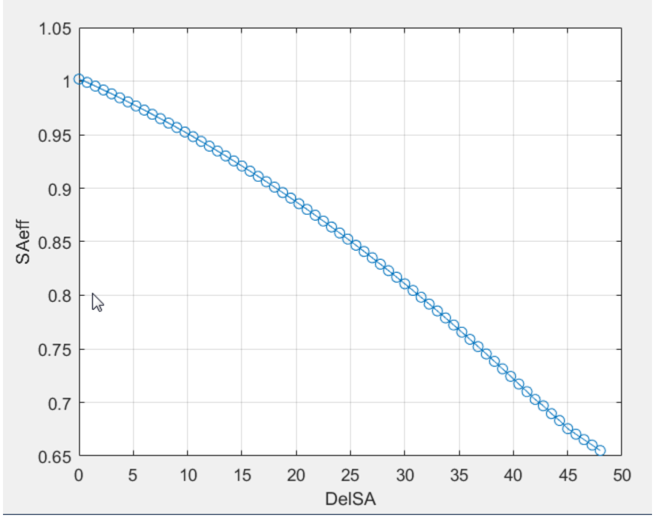
`array`

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.
- ΔSA 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
scalar

Spark retard from optimal inner torque timing breakpoints, in deg.

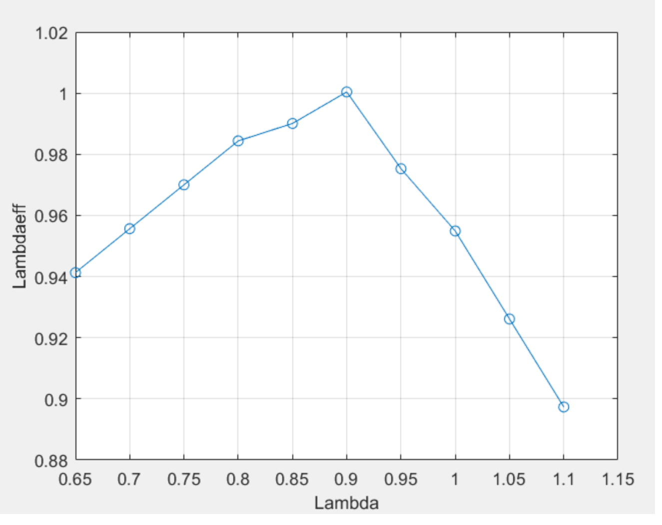
Dependencies

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
array

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

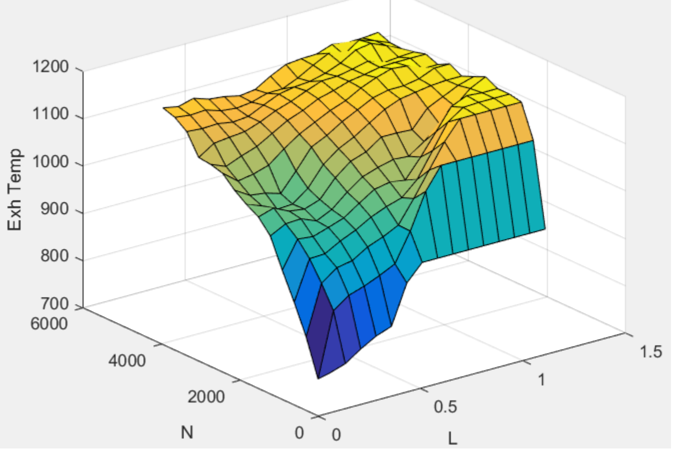
`array`

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

`array`

Engine load breakpoints used for exhaust temperature lookup table, dimensionless.

`Speed breakpoints, f_t_exh_n_bpt` — Breakpoints
`array`

Engine speed breakpoints used for exhaust temperature lookup table, in rpm.

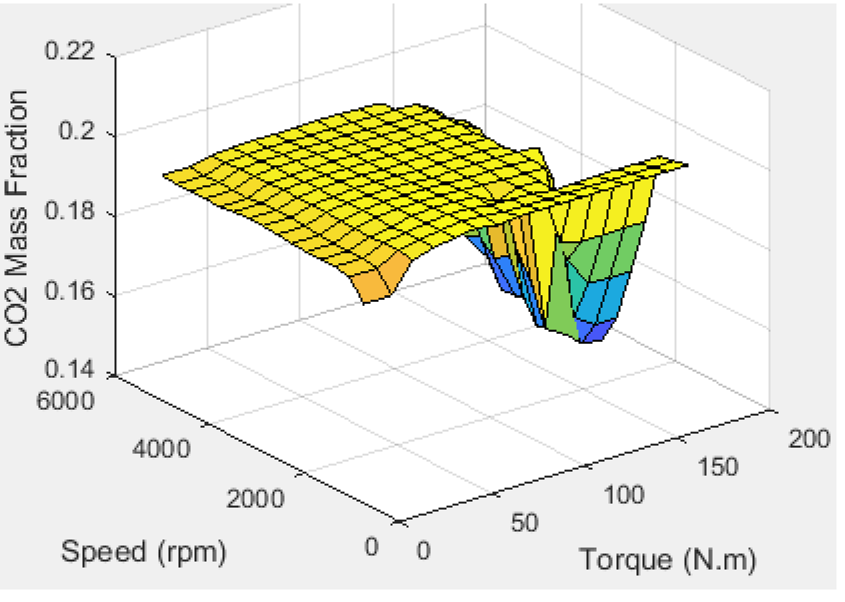
`Exhaust gas specific heat at constant pressure, cp_exh` — Specific heat
`scalar`

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* = f(*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.



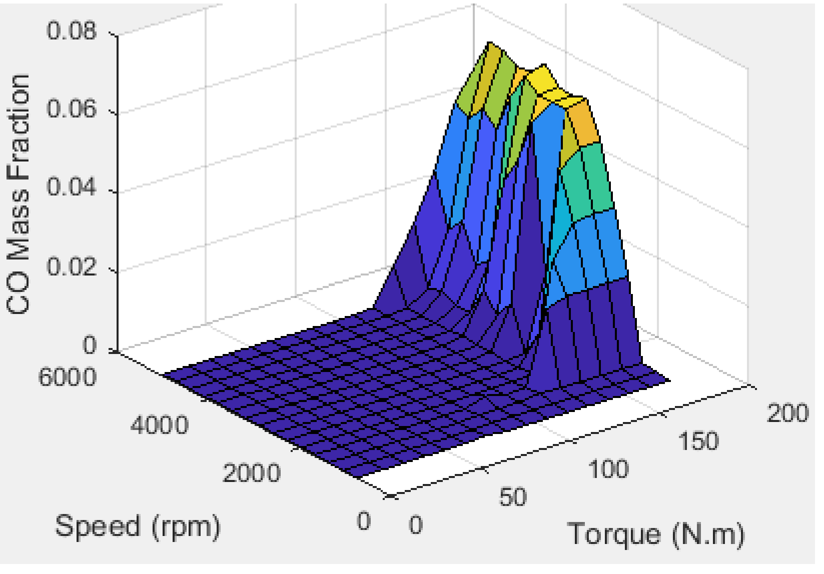
Dependencies

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.



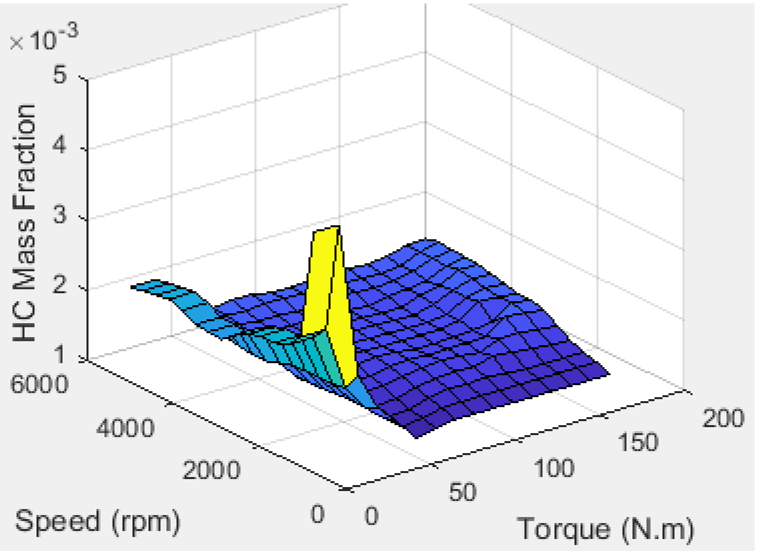
Dependencies

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* = ƒ(*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

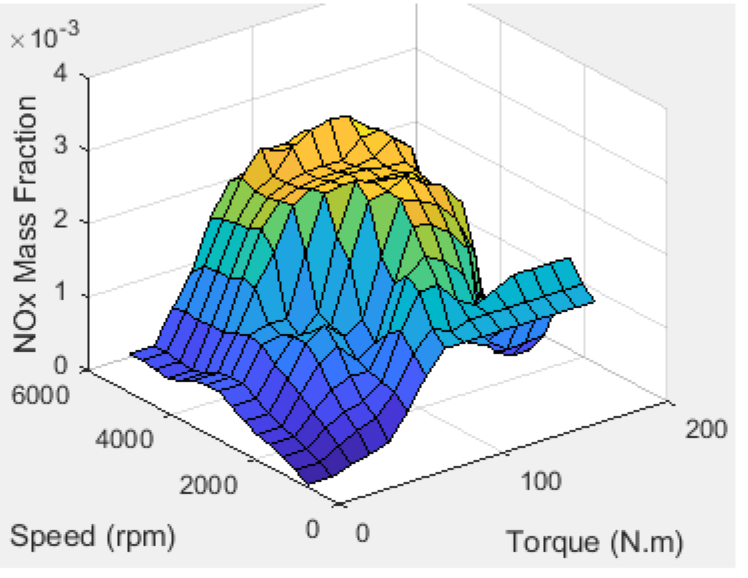
To enable this parameter, on the **Exhaust** tab, select **HC**.

`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* = ƒ(*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

`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
`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
`scalar`

Fuel injector slope, S_{inj}, mg/ms.

`Stoichiometric air-fuel ratio, afr_stoich` — Air-fuel ratio
`scalar`

Air-fuel ratio, AFR.

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.

See Also

Mapped SI Engine | SI Controller

Topics

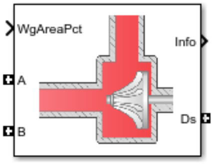
"SI Core Engine Air Mass Flow and Torque Production"

"Engine Calibration Maps"

Introduced in R2017a

Turbine

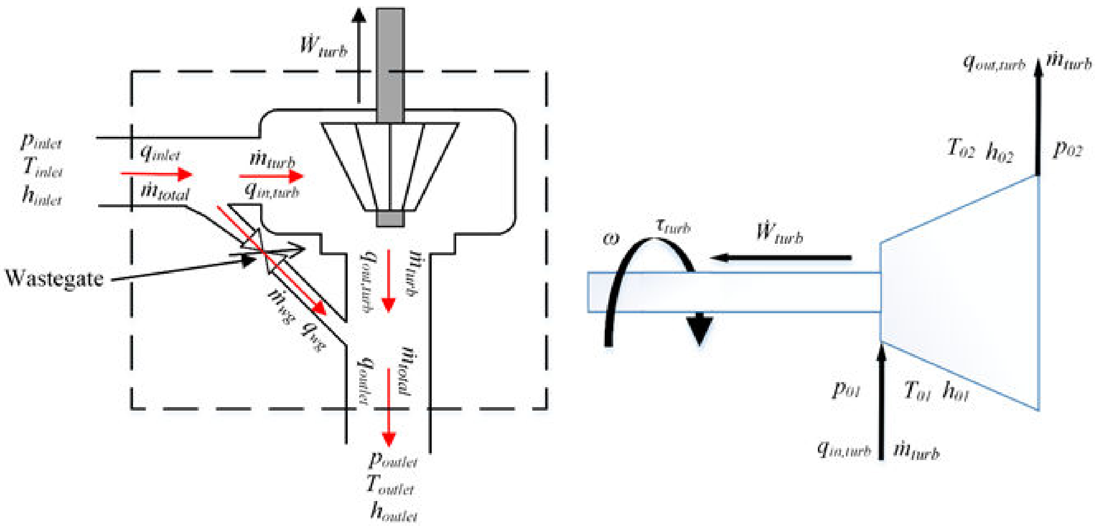
Turbine for boosted engines
Library: Propulsion / Combustion Engine Components / Boost



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.

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.

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	$\dot{W}_{turb} = \dot{m}_{turb} c_p \left(T_{01} - T_{02} \right)$
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	$q_{in,turb} = \dot{m}_{turb} c_p T_{01}$ $q_{out,turb} = \dot{m}_{turb} c_p T_{02}$
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

$\dot{W}_{turb}$	Drive shaft power

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 (2-D table)	$\eta_{turbfx,tbl} = f(\omega_{corr}, p_r)$
	Variable geometry (3-D table)	$\eta_{turbvr,tbl} = f(\omega_{corr}, p_r, L_{rack})$
Corrected mass flow lookup table	Fixed geometry (2-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 2-D lookup table for fixed geometry
$\dot{m}_{corrfx,tbl}$	Corrected mass flow rate 2-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	$\dot{m}_{total} = \dot{m}_{turb} + \dot{m}_{wg}$
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	$T_{outflw} = \begin{cases} \dfrac{q_{outlet}}{\dot{m}_{total} c_p} & \dot{m}_{total} > \dot{m}_{thresh} \\ \dfrac{T_{02} + T_{outflw,wg}}{2} & else \end{cases}$

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

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.

Signal	Description	Variable	Units
`TurbOutletTemp`	Temperature exiting the turbine	T_{02}	K
`DriveshftPwr`	Drive shaft power	$\dot{W}_{turb}$	W
`DriveshftTrq`	Drive shaft torque	τ_{turb}	N.m

Signal	Description	Variable	Units
TurbMassFlw	Turbine mass flow rate	$\dot{m}_{turb}$	kg/s
PrsRatio	Pressure ratio	p_r	N/A
DriveshftCorrSpd	Corrected drive shaft speed	ω_{corr}	rad/s
TurbEff	Turbine isentropic efficiency	η_{turb}	N/A
CorrMassFlw	Corrected mass flow rate	$\dot{m}_{corr}$	kg/s
WgArea	Wastegate valve area	A_{wg}	m^2
WgMassFlw	Mass flow rate through the wastegate valve	$\dot{m}_{wg}$	kg/s
WgOutletTemp	Temperature exiting the wastegate valve	$T_{outflw,wg}$	K

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

Value	Enables Parameters	Creates Ports
`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 | off

Dependencies

Selecting the **Include wastegate** parameter enables:

- **Wastegate flow area, A_wgopen**
- **Pressure ratio linearize limit, Plim_wg**

Performance Tables

`Corrected mass flow rate table, mdot_corrfx_tbl` — 2-D lookup table
`array`

Corrected mass flow rate 2-D lookup table for fixed geometry, $\dot{m}_{corrfx,tbl}$, in kg/s.

Dependencies

To enable this parameter, select `Fixed geometry` for the **Turbine type** parameter.

`Efficiency table, eta_turbfx_tb` — 2-D lookup table
`array`

Efficiency 2-D lookup table for fixed geometry, $\eta_{turbfx,tbl}$.

Dependencies

To enable this parameter, select `Fixed geometry` for the **Turbine type** parameter.

`Corrected speed breakpoints, w_corrfx_bpts1` — Fixed geometry
`array`

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
`array`

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` — 3-D lookup table
`array`

Corrected mass flow rate 3-D lookup table for variable geometry, $\dot{m}_{corrvr,tbl}$, in kg/s.

Dependencies

To enable this parameter, select `Variable geometry` for the **Turbine type** parameter.

`Efficiency table, eta_turbvr_tbl` — 3-D lookup table
`array`

Efficiency 3-D lookup table for variable geometry, $\eta_{turbvr,tbl}$.

Dependencies

To enable this parameter, select `Variable geometry` for the **Turbine type** parameter.

`Corrected speed breakpoints, w_corrvr_bpts2` — Variable geometry
`array`

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

`array`

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

`array`

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

`scalar`

Performance map reference temperature, T_{ref}, in K.

`Reference pressure, P_ref` — Pressure

`scalar`

Performance map reference pressure, P_{ref}, in Pa.

Wastegate

`Wastegate flow area, A_wgopen` — Area

`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
`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
`array`

Ideal gas constant R , in J/(kg*K).

`Specific heat at constant pressure, cp` — Specific heat
`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.

See Also

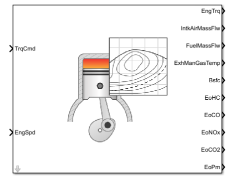
Two-Way Connection | Boost Drive Shaft | Compressor

Introduced in R2017a

Mapped Core Engine

Steady-state core engine model using lookup tables

Library: 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*.

- 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.

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.

Output — Create output ports
power 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
BrkTrq (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
`AirFlw` (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
`FuelFlw` (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
`Texh` (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
`EO HC` (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
`EO CO` (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
`EO NOx` (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

`EO CO2` (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

`EO PM` (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**.

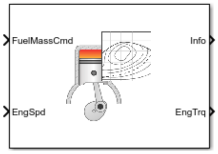
See Also

CI Core Engine | SI Core Engine

Introduced in R2017a

Mapped CI Engine

Compression-ignition engine model using lookup tables
Library: Propulsion / Combustion Engines



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 either injected fuel mass, *F*, or engine torque, *T*, and engine speed, *N*.

Input Command Setting	Lookup Tables
`Fuel mass`	*f(F,N)*
`Torque`	*f(T,N)*

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.

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

Ports

Input

`FuelMassCmd` — Injected fuel mass command
`scalar`

Injected fuel mass command, F, in mg/inj.

Dependencies

To create this port, for **Input command**, select `Fuel mass`.

`TrqCmd` — Torque command
`scalar`

Torque command, T, in N·m.

Dependencies

To create this port, for **Input command**, select `Torque`.

EngSpd — Engine speed
`scalar`

Engine speed, N, in rpm.

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
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

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 either injected fuel mass, *F*, or engine torque, *T*, and engine speed, *N*.

Input Command Setting	Lookup Tables
Fuel mass	*f(F,N)*
Torque	*f(T,N)*

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**.

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**

Configuration

Breakpoints for commanded fuel mass input, f_tbrake_f_bpt — Breakpoints

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

vector

Breakpoints, in N·m.

Dependencies

Setting **Input command** to `Torque` enables this parameter.

Breakpoints for engine speed input, f_tbrake_n_bpt — Breakpoints

vector

Breakpoints, in rpm.

Number of cylinders, NCyl — Number

scalar

Number of cylinders.

Crank revolutions per power stroke, Cps — Crank revolutions

scalar

Crank revolutions per power stroke.

Total displaced volume, Vd — Volume
scalar

Volume displaced by engine, in m^3.

Ideal gas constant air, Rair — Constant
scalar

Ideal gas constant of air and residual gas entering the engine intake port, in J/(kg*K).

Air standard pressure, Pstd — Pressure
scalar

Standard air pressure, in Pa.

Air standard temperature, Tstd — Temperature
scalar

Standard air temperature, in K.

Boost torque line, f_tbrake_bst — Boost lag
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
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
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
`scalar`

Falling maximum fuel mass boost time constant, $\tau_{bst,falling}$, in s.

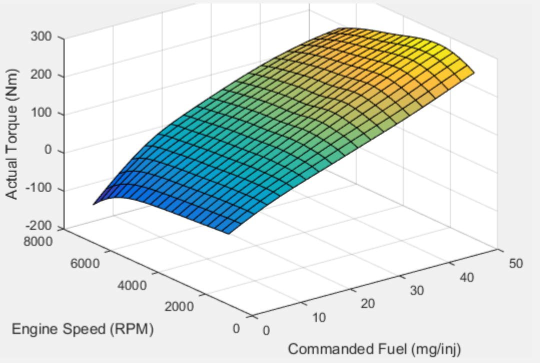
Dependencies

To enable this parameter, select **Include turbocharger lag effect**.

Power

`Brake torque map, f_tbrake` — Torque table
`array`

Dependencies

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.

`Plot brake torque map` — Plot table
button

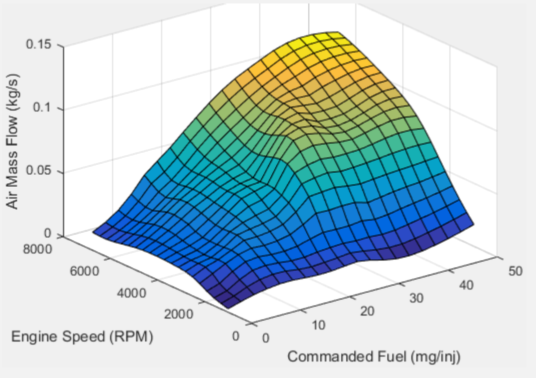
Click to plot table.

Air

`Air mass flow map, f_air` — Lookup table

`array`

Dependencies

Input Command Setting	Description
`Fuel mass`	The air mass flow lookup table is a function of commanded fuel mass and engine speed, $\dot{m}_{intk} = f(F_{max}, N)$, 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. 
`Torque`	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.

`Plot air mass map` — Plot table

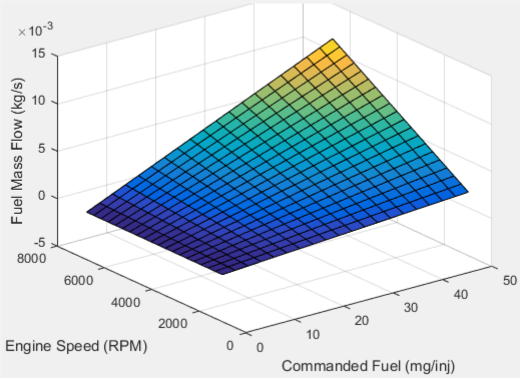
button

Click to plot table.

Fuel

`Fuel flow map, f_fuel` — Lookup table
`array`

Dependencies

<table>
<tr><th>Input Command Setting</th><th>Description</th></tr>
<tr><td><code>Fuel mass</code></td><td>The engine fuel flow lookup table is a function of commanded fuel mass and engine speed, MassFlow= ƒ(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.

</td></tr>
<tr><td><code>Torque</code></td><td>The engine fuel flow lookup table is a function of target torque and engine speed, MassFlow = ƒ(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.</td></tr>
</table>

`Plot fuel flow map` — Plot table
button

Click to plot table.

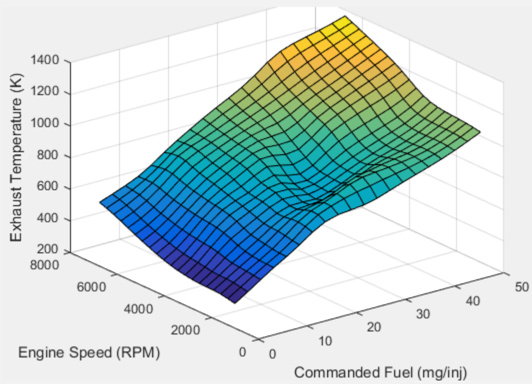
Temperature

`Exhaust temperature map, f_texh` — Lookup table
`array`

Dependencies

<table>
<tr><th>Input Command Setting</th><th>Description</th></tr>
<tr><td><code>Fuel mass</code></td><td>The engine exhaust temperature table is a function of commanded fuel mass and engine speed, $T_{exh}= f(F, N)$, where:

$T_{exh}$is exhaust temperature, in K.
F is commanded fuel mass, in mg per injection.
N is engine speed, in rpm.



</td></tr>
<tr><td><code>Torque</code></td><td>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.
</td></tr>
</table>

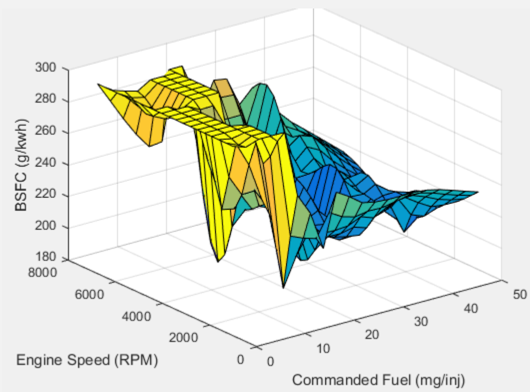
`Plot exhaust temperature map` — Plot table
button

Click to plot table.

Efficiency

`BSFC map, f_eff` — Lookup table
`array`

Dependencies

Input Command Setting	Description
`Fuel mass`	The brake-specific fuel consumption (BSFC) efficiency is a function of commanded fuel mass and engine speed, *BSFC*= ƒ(*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, $BSFC = ƒ(T_{target}, N)$, where: • *BSFC* is BSFC, in g/kWh. • T_{target} is target torque, in N·m. • *N* is engine speed, in rpm.

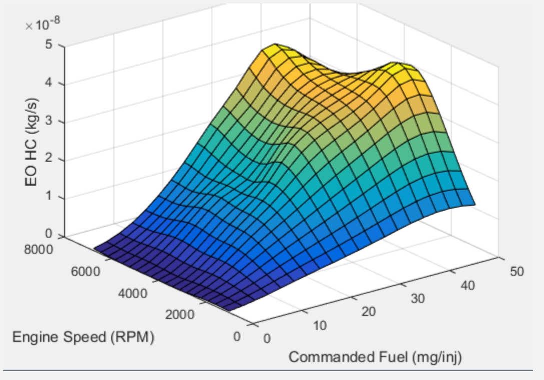
`Plot BSFC map` — Plot table
button

Click to plot table.

HC

`EO HC map, f_hc` — Lookup table
`array`

Dependencies

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.

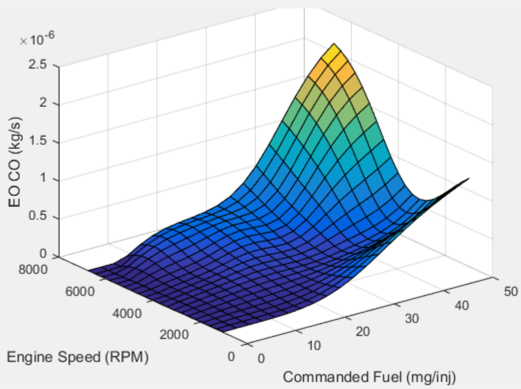
`Plot EO HC map` — Plot table
button

Click to plot table.

CO

`EO CO map, f_co` — Lookup table
`array`

Dependencies

Input Command Setting	Description
`Fuel mass`	The engine-out carbon monoxide emissions are a function of commanded fuel mass and engine speed, $EO\ CO = f(F, N)$, 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. 

Input Command Setting	Description
`Torque`	The engine-out carbon monoxide emissions are a function of target torque and engine speed, $EO\ CO = f(T_{target}, N)$, 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.

`Plot EO CO map` — Plot table
button

Click to plot table.

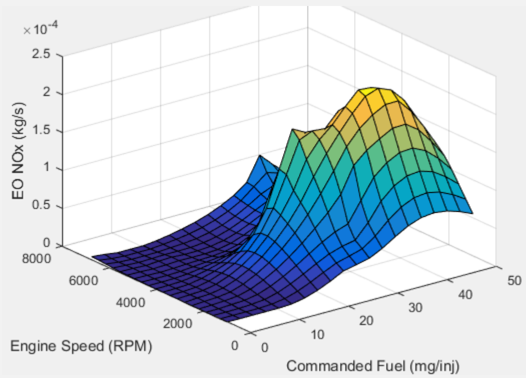
NOx

`EO NOx map, f_nox` — Lookup table
`array`

Dependencies

<table>
<tr><th>Input Command Setting</th><th>Description</th></tr>
<tr><td><code>Fuel mass</code></td><td>
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.



</td></tr>
<tr><td><code>Torque</code></td><td>
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.

</td></tr>
</table>

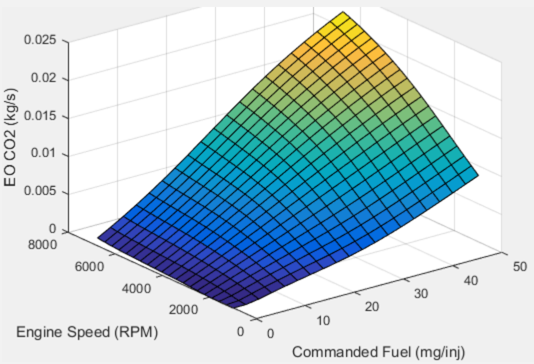
`Plot EO NOx map` — Plot table
button

Click to plot table.

CO2

`EO CO2 map, f_co2` — Lookup table
`array`

Dependencies

Input Command Setting	Description
`Fuel mass`	The engine-out carbon dioxide emissions are a function of commanded fuel mass and engine speed, $EO\ CO2 = f(F, N)$, 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, $EO\ CO2 = f(T_{target}, N)$, 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.

`Plot CO2 map` — Plot table
button

Click to plot table.

PM

`EO PM map, f_pm` — Lookup table
`array`

Dependencies

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.

`Plot EO PM map` — Plot table
button

Click to plot table.

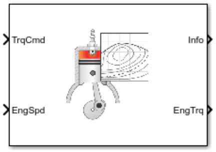
See Also
CI Core Engine

Topics
“Generate Mapped CI Engine from a Spreadsheet”

Introduced in R2017a

Mapped SI Engine

Spark-ignition engine model using lookup tables
Library: Propulsion / Combustion Engines



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.

- Power — $f(T_{cmd},N)$
- Air — $f(T_{brake},N)$
- Fuel — $f(T_{brake},N)$
- Temperature — $f(T_{brake},N)$
- Efficiency — $f(T_{brake},N)$
- Hydrocarbon (HC) emissions — $f(T_{brake},N)$
- Carbon monoxide (CO) emissions — $f(T_{brake},N)$
- Nitric oxide and nitrogen dioxide (NOx) emissions — $f(T_{brake},N)$
- Carbon dioxide (CO_2) emissions — $f(T_{brake},N)$
- Particulate matter (PM) emissions — $f(T_{brake},N)$

To bound the Mapped SI Engine block output, the block does not extrapolate the lookup table data.

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	$\tau_{bst} = \begin{cases} \tau_{bst,rising} & \text{when } T_{stdy} > T_{brake} \\ \tau_{bst,falling} & \text{when } T_{stdy} \leq T_{brake} \end{cases}$
Final time constant	$\tau_{eng} = \begin{cases} \tau_{thr} & \text{when } T_{brake} < f_{bst}(N) \\ \tau_{bst} & \text{when } T_{brake} \geq f_{bst}(N) \end{cases}$

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

Ports

Input

`TrqCmd` — Commanded torque
`scalar`

Torque, T_{cmd}, in N·m.

`EngSpd` — Engine speed
`scalar`

Engine speed, N, in rpm.

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
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

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**

Configuration

`Breakpoints for commanded torque, f_tbrake_t_bpt` — Breakpoints
`vector`

Breakpoints, in N·m.

`Breakpoints for engine speed input, f_tbrake_n_bpt` — Breakpoints
`vector`

Breakpoints, in rpm.

`Number of cylinders, NCyl` — Number
`scalar`

Number of cylinders.

`Crank revolutions per power stroke, Cps` — Crank revolutions
`scalar`

Crank revolutions per power stroke.

Total displaced volume, Vd — Volume
scalar

Volume displaced by engine, in m^3.

Ideal gas constant air, Rair — Constant
scalar

Ideal gas constant of air and residual gas entering the engine intake port, in J/(kg*K).

Air standard pressure, Pstd — Pressure
scalar

Standard air pressure, in Pa.

Air standard temperature, Tstd — Temperature
scalar

Standard air temperature, in K.

Boost torque line, f_tbrake_bst — Boost lag
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
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
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
`scalar`

Falling torque boost time constant, $\tau_{bst,falling}$, in s.

Dependencies

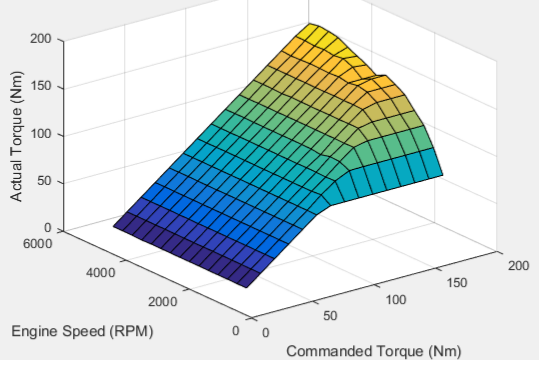
To enable this parameter, select **Include turbocharger lag effect**.

Power

`Brake torque map, f_tbrake` — Torque table
`array`

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

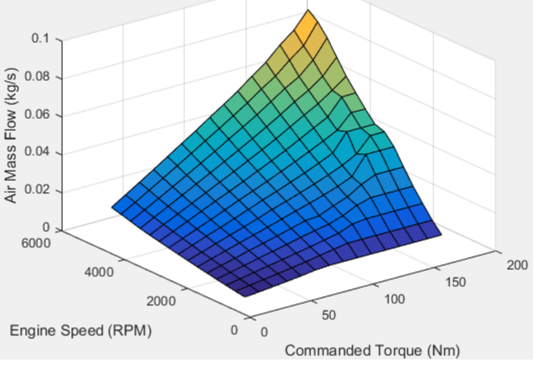
Click to plot table.

Air

`Air mass flow map, f_air` — Lookup table
array

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.



`Plot air mass map` — Plot table
button

Click to plot table.

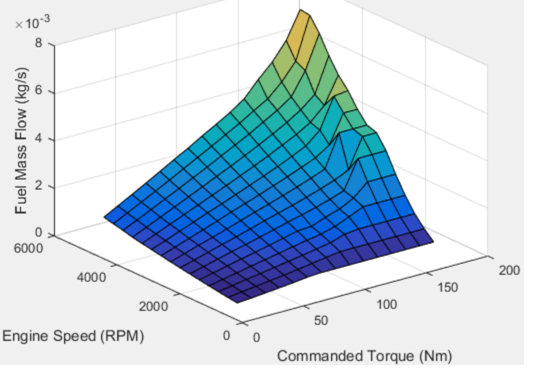
Fuel

`Fuel flow map, f_fuel` — Lookup table
array

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.



`Plot fuel flow map` — Plot table
button

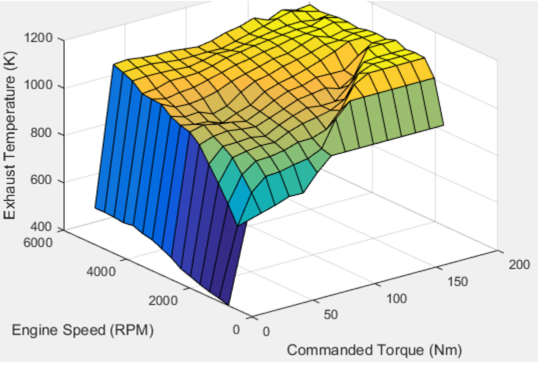
Click to plot table.

Temperature

`Exhaust temperature map, f_texh` — Lookup table
`array`

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.



`Plot exhaust temperature map` — Plot table
button

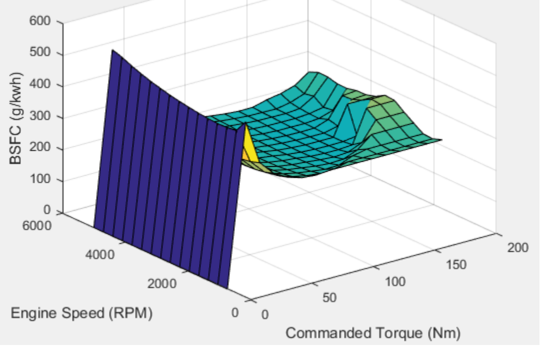
Click to plot table.

Efficiency

`BSFC map, f_eff` — Lookup table
`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.



`Plot BSFC map` — Plot table
button

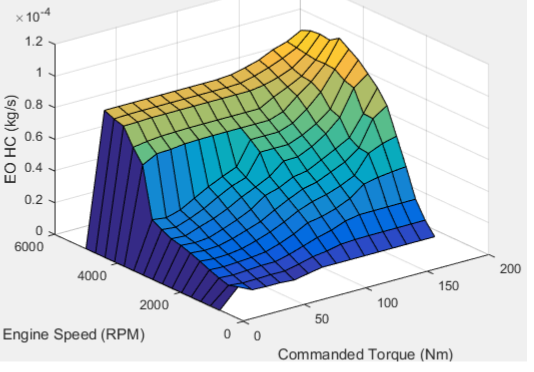
Click to plot table.

HC

`EO HC map, f_hc` — Lookup table
`array`

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.



`Plot EO HC map` — Plot table
button

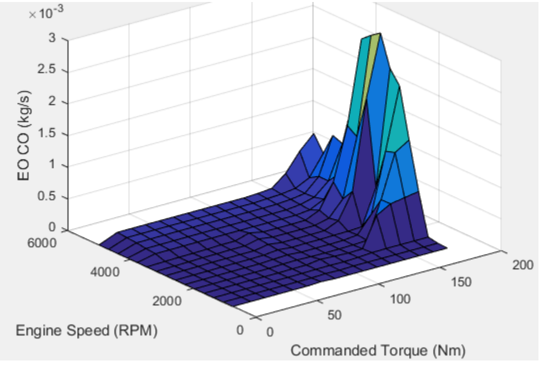
Click to plot table.

CO

`EO CO map, f_co` — Lookup table
`array`

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.



`Plot EO CO map` — Plot table

button

Click to plot table.

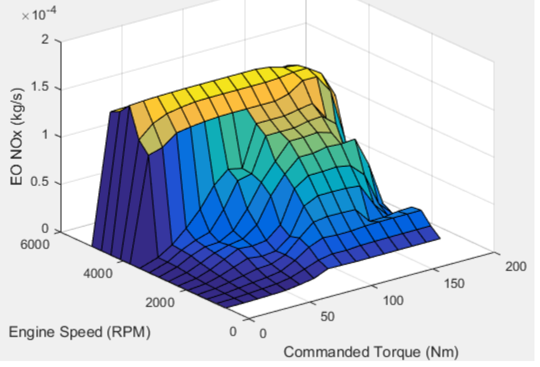
NOx

`EO NOx map, f_nox` — Lookup table

`array`

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.



Plot EO NOx map — Plot table
button

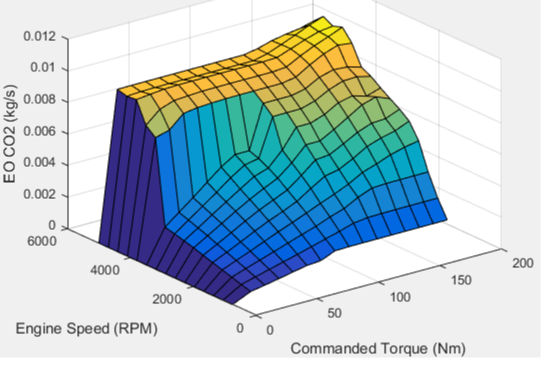
Click to plot table.

CO2

EO CO2 map, f_co2 — Lookup table
array

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.



`Plot CO2 map` — Plot table
button

Click to plot table.

`PM`

`EO PM map, f_pm` — Lookup table
`array`

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.

`Plot EO PM map` — Plot table
button

Click to plot table.

See Also

SI Core Engine

Topics

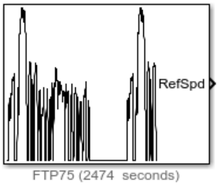
"Generate Mapped SI Engine from a Spreadsheet"

Introduced in R2017a

Scenario Creation Blocks — Alphabetical List

Drive Cycle Source

Standard or specified longitudinal drive cycle
Library: Vehicle Scenario Builder



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.

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.
- `.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**.
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.
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.

Goal	Action
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.

Ports

Output

Speed — Vehicle reference speed
`scalar`

Vehicle reference speed, in units that you specify. To specify the units, use the **Output velocity units** parameter.

`Acceleration` — 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 create 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

Drive Cycle

`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.

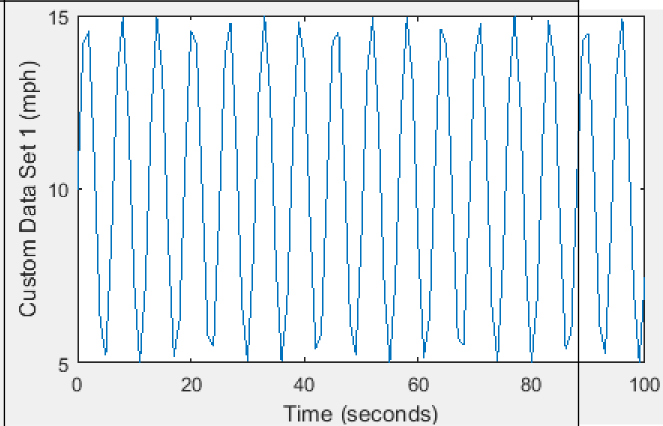
Drive Cycle Source	Enables Parameter
`Wide Open Throttle (WOT)`	**Start time, t_wot1**
	Initial reference speed, xdot_woto
	Nominal reference speed, xdot_wot1
	Time to start deceleration, wot2
	Final reference speed, xdot_wot2
	WOT simulation time, t_wotend
	Source velocity units
`Workspace variable`	**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

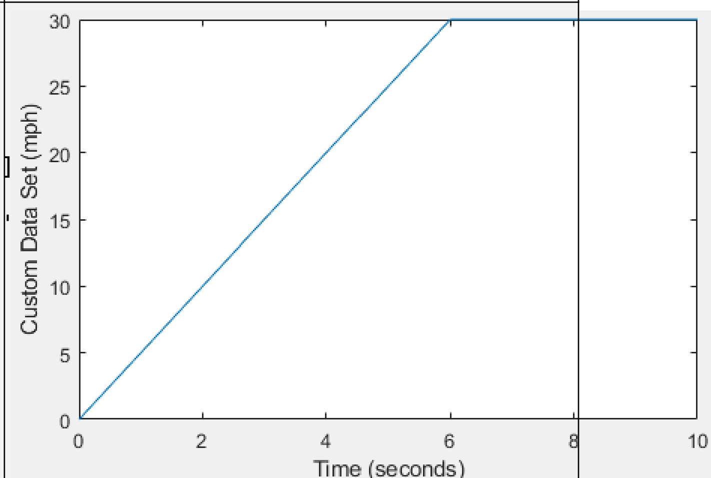
`From workspace` — Workspace
`variable`

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.

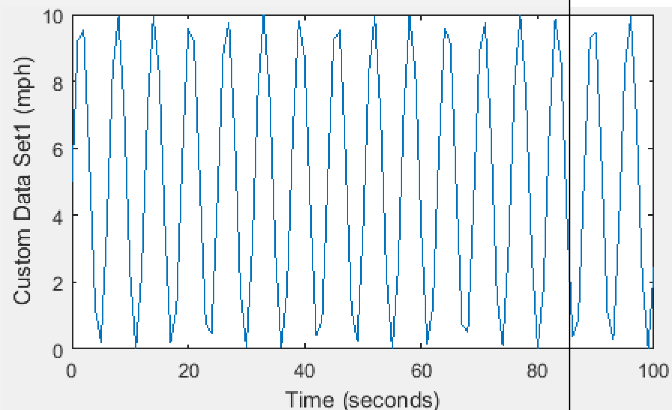
A valid point must exist for each corresponding time value. You cannot specify `inf`, `empty`, or `NaN`.

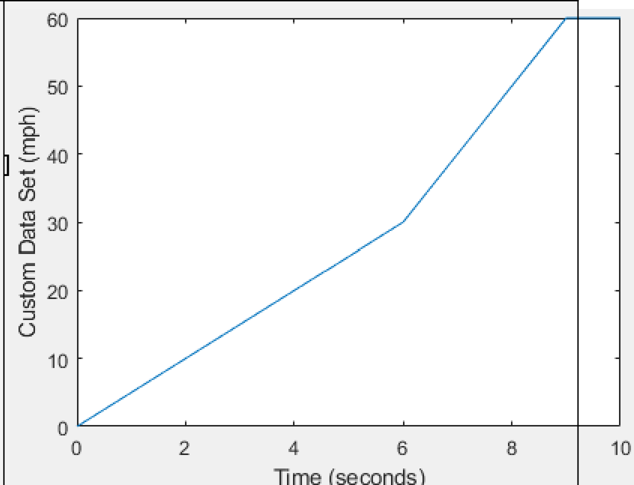
Workspace Variable	Source Velocity Unit	Drive Cycle Plot

Structure without a gear shift schedule
 	
`t = 0:1:100;`
`xdot = 5.*sin(t)+10;`
`myCycleS.time = t';`
`myCycleS.signals.values = xdot';`
	mph	

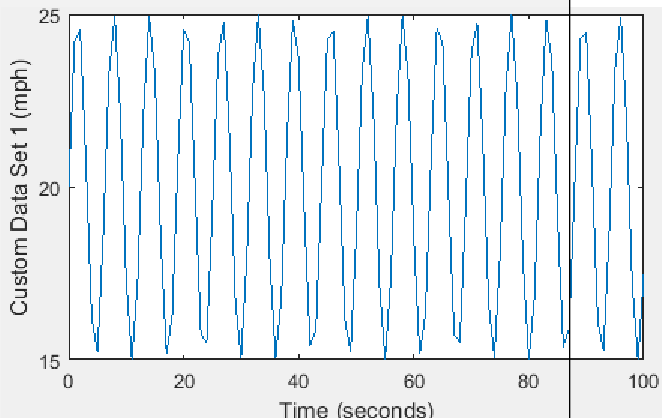
Structure with a gear shift schedule
 	
`gears=[0, 1, 2, 3, 3, 4, 4, 4, 4, 4,`
`t=0:1:10;`
`xdot=[0,5,10,15,20,25,30,30,30,30,30]`
`myCycleS.time=t';`
`myCycleS.signals.values=[xdot',gears'`
	mph	

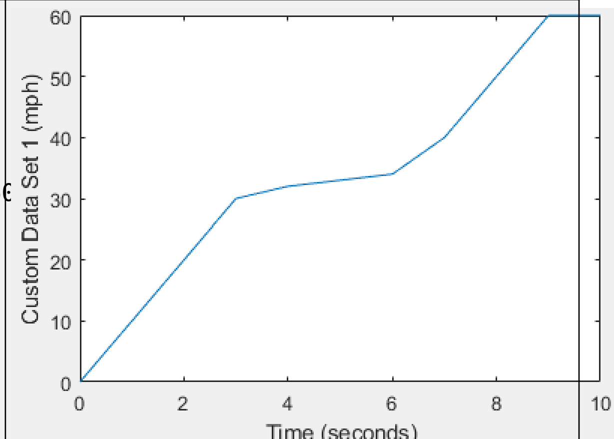
Workspace Variable	**Source Velocity Unit**	**Drive Cycle Plot**

2-D array without a gear shift schedule
 	
`t = 0:1:100;`
`xdot = 5.*sin(t)+5;`
`myCycleA = [t',xdot'];`
	`mph`	

2-D array with a gear shift schedule
 	
`gears=[0, 1, 2, 3, 4, 4, 4, 5, 5, 5,`
`t=0:1:10;`
`xdot=[0,5,10,15,20,25,30,40,50,60,60]`
`myCycleA=[t',xdot',gears'];`
	`mph`	

Workspace Variable	Source Velocity Unit	Drive Cycle Plot

Time series object without a gear shift schedule
 	
`myCycleT = timeseries;`
`t = 0:1:100;`
`xdot = 5.*sin(t)+20;`
`myCycleT.Data = xdot';`
`myCycleT.Time = t;`
	mph	

Time series object without a gear shift schedule
 	
`myCycleT = timeseries;`
`gears=[0, 1, 2, 3, 4, 4, 4, 5, 5, 5,`
`t=0:1:10;`
`xdot=[0,10,20,30,32,33,34,40,50,60,6`
`myCycleT.Data = [xdot',gears'];`
`myCycleT.Time = t';`
	mph	

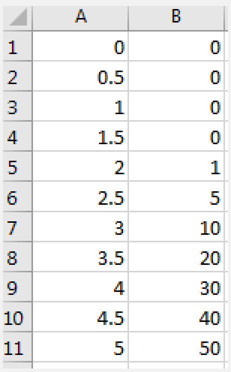
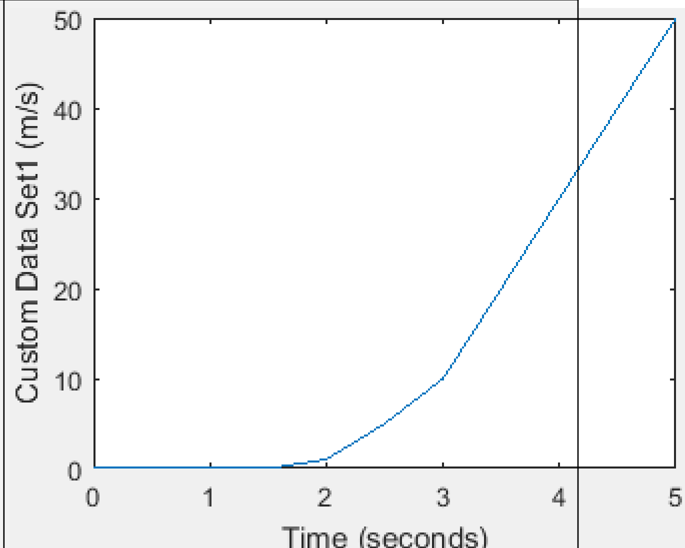
Dependencies

To enable this parameter, select `Workspace variable` from **Drive cycle source**.

`Drive cycle source file` — File name

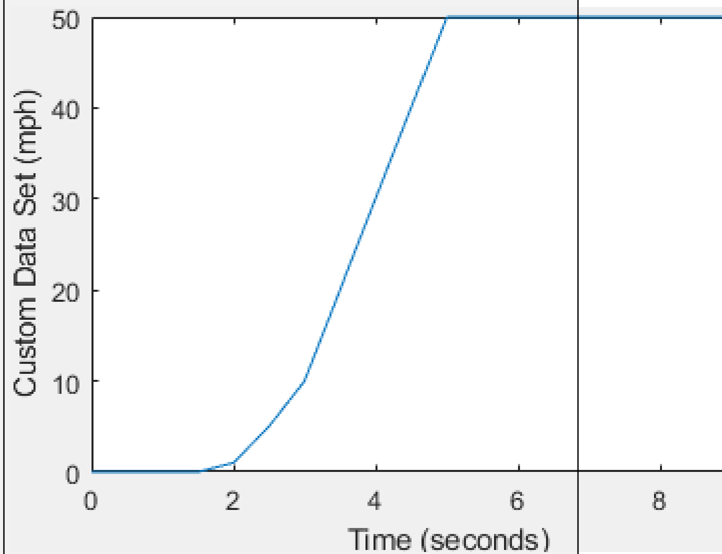
`.mat, .xls, .xlsx or .txt`

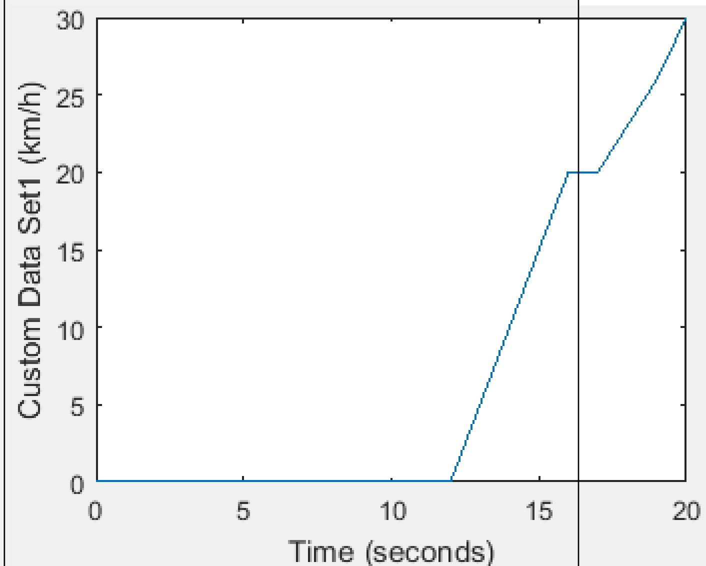
File containing monotonically increasing time, velocity, and, optionally, gear in column or comma-separated format. The block ignores units in the file. Enter units for velocity in the **Source velocity units** parameter field.

<table>
<tr><th>File</th><th>Source Velocity Unit</th><th>Drive Cycle Plot</th></tr>
<tr><td>An <code>.xls</code> or <code>.xlsx</code> 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><code>m/s</code></td><td>
</td></tr>
</table>

<table>
<tr><th>File</th><th>Source 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>
</td>
</tr>
</table>

File	Source 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 s km/h 0 0 1 0 2 0 3 0 4 0 5 0 6 0 7 0 8 0 9 0 10 0 11 0 12 0 13 5 14 10 15 15 16 20 17 20 18 23 19 26 20 30	`km/h`	

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`

Gear	Integer
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)

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)

Dependencies

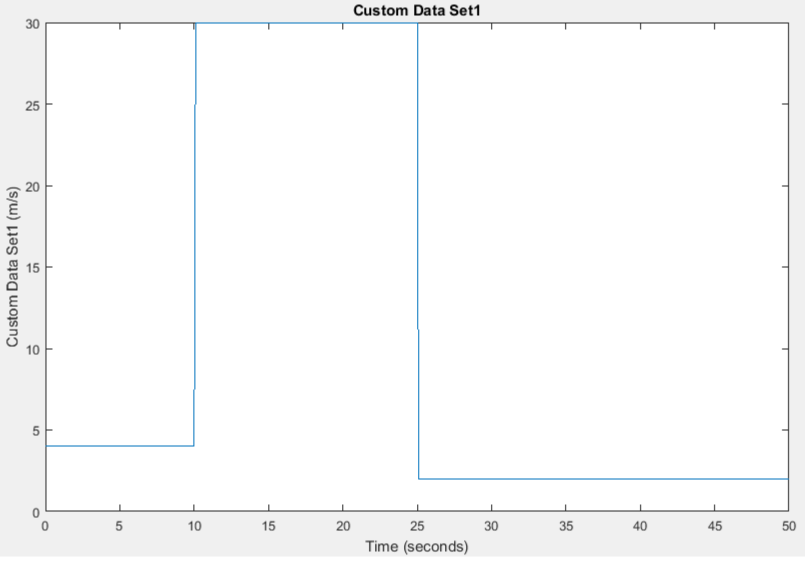
- Specify a drive cycle that contains a gear shift schedule. You can use:
  - A support package to install standard drive cycles that include the gear shift schedules, for example `JC08` and `CUEDC`.
  - Workspace variables.
  - `.mat`, `.xls`, `.xlsx`, or `.txt` files.
- Clicking this parameter creates input port **Gear**.

WOT

`Start time, t_wot1` — Drive cycle start time

`scalar`

Drive cycle start time, in s. For example, this plot shows a drive cycle with a start time of `10` s.



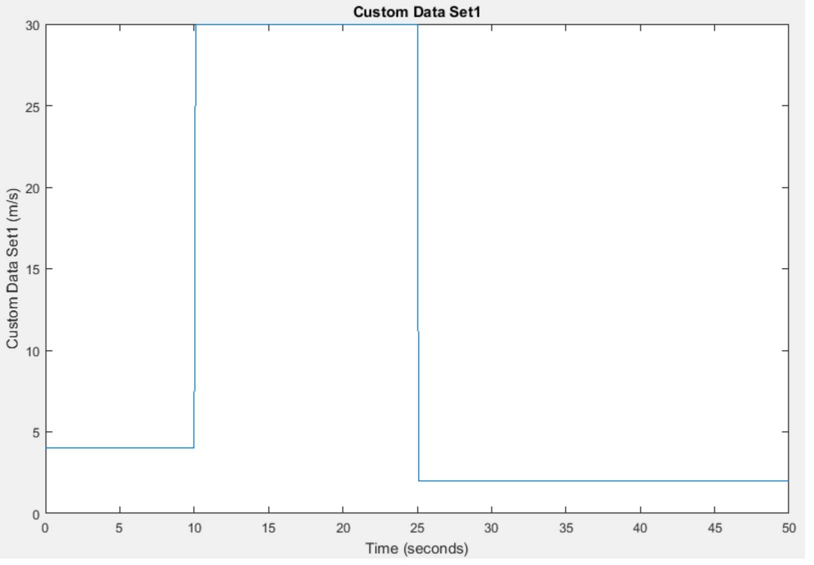
Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

`Initial reference speed, xdot_woto` — Speed

`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.



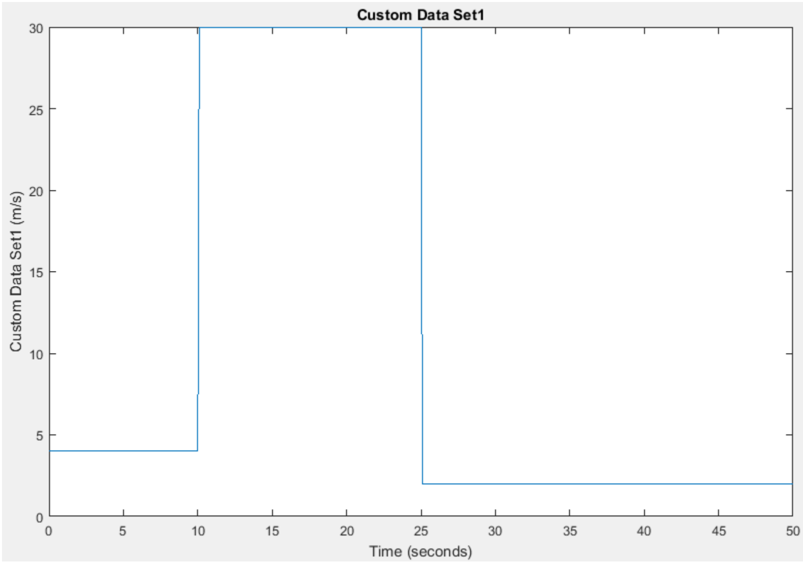
Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

`Nominal reference speed, xdot_wot1` — Speed

`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.

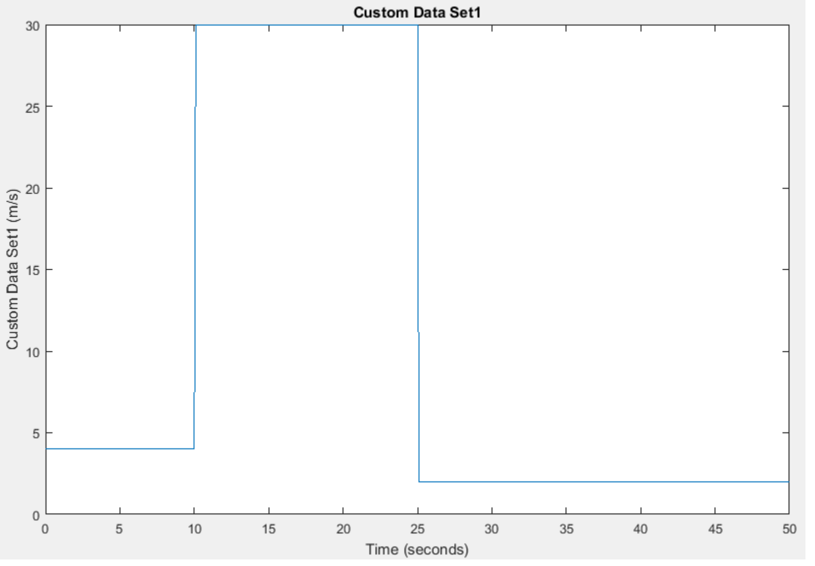


Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

`Time to start deceleration, wot2` — Time
`scalar`

Time to start vehicle deceleration, in s. For example, this plot shows a drive cycle with vehicle deceleration starting at `25` s.

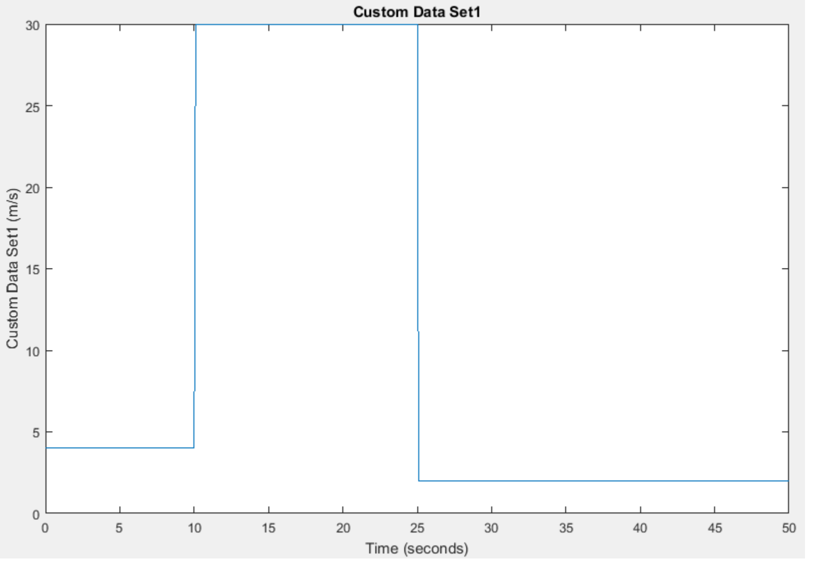


Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

`Final reference speed, xdot_wot2` — Speed
`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.

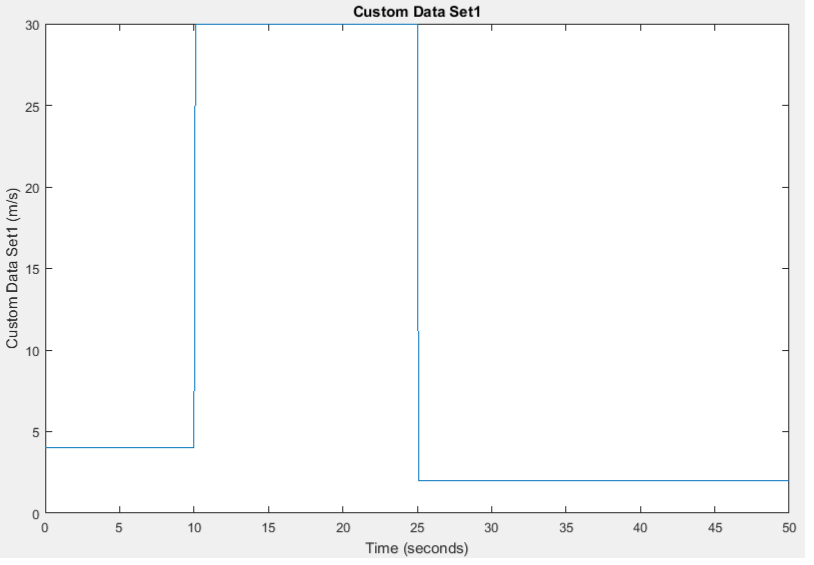


Dependencies

To enable this parameter, select the **Drive cycle source** parameter `Wide Open Throttle (WOT)`.

`WOT simulation time, t_wotend` — Time
`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
`scalar`

Sample rate. Set to `0` for continuous sample period. For a discrete period, specify a non-zero rate.

See Also

Longitudinal Driver

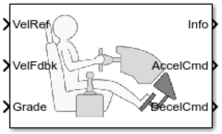
Topics

"Time Series Objects" (MATLAB)

Introduced in R2017a

Longitudinal Driver

Longitudinal speed-tracking controller
Library: Vehicle Scenario Builder



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.

Longitudinal Speed-Tracking Controller

The Longitudinal Driver block implements a Proportional-Integral (PI) controller with tracking anti-windup and feed-forward gains. You can specify parameters to account for road grade loads and feedback error filtering.

The block uses these equations to calculate the speed control output:

$$y = \frac{K_{ff}}{v_{nom}} + \frac{K_p e_{ref}}{v_{nom}} + \left(\frac{K_i}{v_{nom}} + K_{aw} e_{out} \right) \int e_{ref}\, dt + K_g \theta$$

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 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}	Breaking signal
v	Velocity feedback signal

v_{ref}	Reference velocity signal

Ports

Input

`VelRef` — Reference vehicle velocity
`scalar`

Reference velocity, v_{ref}, in m/s.

`VelFdbk` — Forward vehicle velocity
`scalar`

Forward vehicle velocity, in m/s.

`Grade` — Road grade angle
`scalar`

Road grade angle, θ, in deg.

Output

`Info` — Bus signal
bus

Bus signal containing these block calculations.

Signal	Variable	Description
`Accel`	y_{acc}	Commanded vehicle acceleration, normalized from 0 through 1
`Decel`	y_{dec}	Commanded vehicle deceleration, normalized from 0 through 1
`Err`	e_{ref}	Difference in reference vehicle speed and vehicle speed

Signal	Variable	Description
`ErrSqrSum`	$\int_0^t e_{ref}^2 dt$	Integrated square of error
`ErrMax`	$\max(e_{ref}(t))$	Maximum error during simulation
`ErrMin`	$\min(e_{ref}(t))$	Minimum error during simulation

`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.

Parameters

Longitudinal Tracking

`Nominal speed, vnom` — Nominal vehicle speed
`scalar`

Nominal vehicle speed, v_{nom}, in m/s. The block uses the nominal speed to normalize the controller gains.

`Proportional gain, Kp` — Gain
`scalar`

Proportional gain, K_p.

`Integral gain, Ki` — Gain
`scalar`

Proportional gain, K_i.

Anti-windup, Kaw — Gain
scalar

Anti-windup gain, K_{aw}.

Velocity feed-forward, Kff — Gain
scalar

Velocity feed-forward gain, K_{ff}.

Grade feed-forward, Kg — Gain
scalar

Grade feed-forward gain, K_g.

Error filter time constant, tauerr — Filter
scalar

Error filter time constant, τ_{err}, in s. To disable the filter, enter 0.

See Also

Drive Cycle Source | Vehicle Body Total Road Load

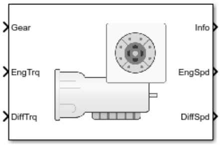
Introduced in R2017a

Transmission Blocks — Alphabetical List

Automated Manual Transmission

Ideal automated manual transmission

Library: 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.

Setting	Block Implementation
`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 $T_S < \left\lvert T_f - Nw_i b_i \right\rvert$	Unlocked	$T_f = T_k$ where, $T_k = F_c R_{eff} \mu_k \tanh\left[4\left(\frac{w_i}{N} - w_d\right)\right]$
$\omega_i = N\omega_t$ and $T_S \geq \left\lvert T_f - Nb_i\omega_i \right\rvert$	Locked	$T_f = T_s$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o^{\,3} - R_i^{\,3})}{3(R_o^{\,2} - R_i^{\,2})}$

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

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

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
scalar

Input shaft inertia, in kg*m^2.

`Input shaft damping, bin` — Damping
scalar

Input shaft damping, in N.m*s/rad.

`Initial input velocity, omegain_o` — Angular velocity
scalar

Angular velocity, in rad/s.

`Gear number vector, G` — Specify number of transmission speeds
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
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
`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
`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
`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
`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
`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
`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, omega_o` — Transmission
`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
`scalar`

Initial gear to engage, G_o.

Clutch and Synchronizer

`Clutch pressure time constant, tauc` — Time
`scalar`

Time required to engage and disengage the clutch during shift events, t_c, in s.

`Sychronization time, ts` — Time
`scalar`

Time required for gear selection and synchronization, t_s, in s.

`Clutch time, tc` — Time
`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
`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
`scalar`

Open loop lock-up clutch gain, K_c, in N.

Clutch static friction coefficient, mus — Coefficient
scalar

Dimensionless clutch disc coefficient of static friction, μ_s.

Clutch kinematic friction coefficient, muk — Coefficient
scalar

Dimensionless clutch disc coefficient of kinetic friction, μ_k.

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

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)

Select to initially lock synchronizer.

See Also

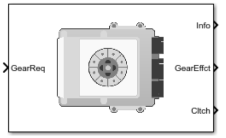
AMT Controller | Continuously Variable Transmission | Dual Clutch Transmission | Ideal Fixed Gear Transmission

Introduced in R2017a

AMT Controller

Automated manual transmission controller with clutch open, close, and synchronization timing

Library: 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
scalar

Initial gear to engage, G_o.

Clutch actuation time, tc — Time
scalar

Time required to engage and disengage the clutch during shift events, t_c, in s.

Synchronizer time, ts — Time
scalar

Time required for gear selection and synchronization, t_s, in s.

Sample period, dt — Time
scalar

Sample period, dt, in s.

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

Selecting this parameter initially locks the clutch.

`Synchronizer initially locked` — Select to initially lock synchronizer
off (default)

Selecting this parameter initially locks the synchronizer.

See Also

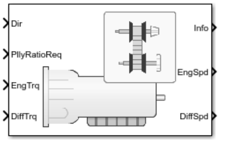
Automated Manual Transmission

Introduced in R2017a

Continuously Variable Transmission

Push belt continuously variable transmission with independent radii control

Library: 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:

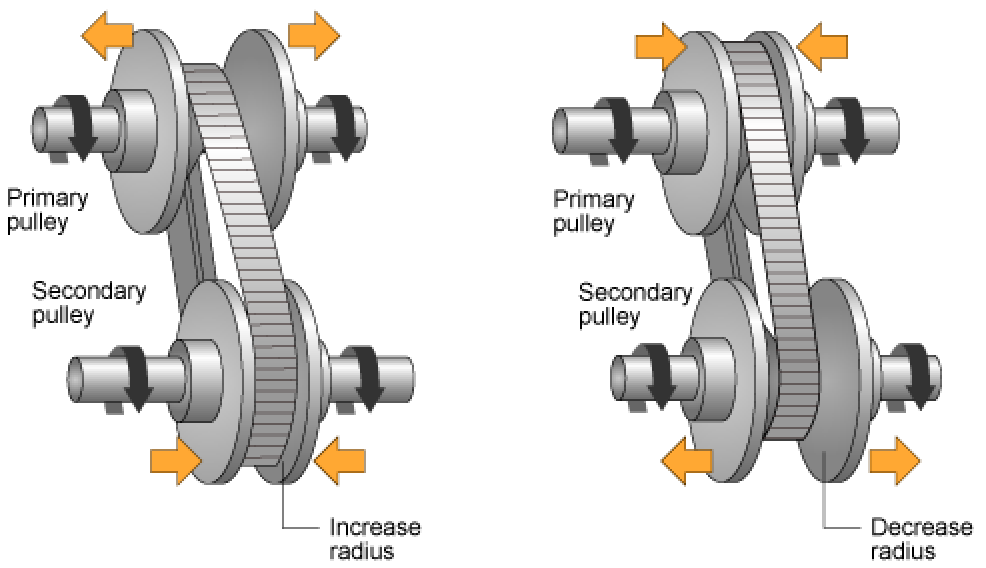
- Internal — Input direction and pulley ratio requests
- External — Input direction and pulley displacement requests

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	✓	✓	✓

Calculation	Pulley Kinematics	Reverse and Final Speed Reduction	Dynamics
Belt and pulley geometry	✓		
Belt linear speed			✓
Wrap angle on secondary and primary pulley	✓		
Primary and secondary pulley radii	✓		

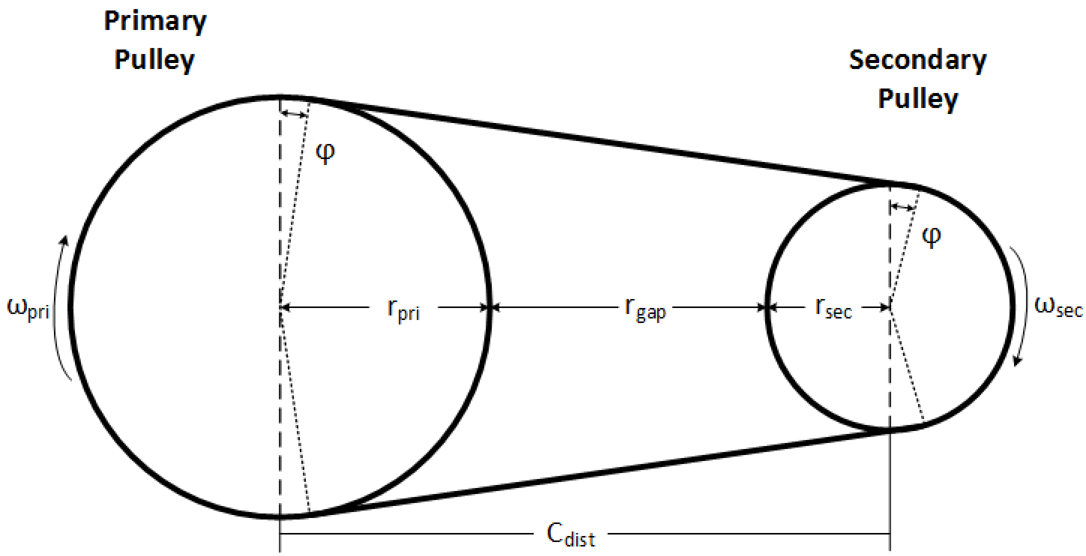
The figure shows the CVT variator with two configurations. In the first configuration, which illustrates speed reduction, the variator is set to decrease the primary pulley radius and increase the secondary pulley radius. In the second configuration, which illustrates overdrive, the variator is set to 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.



$$C_{dist} = rp_{max} + r_{gap} + r_{sec\_max}$$

$$L_0 = f\left(rp_{max}, rs_{max}, rp_{min}, rs_{min}, C_{dist}\right)$$

$$ratio_{command} = f\left(ratio_{request}, ratio_{max}, ratio_{min}\right)$$

$$r_{pri} = f\left(r_0, ratio_{command}, C_{dist}\right)$$

$$r_{\text{sec}} = f\left(r_0, ratio_{command}, C_{dist}\right)$$

$$x_{pri} = f\left(r_0, r_{pri}, \theta_{wedge}\right)$$

$$x_{\text{sec}} = f\left(r_0, r_{\text{sec}}, \theta_{wedge}\right)$$

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	$(J_{pri} + J_i)\dot{\omega}_{pri} = T_{app\_pri} - T_{BoP\_pri} - b_{pri}\omega_{pri}$ $J_{sec}\dot{\omega}_{sec} = T_{app\_sec} - T_{BoP\_sec} - b_{sec}\omega_{sec}$ $m_b\dot{v}_b = \frac{T_{BoP\_pri}}{r_{pri}} + \frac{T_{BoP\_sec}}{r_{sec}} - b_b v_b$ $r_{pri}\omega_{pri} \neq v_b$ $r_{sec}\omega_{sec} \neq v_b$

Condition	Equations
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

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
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

Signal	Description	Variable	Units
TransSpdRatio	Total no-slip gear ratio	N_{final}	N/A

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
scalar

Maximum variator primary pulley radius, rp_{max}, in m.

Maximum variator secondary pulley radius, rs_max — Radius
scalar

Maximum variator secondary pulley radius, rs_{max}, in m.

Minimum variator primary pulley radius, rp_min — Radius
scalar

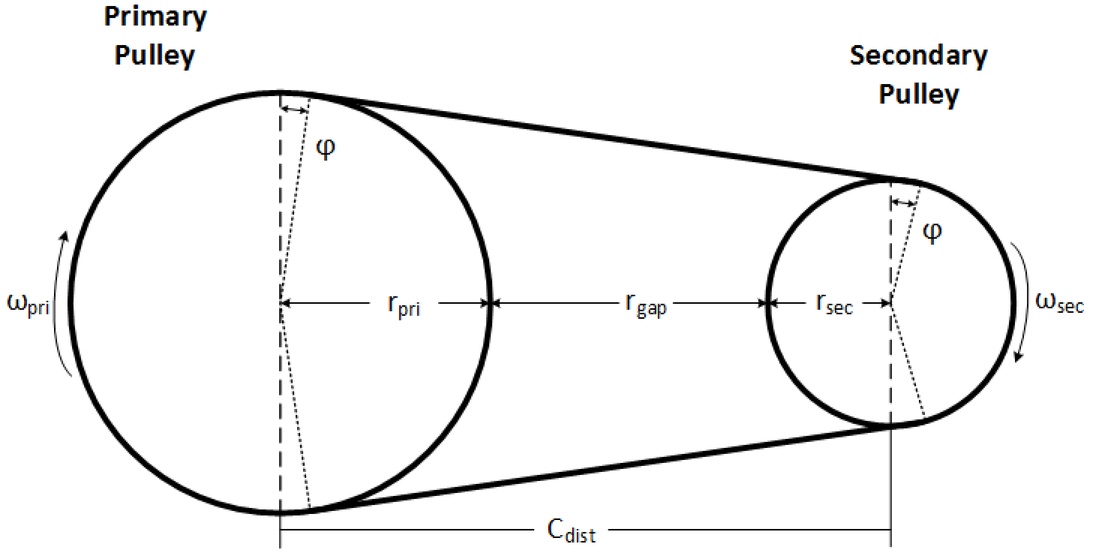
Minimum variator primary pulley radius, rp_{min}, in m.

Minimum variator secondary pulley radius, rs_min — Radius
scalar

Minimum variator secondary pulley radius, rs_{min}, in m.

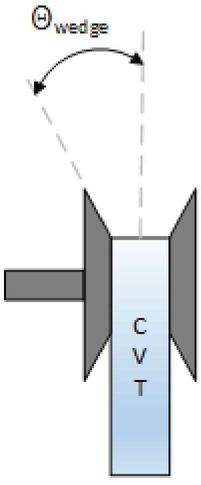
Gap distance between variator pulleys, rgap — Specify crown wheel connection
scalar

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
scalar

Variator wedge angle, Θ_{wedge}, in deg.



Dynamics

Primary pulley inertia, J_pri — Inertia
scalar

Primary pulley inertia, J_{pri}, in kg*m^2.

Secondary pulley inertia, J_sec — Inertia
scalar

Secondary pulley inertia, J_{sec}, in kg*m^2.

Primary pulley damping coefficient, b_pri — Damping
scalar

Primary pulley damping coefficient, b_{pri}, in N.m*s/rad.

Secondary pulley damping coefficient, b_sec — Damping
scalar

Secondary pulley damping coefficient, b_{sec}, in N.m*s/rad.

Belt damping coefficient, b_b — Damping
scalar

Belt damping coefficient, b_b, in kg/s.

`Static friction coefficient, mu_static` — Friction
`scalar`

Static friction coefficient between the belt and primary pulley, μ_{static}, dimensionless.

`Kinetic friction coefficient, mu_kin` — Friction
`scalar`

Kinetic friction coefficient between the belt and primary pulley, μ_{kin}, dimensionless.

`Belt mass, m_b` — Mass
`scalar`

Belt mass, m_b, in kg.

`Pulley clamp force, F_ax` — Pulley clamp force
`scalar`

Pulley clamp force, F_{ax}, in N.

Reverse and Output Ratio

`Forward inertia, J_fwd` — Inertia
`scalar`

Forward inertia, J_{fwd}, in kg*m^2.

`Reverse inertia, J_rev` — Inertia
`scalar`

Reverse inertia, J_{rev}, in kg*m^2.

`Forward efficiency, eta_fwd` — Efficiency
`scalar`

Forward efficiency, η_{fwd}, dimensionless.

`Reverse efficiency, eta_rev` — Efficiency
`scalar`

Reverse efficiency, η_{rev}, dimensionless.

`Reverse gear ratio, N_rev` — Ratio
`scalar`

Reverse gear ratio, N_{rev}, dimensionless.

`Shift time constant, tau_s` — Constant
`scalar`

Shift time constant, τ_s, in s.

`Output gear ratio, N_o` — Ratio
`scalar`

Output gear ratio, N_o, dimensionless.

`Output gear efficiency, eta_o` — Efficiency
`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. http://www.cvt.co.nz/cvt_how_does_it_work.htm

[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.

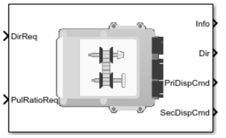
See Also

CVT Controller

Introduced in R2017a

CVT Controller

Continuously variable transmission controller
Library: Transmission / Transmission Controllers



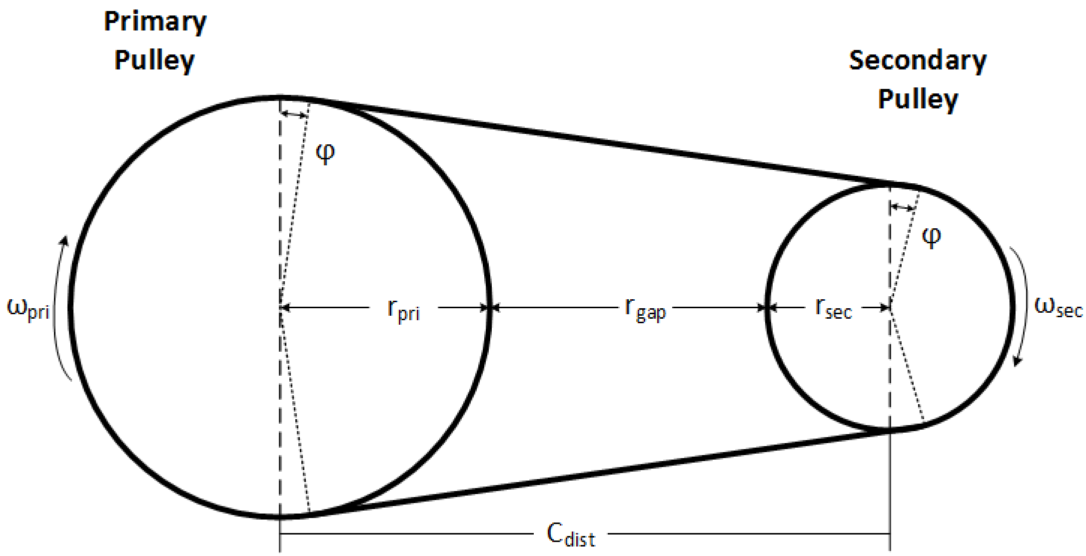
Description

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.



$$C_{dist} = rp_{max} + r_{gap} + r_{sec\_max}$$
$$L_0 = f(rp_{max}, rs_{max}, rp_{min}, rs_{min}, C_{dist})$$
$$ratio_{command} = f\left(ratio_{request}, ratio_{max}, ratio_{min}\right)$$
$$r_{pri} = f(r_0, ratio_{command}, C_{dist})$$
$$r_{\text{sec}} = f(r_0, ratio_{command}, C_{dist})$$
$$x_{pri} = f\left(r_0, r_{pri}, \theta_{wedge}\right)$$
$$x_{\text{sec}} = f\left(r_0, r_{\text{sec}}, \theta_{wedge}\right)$$

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
`scalar`

Maximum variator primary pulley radius, rp_{max}, in m.

`Maximum variator secondary pulley radius, rs_max` — Radius
`scalar`

Maximum variator secondary pulley radius, rs_{max}, in m.

`Minimum variator primary pulley radius, rp_min` — Radius
`scalar`

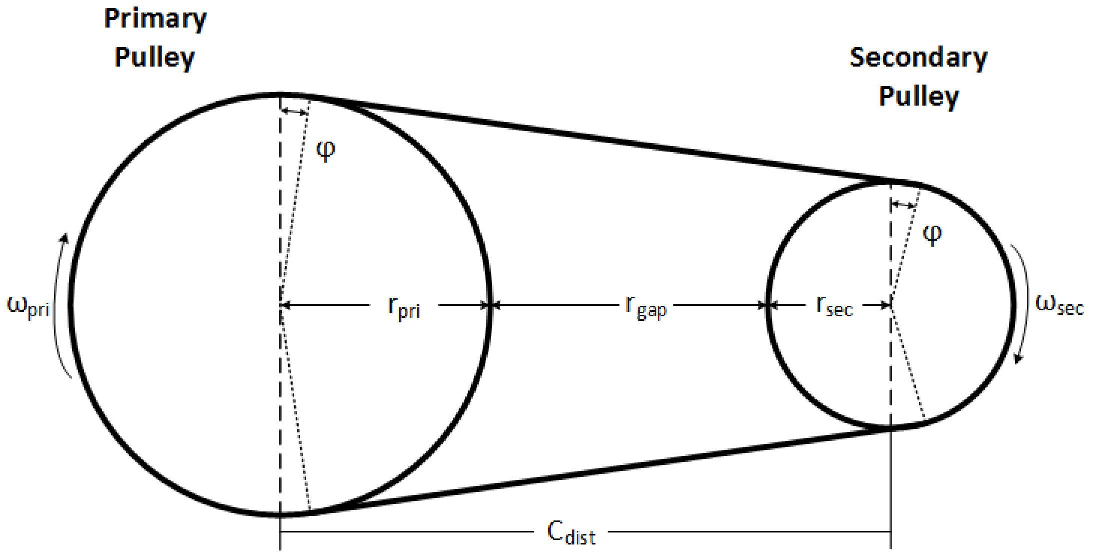
Minimum variator primary pulley radius, rp_{min}, in m.

`Minimum variator secondary pulley radius, rs_min` — Radius
`scalar`

Minimum variator secondary pulley radius, rs_{min}, in m.

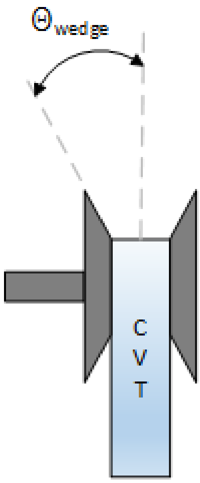
`Gap distance between variator pulleys, rgap` — Specify crown wheel connection
`scalar`

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
`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. http://www.cvt.co.nz/cvt_how_does_it_work.htm

[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.

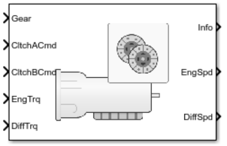
See Also

Continuously Variable Transmission

Introduced in R2017a

Dual Clutch Transmission

Dual clutch transmission that applies torque to the drive shaft
Library: 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 $T_S < \left\|T_f - N w_i b_i\right\|$	Unlocked	$T_f = T_k$ where, $T_k = F_c R_{eff} \mu_k \tanh\left[4\left(\frac{w_i}{N} - w_d\right)\right]$ $T_s = F_c R_{eff} \mu_s$ $R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$

If	Clutch Condition	Friction Model
$\omega_i = N\omega_t$ and $T_S \geq \left\| T_f - Nb_i\omega_i \right\|$	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.

$$\dot{\omega}_d J_N = N T_f - \omega_d b_N + T_d$$

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

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
`Trans`	`TransSpdRatio`	Input to output speed ratio at time t	$\Phi(t)$	NA
	`TransEta`	Ratio of output power to input power	η_N	NA

Signal		Description	Variable	Units
	TransGearCmd	Commanded gear	N_{cmd}	NA
	TransGear	Engaged gear	N	NA

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
`scalar`

Input shaft inertia, in kg*m^2.

`Input shaft damping, bin` — Damping
`scalar`

Input shaft damping, in N.m*s/rad.

`Initial input velocity, omegain_o` — Angular velocity
`scalar`

Angular velocity, in rad/s.

Efficiency torque breakpoints, Trq_bpts — Breakpoints
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
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
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
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]`

To Specify	Set Gear number, G to
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

`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**, **Damping vector**, and **Efficiency vector** parameters must be equal.

`Transmission inertia vector, Jout` — Gear rotational inertia

`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]

To Specify Inertia for	Set Gear number, G to	Set Inertia, J to
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
`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
`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
`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
`scalar`

Initial gear to engage, G_o.

Clutch and Synchronizer

`Clutch pressure time constant, tauc` — Time
`scalar`

Time required to engage and disengage the clutch during shift events, t_c, in s.

`Synchronization time, ts` — Time
`scalar`

Time required for gear selection and synchronization, t_s, in s.

`Clutch time, tc` — Time
`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
`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
`scalar`

Open loop lock-up clutch gain, K_c, in N.

`Clutch static friction coefficient, mus` — Coefficient
`scalar`

Dimensionless clutch disc coefficient of static friction, μ_s.

`Clutch kinematic friction coefficient, muk` — Coefficient
`scalar`

Dimensionless clutch disc coefficient of kinetic friction, μ_k.

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

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)

Selecting this parameter initially locks the synchronizer.

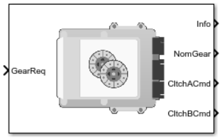
See Also

Automated Manual Transmission | DCT Controller

Introduced in R2017a

DCT Controller

Dual clutch transmission controller
Library: 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}

Signal	Description	Variable
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
scalar

Initial gear to engage, G_o.

Clutch actuation time, tc — Time
scalar

Time required to engage and disengage the clutch during shift events, t_c, in s.

Synchronizer time, ts — Time
scalar

Time required for gear selection and synchronization, t_s, in s.

`Sample period, dt` — Time
`scalar`

Sample period, *dt*, in s.

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

Selecting this parameter initially locks the clutch.

`Synchronizer initially locked` — Select to initially lock synchronizer
off (default)

Selecting this parameter initially locks the synchronizer.

See Also

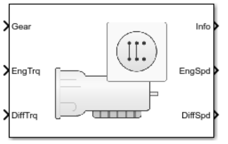
AMT Controller | Dual Clutch Transmission

Introduced in R2017a

Ideal Fixed Gear Transmission

Ideal fixed gear transmission without clutch or synchronization

Library: Transmission / Transmission Systems



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:

$$\dot{\omega}_i \frac{J_N}{N} = \eta_N \left(\frac{T_o}{N} + T_i \right) - \frac{\omega_i}{N^2} b_N$$

$$\omega_i = N \omega_o$$

The block filters the gear command signal:

$$\frac{G}{G_{cmd}}(s) = \frac{1}{\tau_s s + 1}$$

The equations use these variables.

b_N	Engaged gear viscous damping
J_N	Engaged gear 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	Output drive shaft angular speed
ω_i, $\acute{\omega}_i$	Applied drive shaft angular speed and acceleration
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 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_o	N·m
	`DiffSpd`	Drive shaft angular speed output	ω_o	rad/s

Signal		Description	Variable	Units
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

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.

Setting	Block Implementation
`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

`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]`

To Specify	Set Gear number, G to
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
`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
`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
`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
`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

`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

`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

`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 output velocity, omega_o` — Transmission
`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.

`Shift time constant, tau_s` — Time
`scalar`

Shift time constant, τ_s, in s.

See Also

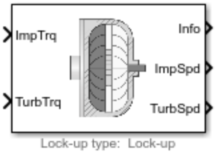
Automated Manual Transmission | Continuously Variable Transmission | Dual Clutch Transmission

Introduced in R2017a

Torque Converter

Three-part torque converter consisting of an impeller, turbine, and stator

Library: Transmission / Torque Converters



Description

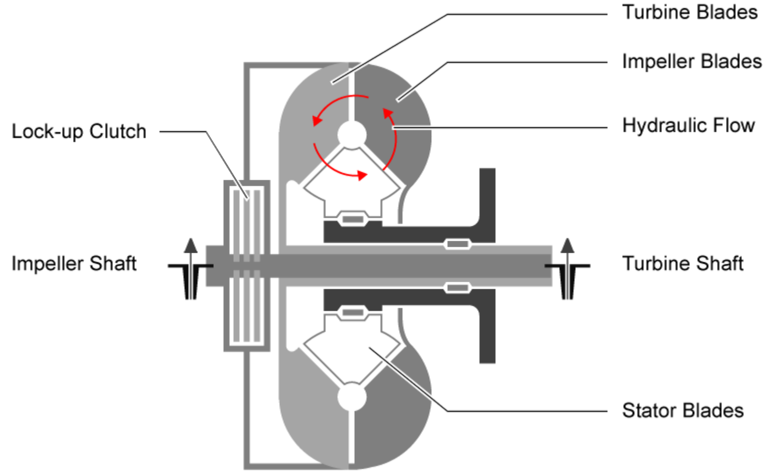
The Torque Converter block implements a three-part torque converter consisting of an impeller, turbine, and stator with an optional clutch lock-up capability. The block can simulate driving (power flowing from impeller to turbine) and coasting (power flowing from turbine to impeller).

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



Equations

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

Based on the clutch lock-up condition, the block implements these friction models.

If	Clutch Condition	Friction Model
$\omega_i \neq \omega_t$ or $T_S < \left\| \frac{J_t}{(J_i + J_t)} \left[T_i + T_f - \omega_i (b_t + b_i) \right] \right\|$	Unlocked	$T_f = T_k$ where: $T_k = F_c R_{eff} m_k \tanh\left[4\left(\omega_i - \omega_t \right) \right]$
$\omega_i = \omega_t$ and $T_S \geq \left\| \frac{J_t}{(J_i + J_t)} \left[T_i + T_f - w_t (b_t + b_i) + w_t b_t \right] \right\|$	Locked	$T_f = T_s$ $T_s = F_c R_{eff} m_s$ $R_{eff} = \frac{2(R_o^3 - R_i^3)}{3(R_o^2 - R_i^2)}$

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.

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]**.

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

`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
`scalar`

Impeller shaft inertia, in kg*m^2.

`Impeller shaft viscous damping, bi` — Viscous damping coefficient
`scalar`

Impeller shaft viscous damping, in N.m*s/rad.

`Turbine shaft inertia, Jt` — Inertia
`scalar`

Turbine shaft inertia, in kg*m^2.

`Turbine shaft viscous damping, bi` — Viscous damping coefficient
`scalar`

Turbine shaft viscous damping, in N.m*s/rad.

`Initial impeller shaft velocity, omegaio` — Angular velocity
`scalar`

Initial impeller shaft velocity, in rad/s.

Initial turbine shaft velocity, omegato — Angular velocity
scalar

Initial turbine shaft velocity, in rad/s.

Speed ratio vector, phi — Ratio
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
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
vector

Vector of turbine torque to impeller speed ratios.

`Fluid torque response time constant (set to 0 to disable), tauTC` — Time constant
`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
`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
`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
`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)

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
`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, omegalmin` — Angular velocity
`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
`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, Kclutch` — Gain
`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, taulu` — Time constant
`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.

See Also
CI Core Engine | SI Core Engine

Introduced in R2017a

7

Functions

mdf

Access information contained in MDF file

Syntax

```
mdfObj = mdf(mdfFileName)
```

Description

`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.

Note This function is supported only on 64-bit Windows® operating systems.

Examples

Create MDF File Object for Specified MDF File

Create an MDF object for a given file, and view the object display.

```
mdfObj = mdf('MDFFile.mf4')
```

```
MDF with properties:

   File Details
                 Name: 'MDFFile.mf4'
                 Path: 'c:\temp\MDFFile.mf4'
               Author: 'HOK'
           Department: 'Research'
              Project: 'MDF'
              Subject: 'CAN bus'
              Comment: 'This file contains CAN messages'
              Version: '4.10'
```

```
            DataSize: 32100
    InitialTimestamp: 2016-02-27 12:09:02

  Creator Details
   ProgramIdentifier: 'mmddff.04'
             Creator: [1×1 struct]

  File Contents
          Attachment: [1×1 struct]
        ChannelNames: {6×1 cell}
        ChannelGroup: [1×6 struct]
```

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

Property	Description
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, and Channel

See Also

Functions
read | saveAttachment

Introduced in R2016b

read

Read channel data from MDF file

Syntax

```
data = read(mdfObj)
data = read(mdfObj,chanGroupIndex,chanName)
data = read(mdfObj,chanGroupIndex,chanName,startPosition)
data = read(mdfObj,chanGroupIndex,chanName,startPosition,
endPosition)
data = read(mdfObj,chanGroupIndex,chanName,startPosition,
endPosition,'OutputFormat',fmtType)
[data,time] = read(mdfObj,chanGroupIndex,chanName,startPosition,
endPosition,'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.

Note This function is supported only on 64-bit Windows operating systems.

`data = read(mdfObj,chanGroupIndex,chanName)` reads all data for the specified channel from the MDF file identified by the MDF file object `mdfObj`.

`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(mdfObj,chanGroupIndex,chanName,startPosition,endPosition,'OutputFormat',fmtType)` returns data with the specified output format.

`[data,time] = read(mdfObj,chanGroupIndex,chanName,startPosition,endPosition,'OutputFormat','Vector')` returns two vectors of channel data and corresponding timestamps.

Examples

Read All Data from MDF File

Read all available data from the MDF file.

```
mdfObj = mdf('MDFFile.mf4');
data = read(mdfObj);
```

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');
```

Input Arguments

`mdfObj` — MDF file
MDF file object

MDF file, specified as an MDF file object.

Example: `mdf('MDFFile.mf4')`

`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
char vector | string

Name of channel, specified as a character vector, string, or array. `chanName` identifies the name of a channel in the channel group. Use a cell array of character vectors or array of string 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`

`fmtType` — Format for output data
`'Timetable'` (default) | `'Vector'` | `'TimeSeries'`

Format for output data, specified as a character vector or string. 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 columns for the MDF channels. Because the column titles must be valid MATLAB identifiers, they might not be exactly the same as those values in the MDF object `ChannelNames` property. The column 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 both data and time vectors.
'TimeSeries'	Return a time series of data from one channel.

Example: `'Vector'`

Data Types: `char` | `string`

Output Arguments

`data` — Channel data
timetable (default) | double | time series | cell array

Channel data, returned as vector of doubles, a time series, a timetable, or cell array of timetables, according to the `'OutputFormat'` option setting 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 the `'OutputFormat'` is set to `'Vector'`.

See Also

Functions
`mdf` | `saveAttachment`

Topics

"Time Series" (MATLAB)
"Represent Dates and Times in MATLAB" (MATLAB)
"Tables" (MATLAB)

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.

Note This function is supported only on 64-bit Windows operating systems.

`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

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.

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','CANape.MF4'));
while hasdata(mdfds)
    m = read(mdfds);
end
```

Input Arguments

`location` — Location of MDF datastore files
character vector | cell array

Location of MDF datastore files, specified as a character vector or cell array of character vectors, identifying either files or folders. The path can be relative or absolute, and can contain the wildcard character *. If `location` specifies a folder, the datastore includes by default all files in that folder with extensions `.mdf`, `.dat`, or `.mf4`.

Example: `'CANape.MF4'`

Data Types: `char` | `cell`

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments. `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

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: `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 extensions supported 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: `{'.myformat1','.myformat2'}`

Data Types: `char` | `cell`

ReadSize — Size of data returned by read
`'file'` (default) | numeric | duration

Size of data returned by `read`, 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 subsequently change the `ReadSize` property value type, the datastore resets.

Example: `50`

Data Types: `double` | `char` | `duration`

`SelectedChannelNames` — Names of channels to read
char | string | cell

Names of channels to read, specified as a character vector, string, or cell array.

Example: `'Counter_B4'`

Data Types: `char` | `string` | `cell`

`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`

Output Arguments

`mdfds` — MDF datastore
MDFDatastore object

MDF datastore returned as an MDFDatastore object, with the following methods and properties.

Method	Purpose
`preview`	Read eight rows from start of datastore (first file), from the selected channel group number and selected channel names
`read`	Read subset of data from datastore

Method	Purpose
readall	Read all data from datastore
hasdata	True if more data available in datastore
reset	Reset datastore to start of data
partition	Part of original datastore
numpartitions	Estimate for number of partitions to use

Property	Purpose
Files	Files included in datastore
ReadSize	Size of data returned by read
ChannelGroups	All channel groups present in first MDF file (read-only)
Channels	All channels present in first MDF file (read-only)
SelectedChannelGroupNumber	Channel group currently selected
SelectedChannelNames	Channels currently selected

See Also

Functions

hasdata | numpartitions | partition | preview | read | readall | reset

Introduced in R2017b

hasdata (MDFDatastore)

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','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 false (0).

See Also

Functions
mdfDatastore | read | readall | reset

Introduced in R2017b

numpartitions (MDFDatastore)

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','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` | `partition` | `read` | `reset`

Introduced in R2017b

partition (MDFDatastore)

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','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` | `numpartitions` | `read` | `reset`

Introduced in R2017b

preview (MDFDatastore)

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','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
`hasdata` | `mdfDatastore` | `read`

Introduced in R2017b

read (MDFDatastore)

Read data in MDF datastore

Syntax

```
data = read(mdfds)
[data,info] = read(mdfds)
```

Description

`data = read(mdfds)` returns data from the MDF datastore `mdfds` into the timetable `data`.

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
`hasdata` | `mdfDatastore` | `preview` | `readall` | `reset`

Introduced in R2017b

readall (MDFDatastore)

Read all data in MDF datastore

Syntax

`data = readall(mdfds)`

Description

`data = readall(mdfds)` reads all the data in the datastore specified by `mdfds` and returns it to timetable `data`.

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.

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);
```

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
hasdata | mdfDatastore | preview | read | reset

Introduced in R2017b

reset (MDFDatastore)

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 your 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','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
`hasdata` | `mdfDatastore` | `read`

Introduced in R2017b