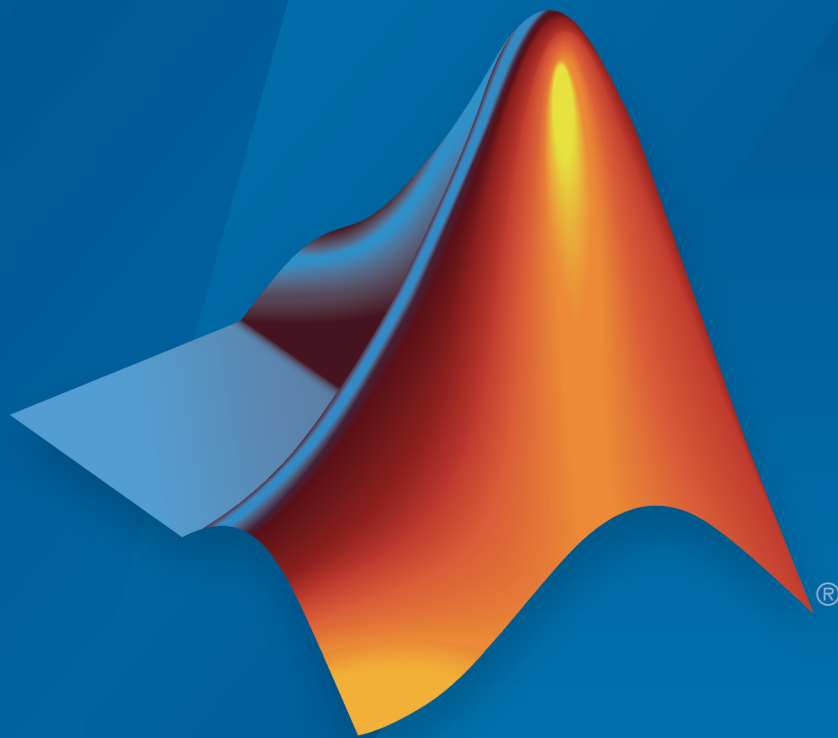


Simscape™ Driveline™

Reference



MATLAB® & SIMULINK®

R2016a



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*Simscape™ Driveline™ Reference*

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### Revision History

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April 2011	Online only	Revised for Version 2.0 (Release 2011a)
September 2011	Online only	Revised for Version 2.1 (Release 2011b)
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September 2015	Online only	Revised for Version 2.9 (Release R2015b)
March 2016	Online only	Revised for Version 2.10 (Release R2016a) (Renamed from <i>SimDriveline</i> <sup>TM</sup> Reference)



## Blocks — Alphabetical List

1

## Function Reference

2

## Relationship of First and Second Generation Technologies

3

<b>First-Generation Models and Libraries</b> . . . . .	3-2
Current First-Generation Functionality . . . . .	3-2
Manual Conversion of First-Generation Models . . . . .	3-3
Modification of Automatically Converted Models . . . . .	3-3
<b>First and Second Generation Libraries</b> . . . . .	3-4
First and Second Generation Block Compatibility . . . . .	3-4
First Generation Library . . . . .	3-5
Second Generation Library . . . . .	3-5
Transitional Library . . . . .	3-6
Correspondence of First and Second Generation Blocks . . . . .	3-7
<b>Manual Reconstruction of First Generation Models</b> . . . . .	3-11
Automatic Conversion Versus Manual Reconstruction . . . . .	3-11
Recreating Equivalent Blocks and Connections . . . . .	3-11
Recreating Equivalent Parameters and Signals . . . . .	3-12
Reconstruct Clutch Parameters and Signals . . . . .	3-12
Recreate Specialized Model Functionality . . . . .	3-14

<b>Automatic Conversion of First Generation Models and Libraries</b> .....	<b>3-15</b>
What Automatic Conversion Does .....	<b>3-15</b>
How the Simscape Driveline Update Function Works .....	<b>3-15</b>
About Automatically Converted Models .....	<b>3-16</b>
<b>Modification and Troubleshooting of Automatically Converted Models</b> .....	<b>3-17</b>
Manually Revise and Optimize Converted Models .....	<b>3-17</b>
Unlink and Replace Transitional Library Blocks .....	<b>3-17</b>
Best Practices with Automatically Converted Models .....	<b>3-19</b>
Transitional Library Input Handling Options .....	<b>3-20</b>
<b>Model and Library Automatic Conversion Examples</b> .....	<b>3-22</b>
About the Automatic Conversion Examples .....	<b>3-22</b>
Convert Example Model .....	<b>3-22</b>
Convert Example Library .....	<b>3-22</b>
Convert Example Model Linked to Example Library .....	<b>3-23</b>

## Technical Conventions

### A

<b>Driveline Abbreviations and Conventions</b> .....	<b>A-2</b>
Abbreviations .....	<b>A-2</b>
Angular Motion .....	<b>A-2</b>
Gear Ratios .....	<b>A-2</b>

## Bibliography

### B

# Blocks — Alphabetical List

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## Band Brake

Frictional brake with flexible band wrapped around rotating drum

## Library

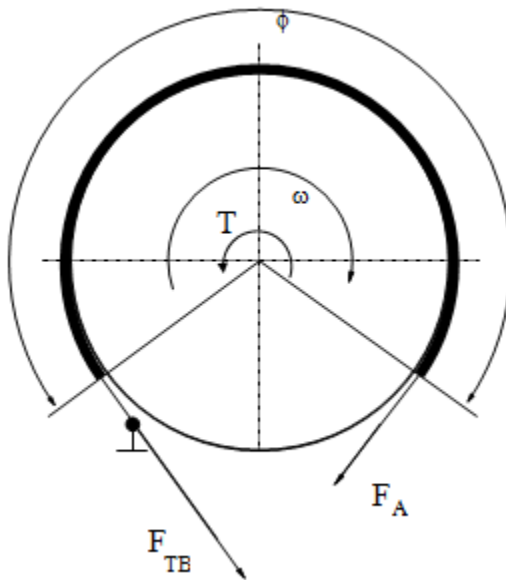
Brakes & Detents/Rotational



## Description

The block represents a frictional brake with a flexible band that wraps around the periphery of a rotating drum to produce a braking action. A positive actuating force causes the band to tighten around the rotating drum and it places the friction surfaces in contact. Viscous and contact friction between the drum and the flexible band surfaces cause the rotating drum to decelerate. Band brakes provide high braking torque at the cost of reduced braking precision in applications that include winch drums, chainsaws, go-karts and mini-bikes. The model employs a simple parameterization with readily accessible brake geometry and friction parameters.





The following formula provides the braking torque as a function of the external brake actuation force that tightens the belt.

$$T = (F_{TB} - F_A) \cdot r_D + \mu_{visc} \cdot \omega,$$

In the formula, the parameters have the following meaning:

Parameter	Description
$T$	Braking torque
$F_{TB}$	Force acting on the tense branch of the band
$F_A$	External brake actuation force
$r_D$	Drum radius
$\mu_{visc}$	Viscous friction coefficient
$\mu$	Contact friction coefficient

Parameter	Description
$\phi$	Wrap angle

Forces  $F_{TB}$  and  $F_A$  satisfy the relationship:

$$\frac{F_{TB}}{F_A} = e^{\mu\phi},$$

Replacing the relationship in the braking torque formula eliminates force  $F_{TB}$ :

$$T = F_A (e^{\mu\phi} - 1) \cdot r_D + \mu_{visc} \cdot \omega,$$

To avoid discontinuity at zero relative velocity, the model defines the actuation force  $F_S$  as a hyperbolic function:

$$F_A = F_{in} \cdot \tanh\left(\frac{4\omega}{\omega_{threshold}}\right),$$

In the previous formula, the parameters represent the following quantities:

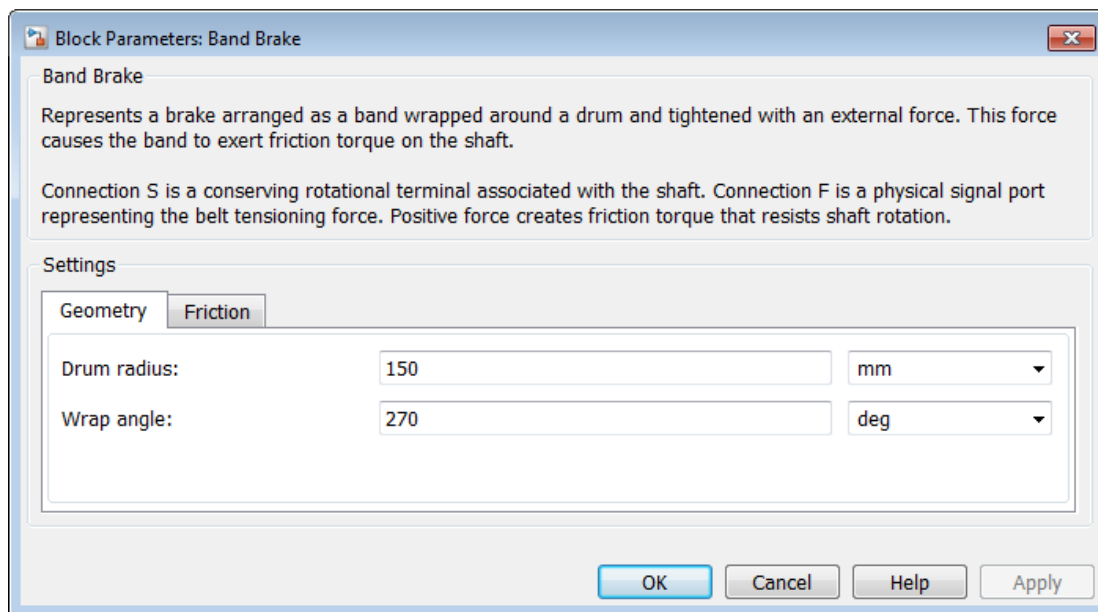
Parameter	Description
$F_{in}$	Force input signal
$\omega_{threshold}$	Angular velocity threshold

Connection F is a physical signal port that represents the external tensioning force applied on the belt. Connection S is a conserving rotational port that represents the rotating drum shaft.

## Assumptions and Limitations

- The model does not account for actuator flow consumption

## Dialog Box and Parameters



### Geometry

#### Drum radius

Radius of the drum contact surface. The parameter must be greater than zero. The default value is 150 mm.

#### Wrap angle

Contact angle between the flexible belt and the rotating drum. The parameter must be greater than zero. The default value is 270 deg.

### Friction

#### Viscous friction coefficient

Value of the viscous friction coefficient at the belt-drum contact surface. The parameter must be greater than or equal to zero. The default value is .01 N\*m/(rad/s).

**Contact friction coefficient**

Value of the Coulomb friction coefficient at the belt-drum contact surface. The parameter must be greater than zero. The default value is 0.3.

**Angular velocity threshold**

Angular velocity at which the friction coefficient at the belt-drum contact surface practically reaches its steady-state value. The parameter must be greater than zero. The default value is 0.01 rad/s.

**Ports**

Port	Description
F	Physical signal port that represents the belt tensioning force
S	Conserving rotational port that represents the rotating drum shaft

**See Also**

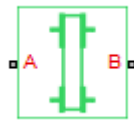
Double-Shoe Brake, Loaded-Contact Rotational Friction, Rotational Detent

# Belt Drive

Power transmission system with taut belt connecting two pulleys

## Library

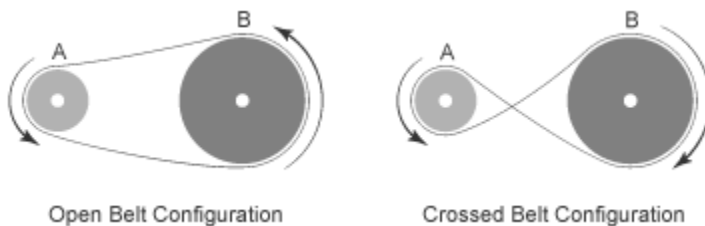
Couplings & Drives



## Description

The block represents a pair of pulleys connected with a flexible flat band or V-shaped belt. The model accounts for friction between the flexible belt and the pulley periphery. If the friction force is not sufficient to drive the load, the model allows slip. The relationship between the tensions in the tight and loose branches conforms to the Euler equation. The model accounts for centrifugal loading in the flexible belt, pulley inertia, and bearing friction.

The schematics show the belt drive in its two possible configurations: open (left) and crossed (right). In the open belt configuration, both pulleys tend to rotate in the same direction, and the larger pulley tends to have a larger belt wrap angle. In the crossed belt configuration, the pulleys tend to rotate in opposite directions, and both pulleys have the same wrap angle.



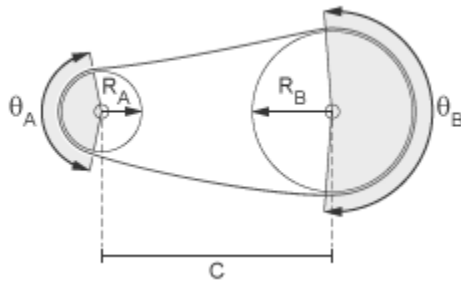
In the open configuration, the wrap angle of the belt around each pulley is given by the expressions:

$$\theta_A = \pi + 2 * \sin^{-1} \frac{R_A - R_B}{C},$$

$$\theta_B = \pi - 2 * \sin^{-1} \frac{R_A - R_B}{C}$$

- $\theta_A$  is the wrap angle of pulley A.
- $\theta_B$  is the wrap angle of pulley B.
- $R_A$  is the effective radius of pulley A.
- $R_B$  is the effective radius of pulley B.
- $C$  is the distance between the centers of pulley A and pulley B.

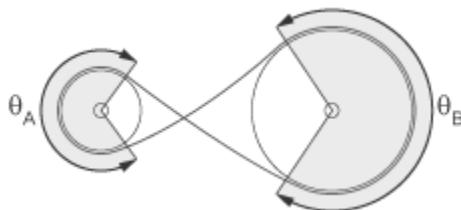
The following figure shows the wrap angles and the equation parameters used in the open-configuration calculations.



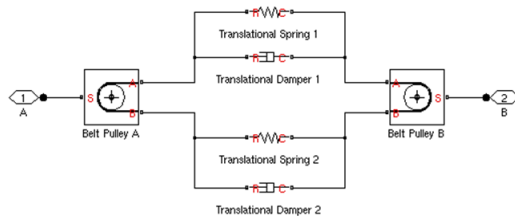
In the crossed configuration, the wrap angle of the belt around each pulley is given by the following expression. The two wrap angles are equal:

$$\theta_A = \theta_B = \pi + 2 * \sin^{-1} \frac{R_A + R_B}{C}$$

The figure shows the wrap angles calculated in the crossed-configuration expression.



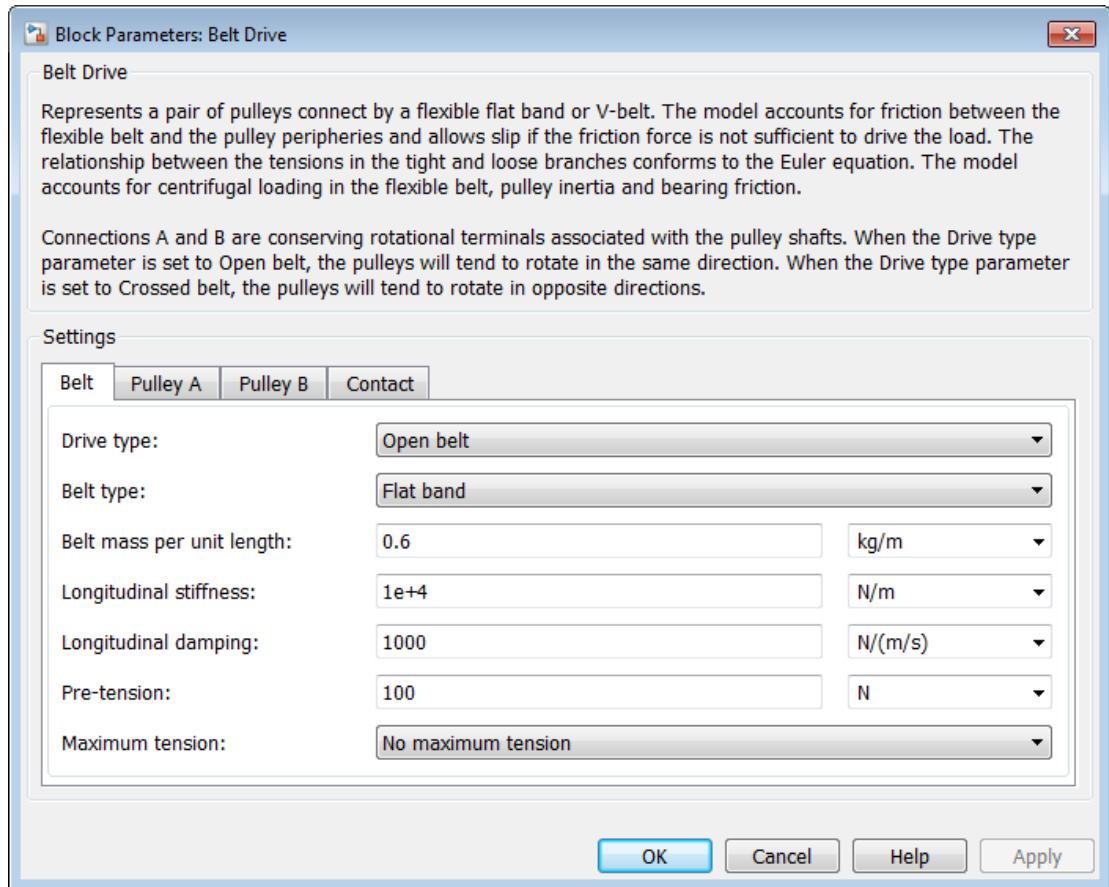
The Belt Drive block is a structural component based on the Simscape™ Driveline™ Belt Pulley block and Simscape Translational Spring and Translational Damper blocks. The Translational Spring and Translational Damper blocks model the compliance of the belt. For the equations governing the contact dynamics between the belt and the pulley, see the Belt Pulley block reference page. The following figure shows the block diagram upon which the Belt Drive block is based.



## Assumptions and Limitations

- The pulleys do not translate.
- The friction coefficient and friction velocity threshold between the belt and each of the pulleys is the same.

## Dialog Box and Parameters



### Drive type

Select the type of belt drive that you want to model.

- Open belt — (Default)
- Crossed belt

The schematic in this page shows the two drive types.



## Belt type

Type of flexible element modeled.

- Flat band — (Default)
- V-belt— Exposes the **V-belt sheave angle** and **Number of V-belts** parameters.

## V-belt sheave angle

Sheave angle of the V-belt. Default is 30 deg.

The **V-belt sheave angle** parameter is visible only when the **Belt type** parameter is V-belt.

## Number of V-belts

Number of parallel V-belts. Default is 1.

Non-integer values are rounded to the nearest integer. Increasing the number of belts increases the friction force, effective mass per unit length, and maximum allowable tension.

The **Number of V-belts** parameter is visible only when the **Belt type** parameter is V-belt.

## Belt mass per unit length

Linear density of each belt. Default is 0.6 kg/m.

The model uses this to calculate the centrifugal loading.

## Longitudinal stiffness

The effective stiffness of the belt. Default is 1e+4 N/m.

## Longitudinal damping

Effective damping of the belt. Default is 1000 N/(m/s).

## Pre-tension

Tension in the belt when the belt and pulleys are at rest. A positive value indicates that both pulley branches are initially in tension. A negative value indicates that the branches are initially slack. The default value is 100 N.

## Maximum tension

Specifies whether the block throws an assertion when the belt tension is too large.

- No maximum tension — (Default)
- Specify maximum tension— Throws an assertion when the belt tension is too high. Exposes the **Belt maximum tension** parameter.

## Belt maximum tension

Maximum allowable tension for each belt. Default is  $1e+5$  N.

When the tension on either end of the belt meets or exceeds this value, the simulation ends with an error.

The **Belt maximum tension** parameter is visible only when the **Maximum tension** parameter is **Specify maximum tension**.

Select the **Pulley A** tab to specify the characteristics of pulley attached to port A, and the **Pulley B** tab to specify the characteristics of pulley attached to port B.

## Pulley radius

Radius of the pulley. Default is 0.15m for pulley A and 0.3 m for pulley B.

## Bearing viscous friction coefficient

Viscous friction associated with the bearings that hold the axis of the pulley. Default is 0 N\*m/(rad/s) for pulley A and 0.001 N\*m/(rad/s) for pulley B.

## Inertia

Specifies whether the block models rotational inertia of the pulley.

- **No inertia** — (Default)
- **Specify inertia and initial velocity**— Models rotational inertia. Exposes the **Pulley inertia** and **Pulley initial velocity** parameters.

## Pulley inertia

Rotational inertia of the pulley. Default is 0.01 kg\*m<sup>2</sup> for pulley A, and 0.03 kg\*m<sup>2</sup> for pulley B.

The **Pulley inertia** parameter is visible only when the **Inertia** parameter is **Specify inertia and initial velocity**.

## Pulley initial velocity

Initial rotational velocity of the pulley. Default is 0 rad/s.

The **Pulley initial velocity** parameter is visible only when the **Inertia** parameter is **Specify inertia and initial velocity**.

Select the **Contact** tab to specify contact characteristics.

## Contact friction coefficient

Coulomb friction coefficient between the belt and the pulley surface. Default is 0.5.

## Wrap calculations

Specifies whether the block calculates the wrap angle of the belt on the pulleys using the pulley radii, center separation, and drive type or if the wrap angles are specified directly.

- **Specify pulley center separation** — (Default) The block calculates the wrap angle of the belt on the pulleys using the pulley radii, center separation, and drive type.

Exposes the **Pulley center separation** parameter.

- **Specify wrap angles** — Uses the wrap angles that you specify.

Exposes the **Pulley A wrap angle** and **Pulley B wrap angle** parameters.

## Pulley center separation

Distance between the centers of the pulleys. Default is 0.5 m.

The **Pulley center separation** parameter is visible only when the **Wrap calculations** parameter is **Specify pulley center separation**.

## Pulley A wrap angle

Angle of contact between the belt and pulley attached to port A. Default is 145 deg.

The **Pulley A wrap angle** parameter is visible only when the **Wrap calculations** parameter is **Specify wrap angles**.

## Pulley B Wrap angle

Angle of contact between the belt and pulley attached to port B. Default is 215 deg.

The **Pulley B wrap angle** parameter is visible only when the **Wrap calculations** parameter is **Specify wrap angles**.

## Friction velocity threshold

Relative velocity required for peak kinetic friction in the contact. The friction velocity threshold improves the numerical stability of the simulation by ensuring that the force is continuous when the direction of the velocity changes. Default is 0.001 m/s.

## Ports

Port	Description
A	Conserving rotational port associated with the shaft of pulley A
B	Conserving rotational port associated with the shaft of pulley B

## See Also

Chain Drive | Belt Pulley

## **More About**

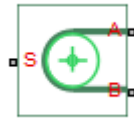
- “Rotational-Translational Couplings”

# Belt Pulley

Power transmission element with frictional belt wrapped around pulley circumference

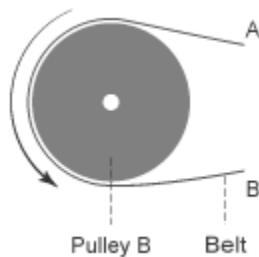
## Library

Couplings & Drives



## Description

This block represents a pulley wrapped in a flexible flat band or V-shaped belt. The model accounts for friction between the flexible belt and the pulley periphery. If the friction force is not sufficient to drive the load, the model allows slip. The relationship between the tensions in the tight and loose branches conforms to the Euler equation. The model accounts for centrifugal loading in the flexible belt, pulley inertia, and bearing friction.



The block dialog box enables you to select the relative belt direction of motion. Depending on the chosen setting, the two belt ends can move in equal or opposite directions. The block model assumes noncompliance in the belt and no resistance to motion due to wrapping around the pulley.

The Belt Pulley block uses the following equations to calculate friction force:

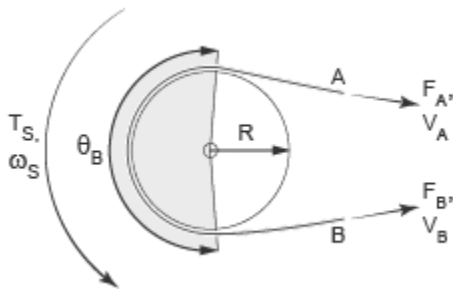
$$V_{rel} = V_A + \omega_S * R,$$

$$F_C = \rho * V_B^2,$$

$$F_{fr} = \begin{cases} F_B - F_C = (F_A - F_C) * \exp(f * \theta), & \text{if } V_{rel} \geq 0 \\ F_A - F_C = (F_B - F_C) * \exp(f * \theta), & \text{if } V_{rel} < 0 \end{cases}$$

$$V_A = -V_B$$

- $V_{rel}$  is the relative velocity between the belt and pulley periphery.
- $V_A$  is the Branch A linear velocity.
- $V_B$  is the Branch B linear velocity.
- $\omega_S$  is the pulley angular velocity.
- $R$  is the pulley radius.
- $F_C$  is the belt centrifugal force.
- $\rho$  is the belt linear density.
- $F_{fr}$  is the friction force between the pulley and the belt.
- $F_A$  is the force acting along branch A.
- $F_B$  is the force acting along branch B.
- $f$  is the friction coefficient.
- $\theta$  is the contact wrap angle.



For a flat band, specify the value of  $f$  directly in the block parameters dialog box. For a V-belt, the model calculates the value using this equation:

$$f = \frac{f}{\sin\left(\frac{\phi}{2}\right)}$$

- $f'$  is the effective friction coefficient for a V-belt.
- $\Phi$  is the V-belt sheave angle.

The idealization of the discontinuity at  $V_{rel} = 0$  is both difficult for the solver to resolve and not completely physically accurate. To alleviate this issue, the friction coefficient is assumed to change its value as a function of the relative velocity, with the following relationship:

$$\mu = -f * \tanh\left(4 * \frac{V_{rel}}{V_{thr}}\right)$$

- $\mu$  is the instantaneous value of the friction coefficient.
- $f$  is the steady-state value of the friction coefficient.
- $V_{thr}$  is the friction velocity threshold.

The friction velocity threshold controls the width of the region within which the friction coefficient changes its value from zero to a steady-state maximum. The friction velocity threshold specifies the velocity at which the hyperbolic tangent equals 0.999. The smaller the value, the steeper is the change of  $\mu$ .

This parameter uses the following equation to calculate the friction force:

$$F_{fr} = F_A - F_C = (F_B - F_C) * \exp(\mu * \theta)$$

The resulting torque on the pulley is given by the following equation:

$$T_S = (F_B - F_A) * R - \omega_S * b$$

- $T_S$  is the pulley torque.
- $b$  is the bearing viscous damping.

The block equations model power transmission between the belt branches or to/from the pulley. The tight and loose branches use the same calculation. Without sufficient tension, the frictional force is not enough to transmit power between the pulley and belt.

The model is valid when both ends of the belt are in tension. An optional warning can display at the MATLAB® command line when either belt end loses tension. When assembling a model, ensure that tension is maintained throughout the simulation. Interpret the results with this in mind.

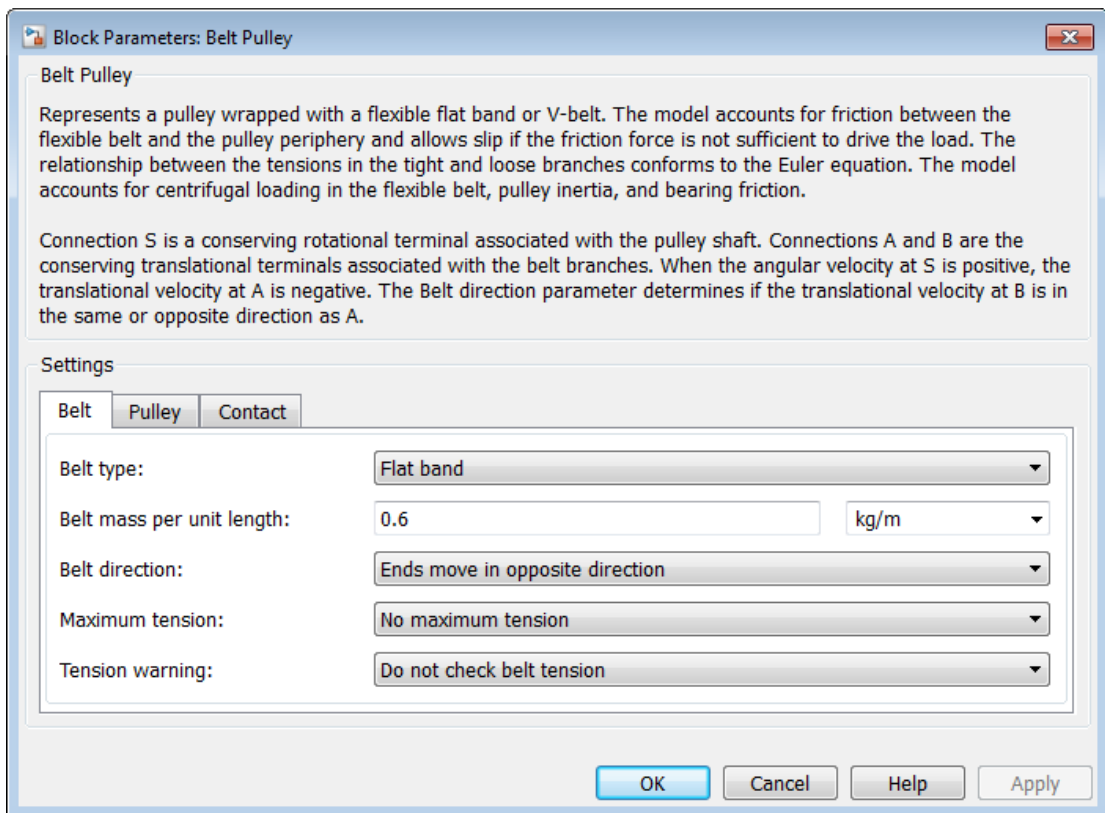


Connection S is a conserving rotational terminal associated with the pulley shaft. Connections A and B are the conserving mechanical translational ports associated with the belt ends. The sign convention is such that a positive rotation in port S tends to give a negative translation for port A and a positive translation for port B.

## Assumptions and Limitations

- The model does not account for compliance along the length of the belt.
- Both belt ends maintain adequate tension throughout the simulation.

## Dialog Box and Parameters



## Belt

### Belt type

Type of flexible element modeled.

- Flat band — (Default)
- V-belt— Exposes the **V-belt sheave angle** and **Number of V-belts** parameters.

### V-belt sheave angle

Sheave angle of the V-belt. Default is 30 deg.

The **V-belt sheave angle** parameter is visible only when the **Belt type** parameter is V-belt.

### Number of V-belts

Number of parallel V-belts. The default value is 1.

Non-integer values are rounded to the nearest integer. Increasing the number of belts increases the friction force, effective mass per unit length, and maximum allowable tension. Non-integer values are rounded to the nearest integer.

The **Number of V-belts** parameter is visible only when the **Belt type** parameter is V-belt.

### Belt mass per unit length

Linear density of each belt. Default is 0.6 kg/m.

The model uses this parameter to calculate the centrifugal loading.

### Belt direction

Relative direction of translational motion of one belt end with respect to the other. Options include:

- Ends move in opposite direction
- Ends move in same direction

### Maximum tension

Specifies whether the block throws an assertion when the belt tension is too large.

- No maximum tension — (Default)

- **Specify maximum tension** — Throws an assertion when the belt tension is too high. Exposes the **Belt maximum tension** parameter.

### **Belt maximum tension**

Maximum allowable tension for each belt. Default is  $1e+5$  N.

When the tension on either end of the belt meets or exceeds this value, the simulation ends with an error.

The **Belt maximum tension** parameter is visible only when the **Maximum tension** parameter is **Specify maximum tension**.

### **Tension warning**

Specifies whether the block writes a warning at the MATLAB command line when the tension at either end of the belt falls below zero.

- **Do not check belt tension** — (Default)
- **Warn if either belt end loses tension**

Select the **Pulley** tab to specify the pulley characteristics.

## **Pulley**

### **Pulley radius**

Radius of the pulley. Default is  $0.15$  m.

### **Bearing viscous friction coefficient**

Viscous friction associated with the bearings that hold the axis of the pulley. Default is  $0.001$  N\*m/(rad/s).

### **Inertia**

Specifies whether the block models rotational inertia of the pulley.

- **No inertia** — (Default)
- **Specify inertia and initial velocity** — Models rotational inertia. Exposes the **Pulley inertia** and **Pulley initial velocity** parameters.

### **Pulley inertia**

Rotational inertia of the pulley. Default is  $0.01$  kg\*m<sup>2</sup>.

The **Pulley inertia** parameter is visible only when the **Inertia** parameter is **Specify inertia and initial velocity**.

### **Pulley initial velocity**

Initial rotational velocity of the pulley. Default is 0 rad/s.

The **Pulley initial velocity** parameter is visible only when the **Inertia** parameter is Specify inertia and initial velocity.

Use the **Contact** pane to specify contact characteristics.

## **Contact**

### **Contact friction coefficient**

Coulomb friction coefficient between the belt and the pulley surface. Default is 0.5.

### **Wrap angle**

Angle of contact between the belt and pulley. Default is 180 deg.

### **Friction velocity threshold**

Relative velocity required for peak kinetic friction in the contact. The friction velocity threshold improves the numerical stability of the simulation by ensuring that the force is continuous when the direction of the velocity changes. Default is 0.001 m/s.

## **Ports**

<b>Port</b>	<b>Description</b>
S	Conserving rotational port associated with the pulley shaft
A	Conserving translational port associated with belt end A
B	Conserving translational port associated with belt end B

## **Example**

The `sdl_power_window` Simscape Driveline example model shows the use of the Belt Pulley block.

## **See Also**

Rope Drum | Belt Drive | Wheel and Axle

## **More About**

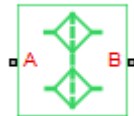
- “Rotational-Translational Couplings”

## Chain Drive

Power transmission system with chain and two sprockets

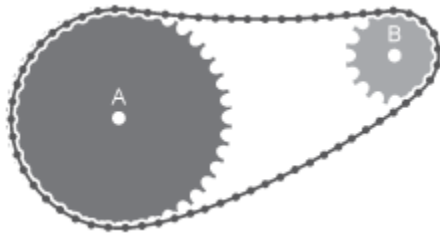
### Library

Couplings & Drives



### Description

This block represents a power transmission system with a chain and two sprockets. The chain meshes with the sprockets, transmitting rotary motion between the two. Power transmission can occur in reverse, i.e., from driven to driver sprocket, due to external loads. This condition is known as back-driving.



The drive chain is compliant. It can stretch under tension and slacken otherwise. The compliance model consists of a linear spring-damper set in a parallel arrangement. The spring resists tensile strain in the chain. The damper resists tensile motion between chain elements.

The spring and damper forces act directly on the sprockets that the chain connects. The spring force is present when one chain branch is taut. The damper force is present

continuously. If you specify a maximum tension value, when the net tensile force in the chain exceeds this value, simulation stops with an error.

The block accounts for viscous friction at the sprocket joint bearings. During motion, viscous friction causes power transmission losses, reducing chain-drive efficiency. These losses compound those due to chain damping. Setting viscous friction and chain damping to zero eliminates power transmission losses in the chain drive.

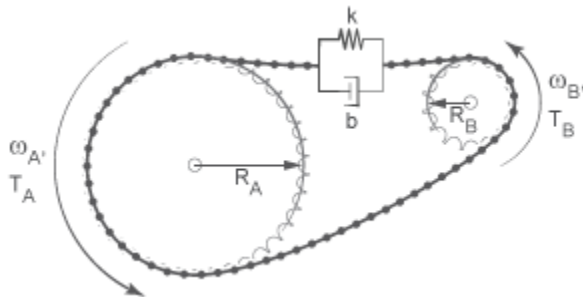
The tensile strain rate in the chain is the difference between the sprocket tangential velocities, each the product of the angular velocity and pitch radii. Mathematically,

$$\dot{x} = \omega_A R_A - \omega_B R_B,$$

where:

- $x$  is the tensile strain.
- $\omega_A, \omega_B$  are the sprocket angular velocities.
- $R_A, R_B$  are the sprocket pitch radii.

The figure shows the relevant equation variables.



The chain tensile force is the net sum of spring and damper forces. The spring force is the product of the tensile strain and the spring stiffness constant. This force is zero whenever the tensile strain is smaller than the chain slack. The damper force is the product of the tensile strain rate and the damping coefficient. Mathematically,

$$F = \begin{cases} -\left(x - \frac{S}{2}\right)k - \dot{x}b, & x > \frac{S}{2} \\ -\dot{x}b, & \frac{S}{2} \geq x \geq -\frac{S}{2}, \\ -\left(x + \frac{S}{2}\right)k - \dot{x}b, & x < -\frac{S}{2} \end{cases}$$

where:

- $S$  is the chain slack.
- $k$  is the spring stiffness constant.
- $b$  is the damper coefficient.

The chain exerts a torque on each sprocket equal to the product of the tensile force and the sprocket pitch radius. The two torques act in opposite directions according to the equations

$$T_A = -F \cdot R_A,$$

and

$$T_B = F \cdot R_B,$$

where:

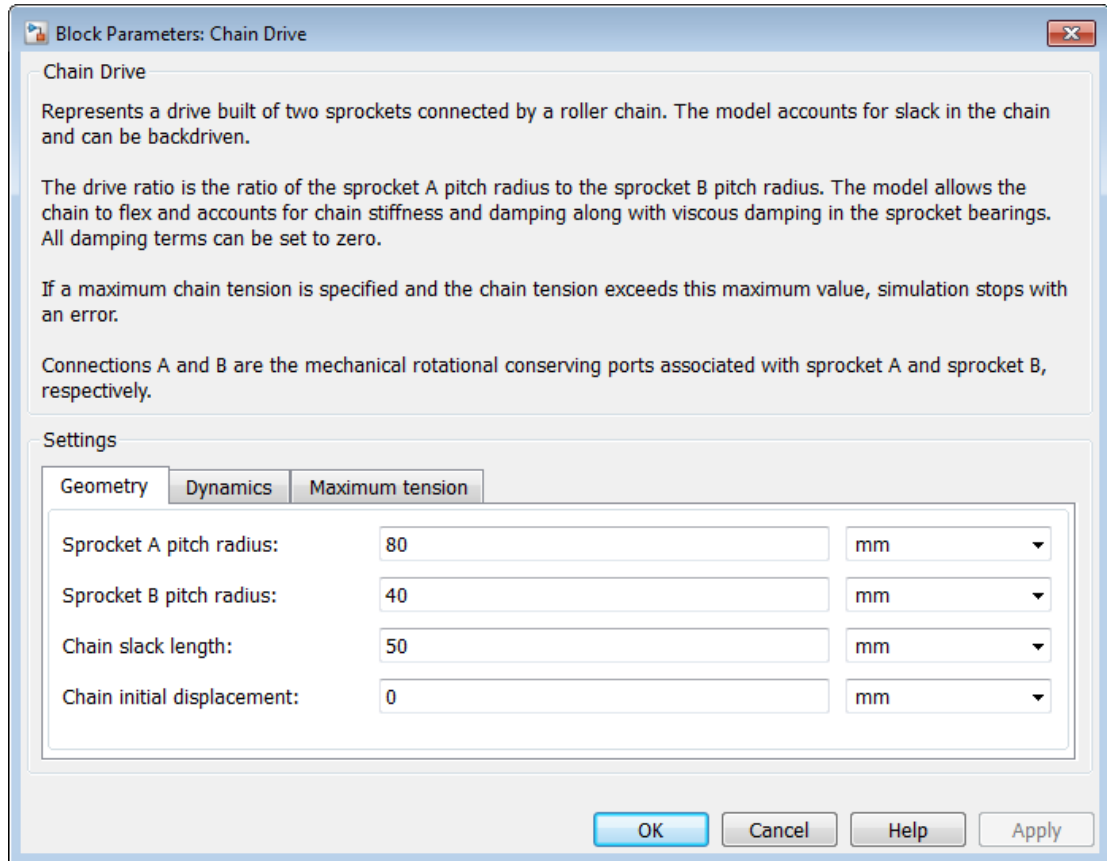
- $T_A$  is the torque that the chain applies on sprocket A.
- $T_B$  is the torque that the chain applies on sprocket B.

## Assumptions and Limitations

- The sprocket tooth ratio equals the sprocket pitch radius ratio.
- Chain inertia is negligible.



## Dialog Box and Parameters



### Geometry

Specify the sprocket and chain dimensions.

#### Sprocket A pitch radius

Radius of the sprocket A pitch circle. The pitch circle is an imaginary circle passing through the contact point between a chain roller and a sprocket cog at full engagement. The default value is 80 mm.

### **Sprocket B pitch radius**

Radius of the sprocket B pitch circle. The pitch circle is an imaginary circle passing through the contact point between a chain roller and a sprocket cog at full engagement. The default value is 40 mm.

### **Chain slack length**

Maximum distance the loose branch of the drive chain can move before it is taut. This distance equals the length difference between actual and fully taut drive chains.

If one sprocket is held in place while the top chain branch is taut, then the slack length is the tangential distance that the second sprocket must rotate before the lower chain branch becomes taut. The default value is 50 mm.

### **Chain initial displacement**

Chain displacement from the neutral position at time zero. In the neutral position (the default value) the chain can move in either direction by half the chain length before it is taut. The default value is 0 mm.

## **Dynamics**

Specify the internal forces acting in the chain and on the sprockets.

### **Chain stiffness**

Linear spring constant in the chain compliance model. This constant describes the chain resistance to strain. The spring element accounts for elastic energy storage in the chain due to deformation. The default value is  $1 \text{e}+5$  N/m.

### **Chain damping**

Linear damping coefficient in the chain compliance model. This coefficient describes the chain resistance to tensile motion between adjacent chain elements. The damper element accounts for power losses in the chain due to deformation. The default value is 5 N/(m/s).

### **Viscous friction coefficient of sprocket A**

Friction coefficient due to the rolling action of the sprocket A joint bearing in the presence of a viscous lubricant. The default value is 0.001 N\*m/(rad/s).

### **Viscous friction coefficient of sprocket B**

Friction coefficient due to the rolling action of the sprocket B joint bearing in the presence of a viscous lubricant. The default value is 0.001 N\*m/(rad/s).

## Maximum tension

Specify the upper tension limit in the drive chain.

### Maximum tension

Select whether to constrain the maximum tensile force in the drive chain.

- **No maximum tension** — Chain tension can be arbitrarily large during simulation.
- **Maximum tension** — Chain tension must remain lower than a maximum value. Simulation stops with an error when tension exceeds this value.

### Chain maximum tension

Maximum allowed value of the tensile force acting in the chain. The default value is  $1e+6$  N.

## Ports

Port	Description
A	Conserving rotational port associated with sprocket A
B	Conserving rotational port associated with sprocket B

## Example

Open `sdl_sheet_metal_feeder` for an example using the Chain Drive block.

## See Also

Simple Gear | Variable Ratio Transmission

## Related Examples

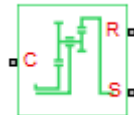
- “Gear Coupling Control with Clutches”

# Compound Planetary Gear

Planetary gear train with stepped planet gear set

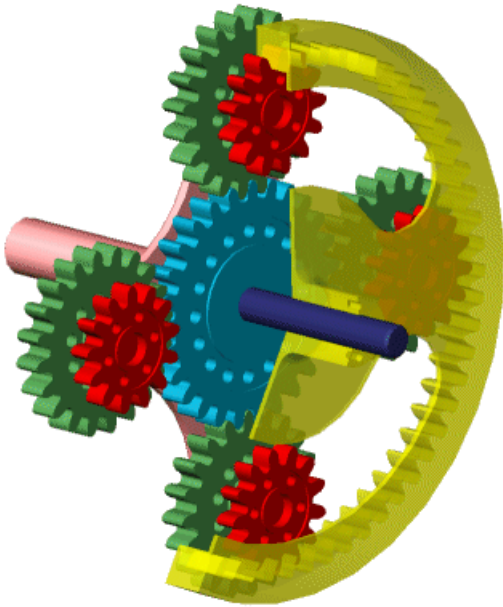
## Library

Gears



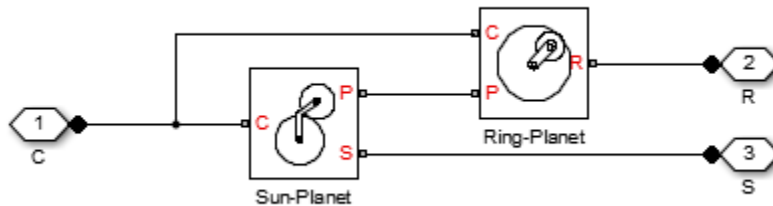
## Description

This block represents a planetary gear train with composite planet gears. Each composite planet gear is a pair of rigidly connected and longitudinally arranged gears of different radii. One of the two gears engages the centrally located sun gear while the other engages the outer ring gear.



### Compound Planetary Gear

The block models the compound planetary gear as a structural component based on Sun-Planet and Ring-Planet Simscape Driveline blocks. The figure shows the block diagram of this structural component.



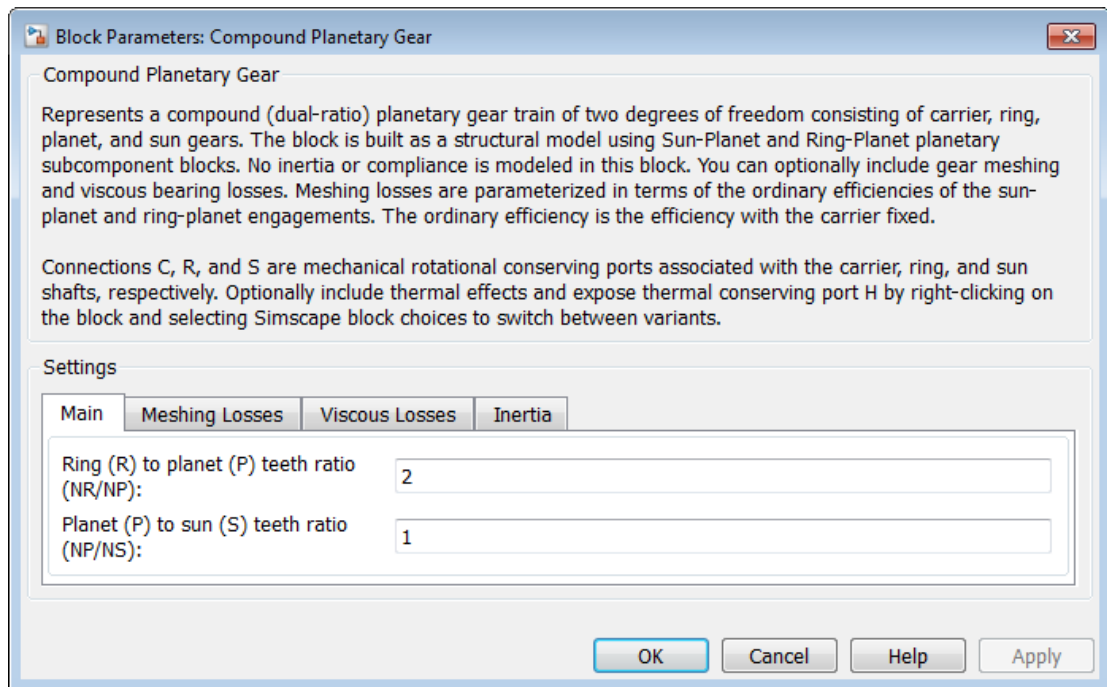
To increase the fidelity of the gear model, you can specify properties such as gear inertia, meshing losses, and viscous losses. By default, gear inertia and viscous losses are assumed negligible. The block enables you to specify the inertias of the internal planet

gears only. To model the inertias of the carrier, sun, and ring gears, connect Simscape Inertia blocks to ports C, S, and R.

## Modeling Thermal Effects

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

Ring (R) to planet (P) teeth ratio (NR/NP)

Fixed ratio  $g_{RP}$  of the ring gear to the planet gear. The gear ratio must be strictly greater than 1. The default is 2.

### **Planet (P) to sun (S) teeth ratio (NP/NS)**

Fixed ratio  $g_{PS}$  of the planet gear to the sun gear. The gear ratio must be strictly positive. The default is 1.

## **Meshing Losses**

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

### **Without Thermal Port**

#### **Friction model**

Select how to implement friction losses from nonideal meshing of gear teeth. The default is **No meshing losses**.

- **No meshing losses** – Suitable for HIL simulation — Gear meshing is ideal.
- **Constant efficiency** — Transfer of torque between gear wheel pairs is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

#### **Constant Efficiency**

##### **Sun-planet and ring-planet ordinary efficiencies**

Vector of torque transfer efficiencies  $[\eta_{SP} \ \eta_{RP}]$  for sun-planet and ring-carrier gear wheel pair meshings, respectively.

##### **Sun-carrier and planet-carrier power thresholds**

Vector of power thresholds  $p_{th}$  above which full efficiency factors apply, for sun-carrier and planet-carrier, respectively. Below these values, a hyperbolic tangent function smooths the efficiency factor, lowering the efficiency losses to zero when no power is transmitted. The default array is  $[0.001 \ 0.001]$  W.

### **With Thermal Port**

#### **Temperature**

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as each efficiency array. The default array is [280 300 320] K.

### **Sun-planet efficiency**

Array of mechanical efficiencies with power flowing from the sun gear to the planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.95 0.9 0.85].

### **Ring-planet efficiency**

Array of mechanical efficiencies with power flowing from the ring gear to the planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.95 0.9 0.85].

### **Sun-carrier and planet-carrier power thresholds**

Array of power thresholds above which the full efficiency factors apply. Enter the thresholds for the sun and planet gears relative to the gear carrier, in this order. A hyperbolic tangent function smooths the efficiency factors between zero at rest and the values provided by the temperature-efficiency lookup tables at the power thresholds. The default array is [0.001 0.001] W.

## **Viscous Losses**

### **Sun-carrier and planet-carrier viscous friction coefficients**

Vector of viscous friction coefficients [ $\mu_S \mu_P$ ] for the sun-carrier and planet-carrier gear motions, respectively. The default is [0 0].

From the drop-down list, choose units. The default is newton-meters/(radians/second) (N\*m/ (rad/s)).

## **Inertia**

### **Planet gear inertia**

Moment of inertia of the combined planet gears. This value must be positive or zero. Enter 0 to ignore gear inertia. The default value is 0 kg\*m<sup>2</sup>.

## **Thermal Port**

### **Thermal mass**



Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Compound Planetary Gear Model

### Ideal Gear Constraints and Gear Ratios

Compound Planetary Gear imposes two kinematic and two geometric constraints on the three connected axes and the fourth, internal wheel (planet):

$$r_C \omega_C = r_S \omega_S + r_{P1} \omega_P, \quad r_C = r_S + r_{P1},$$

$$r_R \omega_R = r_C \omega_C + r_{P2} \omega_P, \quad r_R = r_C + r_{P2}.$$

The ring-planet gear ratio  $g_{RP} = r_R/r_{P2} = N_R/N_{P2}$  and the planet-sun gear ratio  $g_{PS} = r_{P1}/r_S = N_{P1}/N_S$ .  $N$  is the number of teeth on each gear. In terms of these ratios, the key kinematic constraint is:

$$(1 + g_{RP} g_{PS}) \omega_C = \omega_S + g_{RP} g_{PS} \omega_R.$$

The four degrees of freedom reduce to two independent degrees of freedom. The gear pairs are (1,2) = (P2,R) and (S,P1).

---

**Warning** The gear ratio  $g_{RP}$  must be strictly greater than one.

---

The torque transfers are:

$$g_{RP} \tau_{P2} + \tau_R - \tau_{\text{loss}}(\text{P2,R}) = 0, \quad g_{PS} \tau_S + \tau_{P1} - \tau_{\text{loss}}(\text{S,P1}) = 0,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

### Nonideal Gear Constraints and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . See “Model Gears with Losses”.

## Limitations

- Gears are assumed rigid.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
C	Rotational conserving port representing the planet gear carrier
R	Rotational conserving port representing the ring gear
S	Rotational conserving port representing the sun gear
H	Thermal conserving port for thermal modeling

## See Also

Planetary Gear | Ravigneaux Gear | Ring-Planet | Sun-Planet

## Related Examples

- “Represent and Transfer Driveline Motion and Torque”

# Cone Clutch

Friction clutch with conical plates that engage when normal force exceeds threshold

## Library

Clutches



## Description

This block represents a friction clutch with a conical contact interface. The conical interface creates a wedging action between the clutch components, a cone and a cup, thereby reducing the normal force required for clutch engagement.

The cup component connects rigidly to the drive shaft, spinning with it as a unit. The cone component connects rigidly to the driven shaft, which sits in axial alignment with the drive shaft. The clutch engages when the cone slides toward the cup and presses tightly against its internal surface.

Friction at the cone-cup contact interface enables the clutch to transmit rotational power between the drive and driven shafts. The friction model of this block includes both static and kinetic friction contributions, the latter of which leads to power dissipation during slip between the cone and cup components.

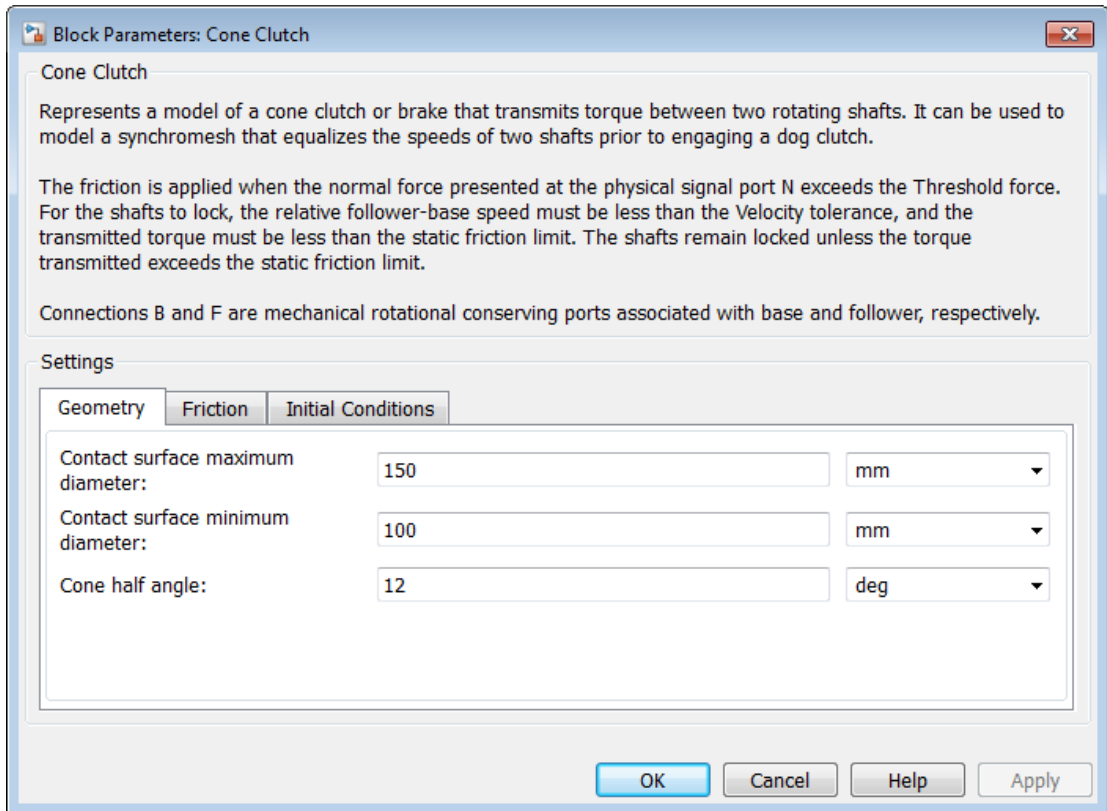
Cone clutches find real-world application in synchromesh gearboxes, which synchronize the drive and driven shaft speeds to enable smoother engagement between transmission gears. For block model details, see “Cone Clutch Model” on page 1-41.

## Ports

B and F are rotational conserving ports representing, respectively, the clutch input (base) and output (follower) driveshaft axes. The clutch motion is measured as the *slip*  $\omega = \omega_F - \omega_B$ , the angular velocity of follower relative to base.

The clutch requires a physical signal input  $N$  that represents the normal force (in newtons) applied between the friction surfaces in contact. This signal should be positive or zero. A signal  $N$  less than zero is interpreted as zero.

## Dialog Box and Parameters



### Geometry

#### Contact surface maximum diameter

Outer conical diameter  $d_o$ . The default is 150.

From the drop-down list, choose units. The default is millimeters (mm).

### **Contact surface minimum diameter**

Inner conical diameter  $d_i$ . The default is 100.

From the drop-down list, choose units. The default is millimeters (mm).

### **Cone half angle**

Half opening angle  $\alpha$  of the cone geometry. The default is 12.

From the drop-down list, choose units. The default is degrees (deg).

## **Friction**

### **Friction model**

Select how to model the dimensionless Coulomb kinetic friction coefficient  $k_K$  across the clutch when the clutch is slipping. The default is **Fixed kinetic friction coefficient**.

- **Fixed kinetic friction coefficient** — Model Coulomb kinetic friction in terms of a constant kinetic friction coefficient.

#### **Fixed Kinetic Friction Coefficient**

##### **Kinetic friction coefficient**

Dimensionless kinetic friction coefficient  $k_K$  applied to the normal force across clutch. The default is 0.3.

- **Table lookup kinetic friction coefficient** — Model Coulomb kinetic friction in terms of a kinetic friction coefficient lookup function defined at discrete relative velocity values. If you select this option, the panel changes from its default.

#### **Table Lookup Kinetic Friction Coefficient**

##### **Kinetic friction coefficient relative velocity vector**

Vector of clutch slip values  $\omega$  at which to define kinetic friction coefficient.

From the drop-down list, choose units. The default is radians/second (rad/s).

##### **Kinetic friction coefficient vector**

Vector of kinetic friction coefficient values  $k_K$ .

**Friction coefficient interpolation method**

Method to interpolate kinetic friction coefficient function between discrete relative velocity values within the range of definition. The default is `Linear`.

**Friction coefficient extrapolation method**

Method to extrapolate kinetic friction coefficient function outside the range of definition. The default is `Linear`.

**Static friction coefficient**

Dimensionless Coulomb static friction coefficient  $k_S$  applied to the normal force across the clutch when the clutch is locked. Must be larger than  $k_K$ . The default is `0.35`.

**Clutch velocity tolerance**

Maximum slip velocity at which the clutch can lock. The slip velocity is the signed difference between the base and follower shaft angular velocities, that is,  $w = w_F - w_B$ . The clutch locks if the actual slip velocity falls below the velocity tolerance and if other conditions are present—i.e., if the kinetic friction torque is nonzero and if the transferred torque is within the static friction torque limits. The default value is `0.001` rad/s.

**Threshold force**

Minimum normal force  $F_{th}$  needed to engage the clutch. This lower bound applies to the physical signal input normal force  $N$ . If  $N$  falls below this value, the clutch applies no normal force. The default is `1`.

From the drop-down list, choose units. The default is newtons (N).

**Initial Conditions**

**Initial state**

Clutch state at the start of simulation. The clutch can be in one of two states, locked and unlocked. A locked clutch constrains the base and follower shafts to spin at the same velocity, i.e., as a single unit. An unlocked clutch allows the two shafts to spin at different velocities, resulting in slip between the clutch plates. The default setting is `Unlocked`.

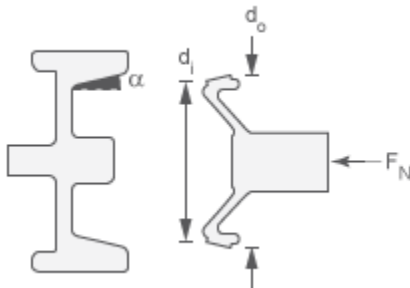
## Cone Clutch Model

The Cone Clutch is based on the Fundamental Friction Clutch. For the complete friction clutch model, consult the Fundamental Friction Clutch block reference page. This section discusses the specialized model implemented in the Cone Clutch.

When you apply a normal force  $F_N$ , the Cone Clutch block can apply two kinds of friction to the driveline motion, kinetic and static. The clutch applies kinetic friction torque only when one driveline axis is spinning relative to the other driveline axis. The clutch applies static friction torque when the two driveline axes lock and spin together. The block iterates through multistep testing to determine when to lock and unlock the clutch.

## Clutch Geometry and Variable Summary

The figure shows the cone clutch geometry and some model parameters. Refer to the table for a summary of variable descriptions.



### Clutch Variables

Parameter	Definition	Significance
$d_o$	Outer diameter of the conical contact surface	<i>See the preceding figure</i>
$d_i$	Inner diameter of the conical contact surface	<i>See the preceding figure</i>
$\alpha$	Cone half angle	<i>See the preceding figure</i>
$\omega$	Relative angular velocity (slip)	$\omega_F - \omega_B$

Parameter	Definition	Significance
$\omega_{\text{Tol}}$	Slip tolerance for clutch locking	<i>See the following model</i>
$F_{\text{N}}$	Normal force applied to conical surfaces	Normal force applied, if greater than threshold: $F_{\text{N}} > F_{\text{th}}$
$a$	Cone half-angle	<i>See the preceding figure</i>
$r_{\text{eff}}$	Effective torque radius	Effective moment arm of clutch friction force
$k_{\text{K}}$	Kinetic friction coefficient	Dimensionless coefficient of kinetic friction of conical friction surfaces. Function of $\omega$ .
$k_{\text{S}}$	Static friction coefficient	Dimensionless coefficient of static friction of conical friction surfaces.
$\tau_{\text{K}}$	Kinetic friction torque	<i>See the following model</i>
$\tau_{\text{S}}$	Static friction torque limit	(static friction peak factor) (kinetic friction torque for $\omega \rightarrow 0$ ) ( <i>See the following model</i> )

## Relation to Fundamental Friction Clutch

The Cone Clutch is based on the Fundamental Friction Clutch. Instead of requiring the kinetic and static friction limit torques as input signals, the Cone Clutch calculates the kinetic and static friction from the clutch parameters and the input normal force signal  $F_{\text{N}}$ . See the Fundamental Friction Clutch reference page for more information about the friction clutch.

### Kinetic Friction

The kinetic friction torque is the product of four factors:

$$\tau_{\text{K}} = k_{\text{K}} \cdot F_{\text{N}} \cdot r_{\text{eff}} \cdot \text{sgn}(\omega) .$$

The kinetic friction torque opposes the relative slip and is applied with an overall minus sign. It changes sign when  $\omega$  changes sign.

You specify the *kinetic friction coefficient*  $k_{\text{K}}$  as either a constant or a tabulated discrete function of relative angular velocity  $\omega$ . The tabulated function is assumed to be symmetric for positive and negative values of the relative angular velocity, so that you need to specify  $k_{\text{K}}$  for positive values of  $\omega$  only.



The *effective torque radius*  $r_{\text{eff}}$  is the effective radius, measured from the driveline axis, at which the kinetic friction forces are applied at the frictional surfaces. It is related to the geometry of the conical friction surface geometry by:

$$r_{\text{eff}} = \frac{1}{3 \sin \alpha} \frac{d_o^3 - d_i^3}{d_o^2 - d_i^2}$$

$d_o$  and  $d_i$  are the contact surface maximum and minimum diameters, respectively.

### Static Friction

The static friction limit is related to the kinetic friction, setting  $\omega$  to zero and replacing the kinetic with the static friction coefficient:

$$\tau_S = k_S \cdot F_N \quad r_{\text{eff}} \geq 0.$$

$k_S > k_K$ , so that the torque  $\tau$  needed across the clutch to unlock it by overcoming static friction is larger than the kinetic friction at the instant of unlocking, when  $\omega = 0$ .

The static friction limit defines symmetric *static friction torque limits* as:

$$\tau_S \equiv \tau_S^+ = -\tau_S^-.$$

The range  $[\tau_S^-, \tau_S^+]$  is used by the Fundamental Friction Clutch.

### Engagement and Locking Conditions

The clutch engages (transmits torque) when the conical friction surfaces are subject to a positive normal force and generate kinetic friction:  $F_N > 0$  and  $\tau_K > 0$ .

The clutch locks if and only if it is engaged, and the slip is less than the velocity tolerance:  $|\omega| < \omega_{\text{Tot}}$ .

### Power Dissipated by the Clutch

The power dissipated by the clutch is  $|\omega \tau_K|$ . The clutch dissipates power only if it is both slipping ( $\omega \neq 0$ ) and applying kinetic friction ( $\tau_K > 0$ ).

### See Also

Fundamental Friction Clutch

## **Related Examples**

- “Gear Coupling Control with Clutches”

# Cycloidal Drive

High-ratio speed reducer based on cycloidal disk motion

## Library

Gears

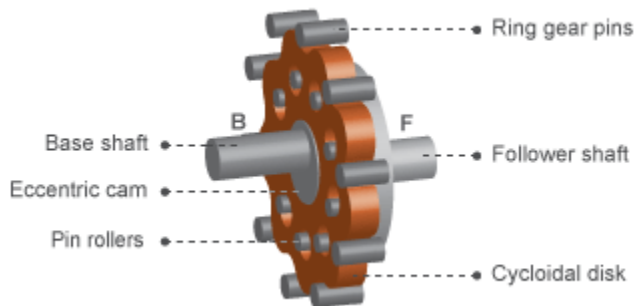


## Description

This block represents a compact, high-ratio, speed-reduction mechanism that contains four key components:

- Eccentric cam
- Cycloidal disk
- Ring-gear housing
- Pin rollers

The eccentric cam, which extends from the base shaft, sits inside the cycloidal disk. This disk meshes with the ring-gear housing. The pin rollers, which extend from the follower shaft, sit in matching holes on the cycloidal disk.



During normal operation, the base shaft drives the eccentric cam. The cam spins inside the cycloidal disk, causing it to rotate in an eccentric pattern about an offset axis. As it moves, the cycloidal disk engages the internal teeth of the ring-gear housing. The internal meshing reverses the rotational velocity direction.

Pin rollers extending from cycloidal disk holes transmit rotational motion to the follower shaft. This shaft spins counter to the base shaft at a highly reduced speed. The large reduction ratio results from the near-equal cycloidal disk and ring gear tooth numbers. The effective gear reduction ratio is

$$r = \frac{n_R - n_C}{n_C},$$

where:

- $r$  is the gear reduction ratio.
- $n_R$  is the number of teeth on the ring gear.
- $n_C$  is the number of teeth on the cycloidal disk.

The gear reduction ratio constrains the angular velocities of the base and follower shafts according to the expression

$$\omega_F = -r\omega_B,$$

where:

- $\omega_F$  is the angular velocity of the follower shaft.
- $\omega_B$  is the angular velocity of the base shaft.

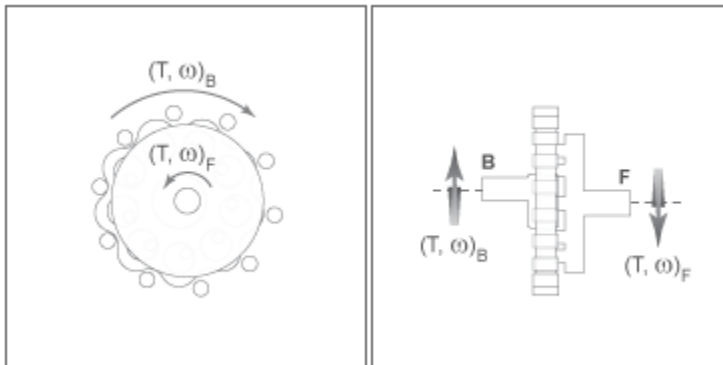
The gear reduction ratio also constrains the torques acting on the base and follower shafts, according to the expression

$$T_B = rT_F + T_f,$$

where:

- $T_B$  is the net torque at the base shaft.
- $T_F$  is the net torque at the follower shaft.
- $T_f$  is the torque loss due to friction. For more information, see “Model Gears with Losses”.

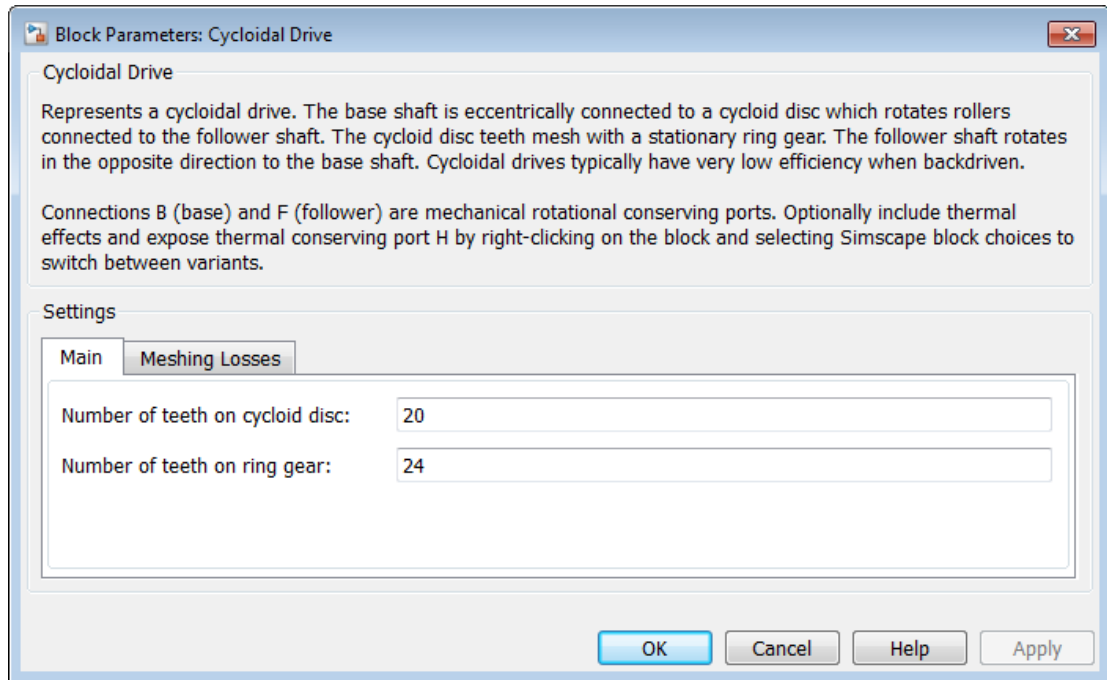
The figure shows the cycloidal drive in front and side views. The kinematics of the drive system cause a reversal of the base and follower shaft angular velocities so that the two shafts spin in opposite directions.



The cycloidal drive can operate in reverse mode, e.g., with power flowing from the follower shaft to the base shaft. In this mode, torque transfer efficiencies are typically negligible. You can adjust the efficiency value in the block dialog box using the **Efficiency from follower shaft to base shaft** parameter.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Number of teeth on cycloid disk

Total number of teeth projecting outward from the cycloidal disk perimeter. This number should be slightly smaller than the number of teeth or pins on the ring gear. The ratio of the gear tooth numbers defines the relative angular velocities of the base and follower shafts. The default value is 20.

#### Number of teeth on ring gear

Total number of teeth or pins projecting inward from the ring gear housing. This number should be slightly larger than the number of teeth on the cycloidal disk. The ratio of the two gear tooth numbers defines the relative angular velocities of the base and follower shafts. The default value is 24.

## Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

### Without Thermal Port

#### Efficiency from base shaft to follower shaft

Torque transfer efficiency in normal operation mode, e.g., with the base shaft driving the follower shaft. Efficiency values must fall in the interval [0, 1]. Larger efficiency values correspond to greater torque transfer between the base and follower shafts. Values approaching unity are typical. The default value is 0.90.

#### Efficiency from follower shaft to base shaft

Torque transfer efficiency in reverse operation mode, e.g., with the follower shaft driving the base shaft. Efficiency values must fall in the interval [0, 1]. Larger efficiency values correspond to greater torque transfer between base and follower shafts. Values approaching zero are typical. The default value is 0.05.

#### Power threshold

Absolute value of the cycloidal disk power above which the full efficiency factor applies. Below this value, a hyperbolic tangent function smooths the efficiency factor to one, lowering the efficiency losses to zero when at rest.

As a guideline, the power threshold should be lower than the expected power transmitted during simulation. Higher values might cause the block to underestimate efficiency losses. Very low values might, however, raise the computational cost of simulation.

The default value is 0.001 W.

### With Thermal Port

#### Temperature

Array of temperatures used to construct 1-D temperature-efficiency lookup tables. The array values must increase left to right. The temperature array must be the same size as each efficiency arrays. The default array is [280 300 320] K.

#### Efficiency from base shaft to follower shaft

Array of mechanical efficiencies with power flowing from the base shaft to the follower shaft. Each array value is the ratio of output power to input power at one of

the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.95 0.85 0.80].

### **Efficiency from follower shaft to base shaft**

Array of mechanical efficiencies with power flowing from the follower shaft to the base shaft. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.10 0.05 0.03].

### **Power threshold**

Absolute value of the cycloidal disk power above which the full efficiency factor applies. A hyperbolic tangent function smooths the efficiency factor between zero when at rest and the value provided by the temperature-efficiency lookup table when at the power threshold. The default value is 0.001 W.

## **Thermal Port**

### **Thermal mass**

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### **Initial temperature**

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## **Ports**

<b>Port</b>	<b>Description</b>
B	Rotational conserving port representing the base shaft
F	Rotational conserving port representing the follower shaft
H	Thermal conserving port for thermal modeling

## **See Also**

Harmonic Drive | Simple Gear | Simple Gear with Variable Efficiency

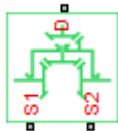


# Differential

Gear mechanism that allows driven shafts to spin at different speeds

## Library

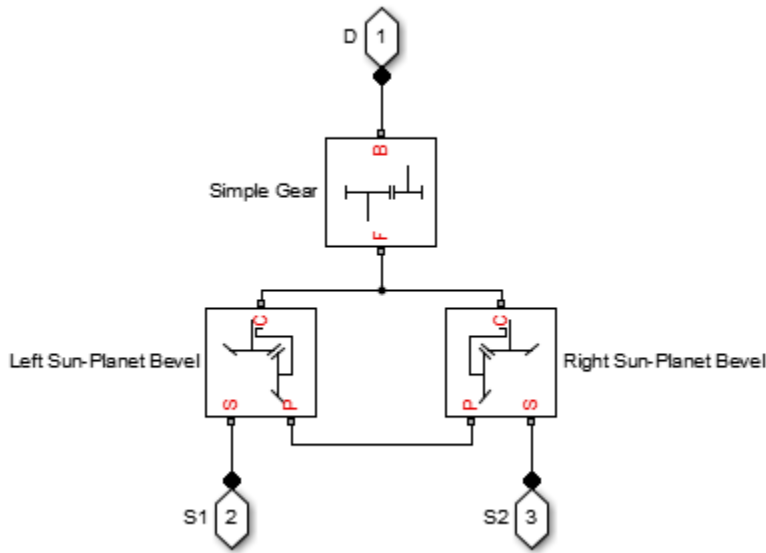
Gears



## Description

This block represents a gear mechanism that allows the driven shafts to spin at different speeds. Differentials are common in automobiles, where they enable the various wheels to spin at different speeds while cornering. Ports S, D1, and D2 represent the driving and driven shafts of the differential. Any of the shafts can drive the remaining two.

The block models the differential mechanism as a structural component based on **Simple Gear** and **Sun-Planet Bevel** Simscape Driveline blocks. The figure shows the block diagram of this structural component.

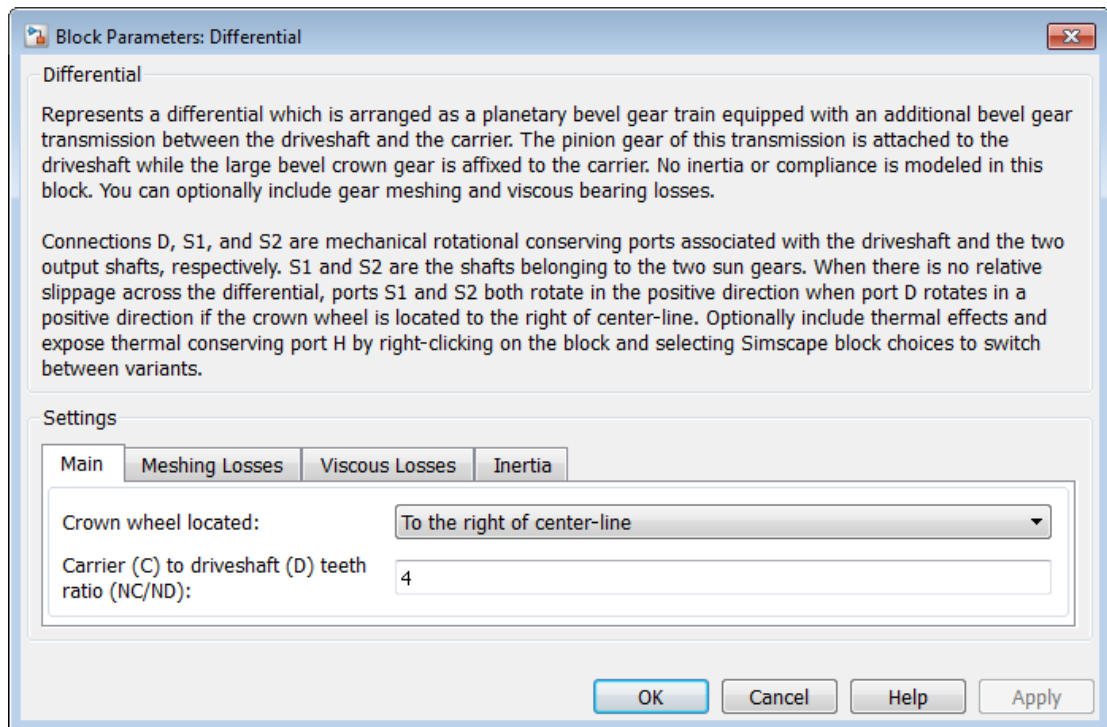


To increase the fidelity of the gear model, you can specify properties such as gear inertia, meshing losses, and viscous losses. By default, gear inertia and viscous losses are assumed negligible. The block enables you to specify the inertias of the gear carrier and internal planet gears only. To model the inertias of the outer gears, connect Simscape *Inertia* blocks to ports D, S1, and S2.

## Modeling Thermal Effects

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Crown wheel located

Select the placement of the bevel crown gear with respect to the center-line of the gear assembly. The default is **To the right of the center-line**.

#### Carrier (C) to driveshaft (D) teeth ratio (NC/ND)

Fixed ratio  $g_D$  of the carrier gear to the longitudinal driveshaft gear. The default is **4**.

### Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

## Without Thermal Port

### Friction model

Select how to implement friction losses from nonideal meshing of gear teeth. The default is `No meshing losses`.

- `No meshing losses` — Suitable for HIL simulation — Gear meshing is ideal.
- `Constant efficiency` — Transfer of torque between gear wheel pairs is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

### Constant Efficiency

#### Sun-sun and carrier-driveshaft ordinary efficiencies

Vector of torque transfer efficiencies  $[\eta_{SS} \ \eta_D]$  for sun-sun and carrier-longitudinal driveshaft gear wheel pair meshings, respectively.

#### Sun-carrier and driveshaft-casing power thresholds

Vector of power thresholds  $p_{th}$  above which full efficiency loss is applied, for sun-carrier and longitudinal driveshaft-casing  $[p_S \ p_D]$ , respectively.

## With Thermal Port

### Temperature

Array of temperatures used to construct 1-D temperature-efficiency lookup tables. The array values must increase left to right. The temperature array must be the same size as each efficiency arrays. The default array is `[280 300 320]` K.

### Sun-sun efficiency

Array of mechanical efficiencies with power flowing from one of the sun gears to the other. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is `[0.95 0.9 0.85]`.

### Carrier-driveshaft efficiency

Array of mechanical efficiencies with power flowing from the gear carrier to the longitudinal driveshaft. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is `[0.95 0.9 0.85]`.

### Sun-carrier and driveshaft-casing power thresholds

Array of power thresholds above which the full efficiency factors apply. Enter the thresholds for sun-carrier and longitudinal driveshaft-casing, in this order. A hyperbolic tangent function smooths the efficiency factors between zero when at rest and the values provided by the temperature-efficiency lookup tables at the power thresholds. The default array is [0.001 0.001] W.

## Viscous Losses

### Sun-carrier and driveshaft-casing viscous friction coefficients

Vector of viscous friction coefficients [ $\mu_S \mu_D$ ] for the sun-carrier and longitudinal driveshaft-casing gear motions, respectively. The default is [0 0].

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (rad/s)$ ).

## Inertia

### Carrier inertia

Moment of inertia of the planet gear carrier. This value must be positive or zero. Enter 0 to ignore carrier inertia. The default value is  $0 \text{ kg} \cdot \text{m}^2$ .

### Planet gear inertia

Moment of inertia of the combined planet gears. This value must be positive or zero. Enter 0 to ignore gear inertia. The default value is  $0 \text{ kg} \cdot \text{m}^2$ .

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Differential Gear Model

### Ideal Gear Constraints and Gear Ratios

Differential imposes one kinematic constraint on the three connected axes:

$$\omega_D = \pm(1/2)g_D(\omega_{S1} + \omega_{S2}) ,$$

with the upper (+) or lower (–) sign valid for the differential crown to the right or left, respectively, of the center line. The three degrees of freedom reduce to two independent degrees of freedom. The gear pairs are (1,2) = (S,S) and (C,D). C is the carrier.

The *sum* of the lateral motions is the transformed longitudinal motion. The *difference* of side motions  $\omega_{S1} - \omega_{S2}$  is independent of the longitudinal motion. The general motion of the lateral shafts is a superposition of these two independent degrees of freedom, which have this physical significance:

- One degree of freedom (longitudinal) is equivalent to the two lateral shafts rotating at the same angular velocity ( $\omega_{S1} = \omega_{S2}$ ) and at a fixed ratio with respect to the longitudinal shaft.
- The other degree of freedom (differential) is equivalent to keeping the longitudinal shaft locked ( $\omega_D = 0$ ) while the lateral shafts rotate with respect to each other in opposite directions ( $\omega_{S1} = -\omega_{S2}$ ).

The torques along the lateral axes,  $\tau_{S1}$  and  $\tau_{S2}$ , are constrained to the longitudinal torque  $\tau_D$  in such a way that the power flows into and out of the gear, less any power loss  $P_{loss}$ , sum to zero:

$$\omega_{S1}\tau_{S1} + \omega_{S2}\tau_{S2} + \omega_D\tau_D - P_{loss} = 0 .$$

When the kinematic and power constraints are combined, the ideal case yields:

$$g_D\tau_D = 2(\omega_{S1}\tau_{S1} + \omega_{S2}\tau_{S2}) / (\omega_{S1} + \omega_{S2}) .$$

### Fundamental Sun-Planet Bevel Gear Constraints

The effective differential constraint is composed of two subconstraints.

- The first comes from the coupling of the two sun-planet bevel gears to the carrier:  $(\omega_{S1} - \omega_C)/(\omega_{S2} - \omega_C) = -g_{SP2}/g_{SP1}$  .
- The second comes from the coupling of the carrier to the longitudinal driveshaft:  $\omega_D = \pm g_D\omega_C$ .

$g_{SP1} = r_{S1}/r_{P1}$  and  $g_{SP2} = r_{S2}/r_{P2}$  are the sun-planet gear ratios of the underlying sun-planet bevel gears, in terms of the radii  $r$  of the sun and planet gears. The Differential block is implemented with  $g_{SP1} = g_{SP2} = 1$ , leaving  $g_D$  free to adjust.

## Nonideal Gear Constraints and Losses

In the nonideal case,  $\tau_{loss} \neq 0$ . See “Model Gears with Losses”.

## Limitations

- Gears are assumed rigid.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Examples

These Simscape Driveline example models contain working examples of differential gears:

- `sdl_4wd_dynamics`
- `sdl_limited_slip_differential`
- `sdl_torsen_differential`

## Ports

Port	Description
D	Rotational conserving port representing the longitudinal driveshaft
S1	Rotational conserving port representing one of the sun gears
S2	Rotational conserving port representing one of the sun gears
H	Thermal conserving port for thermal modeling

## See Also

Disk Friction Clutch, Simple Gear, Sun-Planet Bevel

“Represent and Transfer Driveline Motion and Torque”



# Disk Friction Clutch

Friction clutch with disk plates that engage when plate pressure exceeds threshold

## Library

Clutches



## Description

This block represents a friction clutch with two flat friction plate sets that come into contact in order to engage. The clutch engages when the applied plate pressure exceeds an engagement threshold pressure. Once engaged, the plates experience frictional torques that enable them to transmit power between the base and follower driveshafts.

The clutch can be bidirectional or unidirectional. A bidirectional clutch can slip in the positive and negative directions. A unidirectional clutch can slip only in the positive direction. The slip direction is positive if the follower shaft spins faster than the base shaft and negative if it slips slower. The block defines the slip velocity as the difference

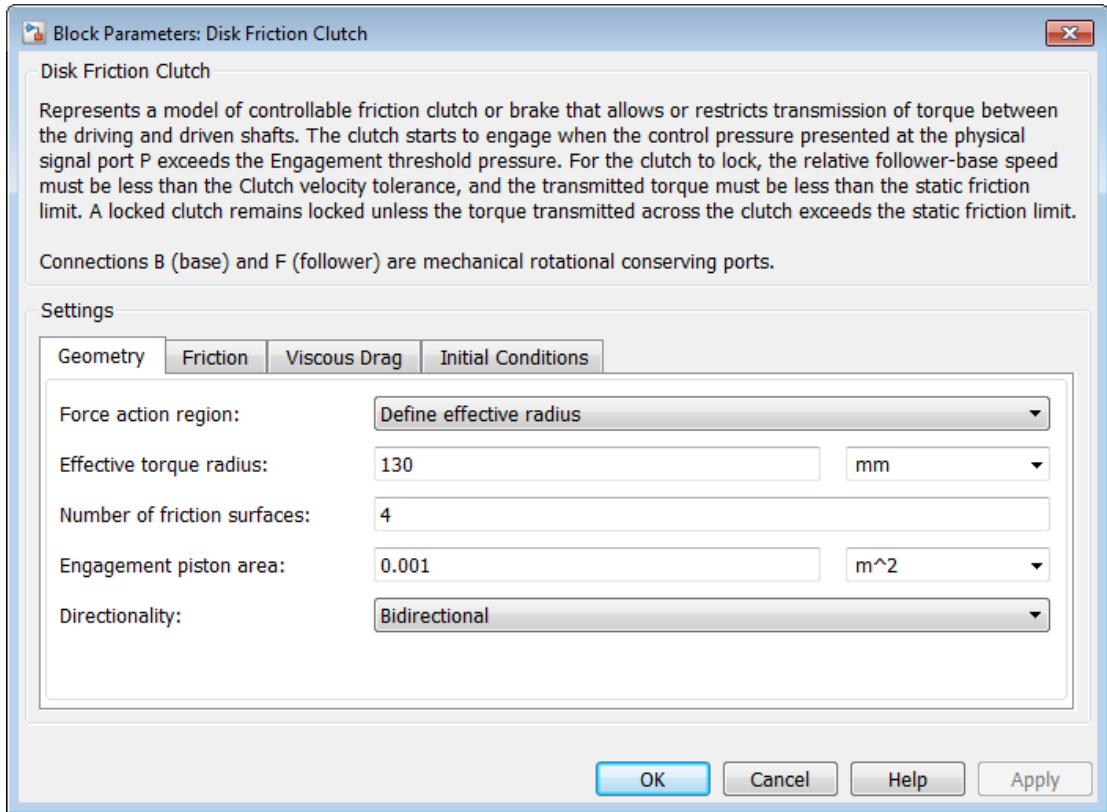
$$\omega = \omega_F - \omega_B,$$

where:

- $\omega$  is the slip velocity.
- $\omega_F$  is the angular velocity of the follower driveshaft.
- $\omega_B$  is the angular velocity of the base driveshaft.

The block provides a physical signal input port (P) for the applied pressure between the clutch plates. The applied pressure must be greater than or equal to zero and has units of Pascals. If the input signal falls below zero, the block treats the plate pressure as zero.

## Dialog Box and Parameters



### Geometry

#### Force action region

Select how to model the clutch friction geometry. The default is **Define effective radius**.

- **Define effective radius** — Model friction geometry in terms of disk radius.

#### **Effective Radius**

#### **Effective torque radius**

Effective moment arm radius  $r_{\text{eff}}$  that determines the kinetic friction torque inside the clutch. The default is 130.

From the drop-down list, choose units. The default is millimeters (mm).

- **Define annular region** — Model friction geometry in terms of annulus dimensions. If you select this option, the panel changes from its default.

### **Annular Region**

#### **Friction disk outside diameter**

Diameter  $2r_o$  across the outer edge of the friction disk annulus. The default is 150.

From the drop-down list, choose units. The default is millimeters (mm).

#### **Friction disk inside diameter**

Diameter  $2r_i$  across the inner edge of the friction disk annulus. The default is 100.

From the drop-down list, choose units. The default is millimeters (mm).

### **Number of friction surfaces**

Number  $N$  of friction-generating contact surfaces inside the clutch. The default is 4.

### **Engagement piston area**

Effective area  $A$  of the clutch piston when the piston is applying pressure across the clutch. The default is 0.001.

From the drop-down list, choose units. The default is meters-squared ( $\text{m}^2$ ).

### **Directionality**

Slip directions the clutch allows between its plates. A bidirectional clutch allows positive and negative slip velocities. A unidirectional clutch allows only positive slip velocities. The default setting is **Bidirectional**.

The unidirectional clutch is equivalent to a friction clutch connected in parallel to a one-way clutch that disengages only when the slip velocity becomes positive. To model a unidirectional clutch with slip in the negative direction, reverse the base and follower port connections.

## Friction

### Friction model

Modeling approach for the kinetic friction coefficient. You can treat the coefficient as a constant or as a function of the clutch slip velocity in a lookup table format. The default setting is `Fixed kinetic friction coefficient`.

- `Fixed kinetic friction coefficient` — Model the kinetic friction coefficient as a constant.

### Fixed Kinetic Friction Coefficient

#### Kinetic friction coefficient

Friction coefficient between the clutch plates when they spin with respect to each other. The friction coefficient determines the kinetic friction torque as a linear function of the clutch slip velocity. The default value is `0.3`.

- `Table lookup kinetic friction coefficient` — Model the kinetic friction coefficient as a function of the clutch slip velocity that you provide in a lookup table format.

### Table Lookup Kinetic Friction Coefficient

#### Kinetic friction coefficient relative velocity vector

MATLAB vector with the slip velocity sample values at which the kinetic friction coefficient is known.

#### Kinetic friction coefficient vector

MATLAB vector with the kinetic friction coefficient values for the slip velocities in **Kinetic friction coefficient relative velocity vector**.

#### Friction coefficient interpolation method

Interpolation method for determining the kinetic friction coefficient between lookup table data points. The available methods include `Linear` and `Smooth`. The default setting is `Linear`.

#### Friction coefficient extrapolation method

Extrapolation method for determining the kinetic friction coefficient outside of the slip velocity range of the lookup table. The available methods include `Linear` and `Nearest`. The default setting is `Linear`.

### Static friction coefficient

Dimensionless Coulomb static friction coefficient  $k_S$  applied to the normal force across the clutch when the clutch is locked. Must be larger than  $k_K$ . The default value is 0.35.

### De-rating factor

Dimensionless de-rating factor  $D$  that accounts for clutch disk wear by proportionately reducing clutch friction. The default value is 1.

### Clutch velocity tolerance

Maximum slip velocity at which the clutch can lock. The slip velocity is the signed difference between the base and follower shaft angular velocities, that is,  $w = w_F - w_B$ . The clutch locks if the actual slip velocity falls below the velocity tolerance and if other conditions are present—i.e., if the kinetic friction torque is nonzero and if the transferred torque is within the static friction torque limits. The default value is 0.001 rad/s.

### Engagement threshold pressure

Minimum pressure  $P_{th}$  at which the clutch engages. If the pressure input signal falls below this threshold, the clutch automatically disengages. The default value is 100.

## Viscous Drag

### Viscous drag torque coefficient

Viscous friction coefficient  $\mu$  applied to the relative slip  $\omega$  between the base and follower axes. The default is 0.

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (rad / s)$ ).

## Initial Conditions

### Initial state

Clutch state at the start of simulation. The clutch can be in one of two states, locked and unlocked. A locked clutch constrains the base and follower shafts to spin at the same velocity, i.e., as a single unit. An unlocked clutch allows the two shafts to spin at different velocities, resulting in slip between the clutch plates. The default setting is Unlocked.

## Disk Friction Clutch Model

The Disk Friction Clutch is based on the Fundamental Friction Clutch. For the complete friction clutch model, consult the Fundamental Friction Clutch block reference page. This section discusses the simplified model implemented in the Disk Friction Clutch.

When you apply a pressure signal above threshold ( $P \geq P_{th}$ ), the Disk Friction Clutch block can apply two kinds of friction to the driveline motion, kinetic and static. The clutch applies kinetic friction torque only when one driveline axis is spinning relative to the other driveline axis. The clutch applies static friction torque when the two driveline axes lock and spin together. The block iterates through multistep testing to determine when to lock and unlock the clutch.

### Clutch Variable, State, and Mode Summary

This table summarizes the clutch variables.

#### Clutch Variables

Symbol	Definition	Significance
$\omega$	Relative angular velocity (slip)	$\omega_F - \omega_B$
$\omega_{Tol}$	Slip tolerance for clutch locking	<i>See the following model</i>
$P, P_{th}$	Clutch pressure and threshold	Input pressure applied to clutch discs; threshold clutch pressure: $P_{th}, P > 0$ .
$P_{fric}$	Clutch friction capacity	$\max[(P - P_{th}), 0]$
$D$	Clutch de-rating factor	<i>See the following model</i>
$N$	Number of friction surfaces	<i>See the following model</i>
$A$	Engagement surface area	<i>See the following model</i>
$r_{eff}$	Effective torque radius	Effective moment arm of clutch friction force
$k_K$	Kinetic friction coefficient	Dimensionless coefficient of kinetic friction of clutch discs. Function of $\omega$ .
$k_S$	Static friction coefficient	Dimensionless coefficient of static friction of clutch discs.
$\mu$	Viscous drag coefficient	<i>See the following model</i>

Symbol	Definition	Significance
$\tau_K$	Kinetic friction torque	<i>See the following model</i>
$\tau_S$	Static friction torque limit	(static friction peak factor) (kinetic friction torque for $\omega \rightarrow 0$ ) ( <i>See the following model</i> )

## Relation to Fundamental Friction Clutch

Instead of requiring the kinetic and static friction limit torques as input signals, the Disk Friction Clutch calculates the kinetic and static friction from the clutch parameters and the input pressure signal  $P$ .

### Kinetic Friction

The kinetic friction torque is the positive sum of viscous drag and surface contact friction torques:

$$\tau_K = \mu\omega + \tau_{\text{contact}} .$$

(The kinetic friction torque opposes the relative slip and is applied with an overall minus sign.) The contact friction is a product of six factors:

$$\tau_{\text{contact}} = k_K \cdot D \cdot N \cdot r_{\text{eff}} \cdot P_{\text{fric}} \cdot A \geq 0 .$$

You specify the *kinetic friction coefficient*  $k_K$  as either a constant or a tabulated discrete function of relative angular velocity  $\omega$ . The tabulated function is assumed to be symmetric for positive and negative values of the relative angular velocity, so that you need to specify  $k_K$  for positive values of  $\omega$  only.

The clutch applies a normal force from its piston as the product of the clutch friction capacity  $P_{\text{fric}}$  and engagement surface area  $A$ , on each of  $N$  friction surfaces. The pressure signal  $P$  should be nonnegative. If  $P$  is less than  $P_{\text{th}}$ , the clutch applies no friction at all.

The *effective torque radius*  $r_{\text{eff}}$  is the effective radius, measured from the driveline axis, at which the kinetic friction forces are applied at the frictional surfaces. It is related to the geometry of the friction surface by:

$$r_{\text{eff}} = \frac{2 r_o^3 - r_i^3}{3 r_o^2 - r_i^2}$$

$r_o$  and  $r_i$  are the outer and inner radii, respectively, of the friction surface, modeled as an annular disk.

The *clutch de-rating factor*  $D$  accounts for clutch wear. For a new clutch,  $D$  is one. For a clutch approaching a “uniform wear” state:

$$D \rightarrow \frac{3}{4} \frac{(r_o + r_i)^2}{r_o^2 + r_o r_i + r_i^2}$$

### Static Friction

The static friction limit is related to the kinetic friction, setting  $\omega$  to zero and replacing the kinetic with the static friction coefficient:

$$\tau_S = k_S \cdot D \cdot N \cdot r_{\text{eff}} \cdot P_{\text{fric}} \cdot A \geq 0 .$$

$k_S > k_K$ , so that the torque  $\tau$  needed across the clutch to unlock it by overcoming static friction is larger than the kinetic friction at the instant of unlocking, when  $\omega = 0$ .

The *static friction torque range* or limits are then defined symmetrically as:

$$\tau_S \equiv \tau_S^+ = -\tau_S^- .$$

### Wait State: Locking and Unlocking

The Wait state of the Disk Friction Clutch is identical to the Wait state of the Fundamental Friction Clutch, with the replacement of the positive kinetic friction condition ( $\tau_K > 0$ ) by the positive clutch friction capacity condition ( $P \geq P_{\text{th}}$ ).

### Power Dissipated by the Clutch

The power dissipated by the clutch is  $|\omega \tau_K|$ . The clutch dissipates power only if it is both slipping ( $\omega \neq 0$ ) and applying kinetic friction ( $\tau_K > 0$ ).

## Examples

These Simscape Driveline example models contain working examples of disk friction clutches that change gear couplings:

- `sdl_simple_clutch`
- `sdl_clutch_engage`



- `sdl_simple_transmission`
- `sdl_dual_clutch`
- `sdl_hydraulic_clutch`
- `sdl_crcr`
- `sdl_vehicle`

## Ports

- B — Rotational conserving port that represents the base driveshaft
- F — Rotational conserving port that represents the follower driveshaft
- P — Physical signal input port for the applied pressure between the clutch plates

## See Also

Fundamental Friction Clutch | Torque Converter | Variable Ratio Transmission | Differential

## Related Examples

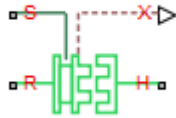
- “Gear Coupling Control with Clutches”

# Dog Clutch

Clutch with toothed plates that engage when plate teeth become enmeshed

## Library

Clutches



## Description

This block represents a nonslip clutch, a mechanical device that relies on the positive engagement of interlocking teeth to transfer torque between driveline shafts. The clutch contains three key components:

- Ring
- Hub
- Shift linkage

The ring and the hub are toothed components. The ring spins with the output shaft, sliding along its longitudinal axis to engage or disengage the coaxial hub. The hub, which sits on a bearing encircling the same shaft, can spin independently until engaged.

Engagement occurs when the toothed components interlock. Once engaged, the ring and the hub spin together as a unit. To control engagement, the dog clutch contains a shift linkage that governs the position of the ring with respect to the hub.

Moving the ring towards the hub so that their teeth interlock changes the clutch state to engaged. Tooth overlap must exceed a minimum value for engagement. Moving the ring in reverse so that the two sets of teeth no longer interlock changes the clutch state back to disengaged.

The translational conserving port S specifies the shift linkage position. When the clutch is fully disengaged, the shift linkage position is zero. When the clutch is fully engaged,

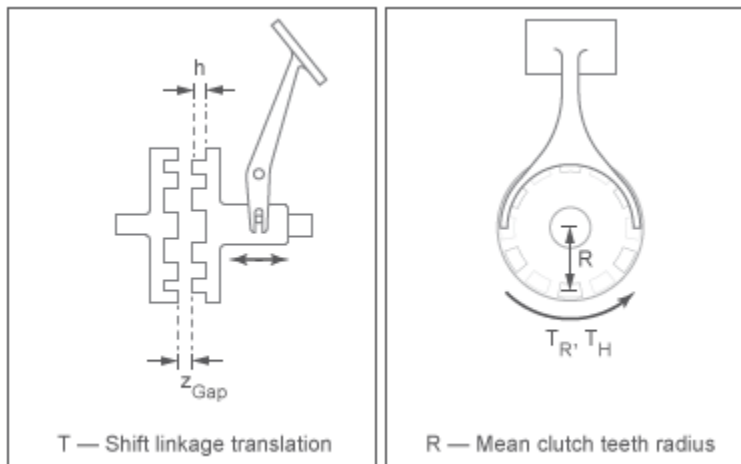
the shift linkage position equals the sum of the tooth height and the ring-hub clearance of the fully disengaged state:

$$z = h + z_{Gap},$$

where:

- $z$  is the shift linkage position.
- $h$  is the tooth height.
- $z_{Gap}$  is the ring-hub clearance when disengaged.

The figure shows side and front views of the dog clutch and some of its relevant variables.



## Torque Transmission Models

The Dog Clutch block provides a choice of two torque transmission models.

### Friction Clutch Approximate Model

Treat clutch engagement as a friction phenomenon between the ring and the hub. This model ignores special effects such as backlash, an approximation that makes the block better suited for linearization, fixed-step simulation, and hardware-in-loop (HIL) simulation. The **Fundamental Friction Clutch** block provides the foundation for the model.

In the friction approximate model, the clutch has three possible configurations: disengaged, engaged, and locked. When disengaged, the contact force between the ring and the hub is zero. This force remains zero until the shift linkage reaches the minimum position for engagement.

When the ring-hub tooth overlap ( $h$ ) exceeds the minimum value for engagement, the contact force between the two components begins to increase linearly with the shift linkage position ( $z$ ).

At full engagement, the contact force reaches its maximum value, and the clutch state switched to locked. In this state, the ring and the hub spin as a unit without slip. To unlock the clutch, the transmitted torque must exceed the maximum allowed value that you specify.

### Dynamical Model with Backlash

Capture clutch phenomena such as backlash, torsional compliance, and contact forces between ring and hub teeth. This model provides greater accuracy than the friction clutch approximation.

In the dynamical model, the clutch has two possible configurations: disengaged and engaged. When disengaged, the contact force between the ring and the hub is zero. This force remains zero until the shift linkage reaches the minimum position for engagement.

When the ring-hub tooth overlap ( $h$ ) exceeds the minimum value for engagement, a contact force kicks in between the two components. This force is the sum of torsional spring and damper components. Including backlash between the ring and hub teeth:

$$T_C = \begin{cases} -k_{RH} \left( \phi - \frac{\delta}{2} \right) - \mu_R \cdot \omega & \phi > \frac{\delta}{2} \\ 0 & -\frac{\delta}{2} < \phi < \frac{\delta}{2} \\ -k_{RH} \left( \phi + \frac{\delta}{2} \right) - \mu_R \omega & \phi < -\frac{\delta}{2} \end{cases}$$

where:

- $k_{RH}$  is the torsional stiffness of the ring-hub coupling.
- $\phi$  is the relative angle, about the common rotation axis, between the ring and the hub.
- $\delta$  is the backlash between ring and hub teeth.

- $\omega$  is the relative angular velocity between the ring and the hub. This variable describes how fast the two components slip past each other.

Compliant end stops limit the translational motion of the clutch shift linkage and the ring. The compliance model treats the end stops as linear spring-damper sets. The location of the end stops depends on the relative angle and angular velocity between the ring and hub teeth:

- If the teeth align and the relative angular velocity is smaller than the maximum value for clutch engagement, the end-stop location is the sum of the ring-hub clearance when fully disengaged and the tooth height. With the end stop at this location, the clutch can engage.
- If the teeth do not align or the relative angular velocity exceeds the maximum value for clutch engagement, the end-stop location is set to prevent the ring from engaging the hub. The clutch remains disengaged.

Translational friction opposes shift linkage and ring motion. This friction is the sum of Coulomb and viscous components:

$$F_Z = -k_K \cdot F_N \cdot \tanh\left(\frac{4v}{v_{th}}\right) - \mu_T v,$$

where:

- $F_Z$  is the net translational friction force acting on the shift linkage and ring.
- $k_K$  is the kinetic friction coefficient between ring and hub teeth.
- $F_N$  is the normal force between ring and hub teeth.
- $v$  is the translational velocity of the shift linkage and the ring.
- $v_{th}$  is the translational velocity threshold. Below this threshold, a hyperbolic tangent function smooths the Coulomb friction force to zero as the shift linkage and ring velocity tends to zero.
- $\mu_T$  is the viscous damping coefficient acting on the shift linkage and the ring.

## Clutch Engagement Conditions

The clutch engages when it satisfies a set of geometrical and dynamical conditions. These conditions specify the values that certain variables can take for clutch engagement to occur:

- The minimum position at which the ring and the hub can engage is

$$z = h_0 + z_{Gap},$$

where  $h_0$  is the minimum tooth overlap for clutch engagement. Adjust this parameter to minimize engagement instability, i.e., the tendency of the clutch to switch rapidly between engaged and disengaged states

- The magnitude of the relative angular velocity between the ring and the hub must be smaller than the maximum engagement velocity:

$$|\omega| < |\omega_{\max}|,$$

where  $\omega_{\max}$  is the maximum value of the relative angular velocity at which engagement can occur.

- If using the friction clutch approximate model, engagement occurs only if torque transfer between the ring and the hub remains smaller than the maximum transmitted torque that the clutch supports.
- If using the dynamical model with backlash, engagement occurs only if the relative angular position of the ring and hub teeth allows them to interlock.

## Rotational Power Dissipation

When the clutch slips under an applied torque, it dissipates power. The power loss equals the product of the slip angular velocity and the contact torque between the ring and the hub:

$$P_{loss} = \omega \cdot T_C,$$

where:

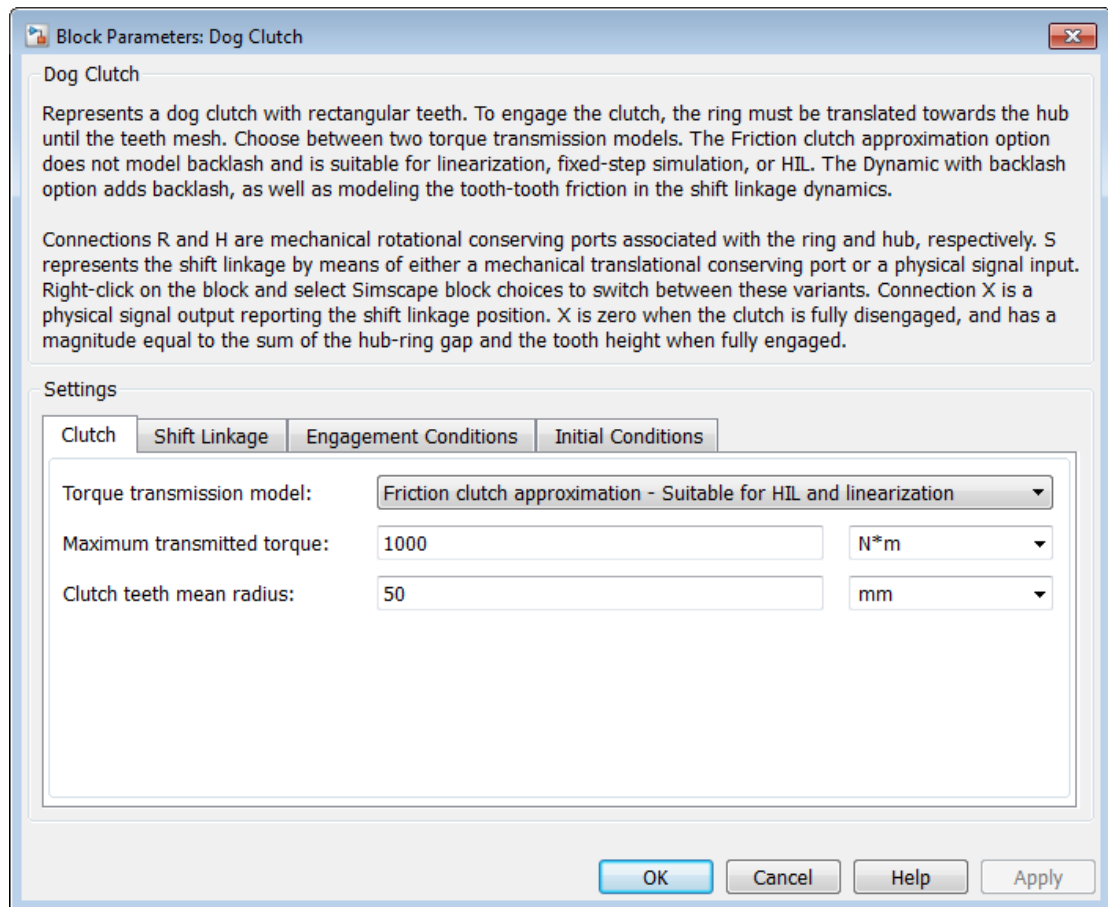
- $P_{loss}$  is the dissipated power due to slipping.
- $T_C$  is the kinetic contact torque.

## Shift Linkage Variants

The block provides two shift linkage variants. One variant accepts the position input through a physical signal port, the other through a translational conserving port. To

select either variant, right-click the block and, under **Simscape** > **Block choices**, select Physical signal position input or Mechanical port shift linkage. The variant selected changes the block dialog box parameters.

## Dialog Box and Parameters



## Clutch

### Torque transmission model

Computational framework with which to model the dynamic behavior of the dog clutch. The default setting is **Friction clutch approximation – Suitable for HIL and linearization**.

- **Friction clutch approximation - Suitable for HIL and linearization** — Model clutch engagement as a friction phenomenon between the ring and the hub. This model, based on the **Fundamental Friction Clutch** block, provides a computationally efficient approximation of the dog clutch.

### **Friction Clutch Approximation**

#### **Maximum transmitted torque**

Largest torque that the clutch can transmit, corresponding to a nonslip engaged configuration. If the torque transmitted between the ring and the hub exceeds this value, the two components begin to slip with respect to each other. This torque determines the static friction limit in the friction clutch approximation. The default value is 1000.

#### **Clutch teeth mean radius**

Distance from the ring or hub center to the corresponding tooth center. The mean tooth radius determines the normal contact forces between ring and hub teeth given the transmission torque between the two components. The mean radius must be greater than zero. The default value is 50.

- **Dynamic with backlash** — Model clutch engagement in detail, accounting for such phenomena as backlash, torsional compliance, and contact forces between ring and hub teeth. Selecting this option causes additional parameters to appear in the **Shift Linkage** and **Initial Conditions** tabs.

### **Dynamic with Backlash**

#### **Number of teeth**

Total number of teeth in the ring or the hub. The two components have equal tooth numbers. The number of teeth must be greater than or equal to one. The default value is 6.

#### **Rotational backlash**

Allowable angular motion, or play, between the ring and hub teeth in the engaged clutch configuration. The backlash must be greater than zero. The default value is 10 deg.

#### **Clutch teeth mean radius**



Distance from the ring or hub center to the corresponding tooth center. The mean tooth radius determines the normal contact forces between ring and hub teeth given the transmission torque between the two components. The mean radius must be greater than zero. The default value is 50 mm.

**Torsional stiffness**

Linear torsional stiffness coefficient at the contact interface between the ring and hub teeth. This coefficient characterizes the restoring component of the contact force between the two sets of teeth. Greater stiffness values correspond to greater contact forces. The stiffness coefficient must be greater than zero. The default value is  $1e+7$  N\*m/rad.

**Torsional damping**

Linear torsional damping coefficient at the contact interface between the ring and hub teeth. This coefficient characterizes the dissipative component of the contact force between the two sets of teeth. Greater damping values correspond to greater energy dissipation during contact. The damping coefficient must be greater than zero. The default value is  $100$  N\*m/(rad/s).

## Shift Linkage

**Tooth height**

Distance between the base and crest of a tooth. Ring and hub teeth share the same height. The tooth height and the ring-hub clearance when fully disengaged determine the maximum travel span of the shift linkage. The tooth height must be greater than zero. The default value is 10 mm.

**Hard stop at back of shift linkage**

Choice of translational motion limiting device. Select whether to stop the shift linkage when fully disengaged. The default value is **Hard stop when fully disengaged**.

**Ring-hub clearance when disengaged**

Maximum open gap between the ring and hub tooth crests along the shift linkage translation axis. This gap corresponds to the fully disengaged clutch state. The tooth height and the ring-hub clearance when fully disengaged determine the maximum travel span of the shift linkage. The ring-hub clearance must be greater than zero. The default value is 3 mm.

**Ring stop stiffness**

Linear stiffness coefficient of the ring end stop. This coefficient characterizes the restoring component of the contact force that resists translational motion past the end stops. Greater stiffness values correspond to greater contact forces and a smaller end stop compliance. The stiffness coefficient must be greater than zero. The default value is  $1e+6$  N/m.

#### **Ring stop damping**

Linear damping coefficient of the ring end stop. This coefficient characterizes the dissipative component of the contact force that resists translational motion past the end stops. Greater damping values correspond to greater energy dissipation during contact. The damping coefficient must be greater than or equal to zero. The default value is  $1000$  N/(m/s).

#### **Shift linkage viscous friction coefficient**

Linear damping coefficient acting on the shift linkage. This coefficient characterizes the dissipative force that resists shift linkage motion due to viscous damping. Greater coefficient values correspond to greater energy dissipation during shift linkage motion. The viscous friction coefficient must be greater than zero. The default value is  $100$  N/(m/s).

#### **Tooth-tooth friction coefficient**

Kinetic friction coefficient at the contact interface between ring and hub teeth. This coefficient characterizes the dissipative force that resists shift linkage motion due to tooth-tooth contact during clutch engagement/disengagement.

Greater coefficient values correspond to greater energy dissipation during shift linkage motion. The friction coefficient must be greater than zero. The default value is  $0.05$ .

### **Engagement Conditions**

#### **Linkage travel direction**

Direction the shift linkage must travel in to engage the clutch. Choices include positive and negative displacements. The default setting is `Positive shift linkage displacement engages clutch`.

#### **Maximum engagement velocity**

Relative angular velocity between the ring and the hub above which the clutch cannot engage. The maximum engagement velocity must be greater than zero. The default value is `inf` (infinity) rad/s.

#### **Tooth overlap to engage**

Overlap length between ring and hub teeth along the common longitudinal axis above which the clutch can engage. The clutch remains disengaged until the tooth overlap by at least this length. The tooth overlap to engage must be greater than zero. The default value is 3 mm.

## Initial Conditions

### Clutch Initial state

Clutch configuration at the start of simulation. Options include:

- **Disengaged** — Clutch transmits zero torque between the ring and the hub.
- **Engaged** — Clutch transmits torque between the ring and the hub.

The default value is **Disengaged**.

### Initial shift linkage position

Shift linkage position at simulation time zero. Values between zero and the sum of the ring-hub clearance and the tooth overlap to engage are consistent with a disengaged clutch. Larger values are consistent with an engaged clutch. The default value is 0 mm.

### Initial ring-hub offset angle

Rotation angle between the ring and the hub at simulation time zero. This angle determines whether the ring and hub teeth can interlock, and hence whether the clutch can engage. The initial offset angle must satisfy these conditions:

- If the clutch initial state is disengaged, the initial offset angle must fall in the range

$$-\frac{180^\circ}{N} \leq \phi_0 \leq +\frac{180^\circ}{N},$$

where  $N$  is the number of teeth present in the ring or the hub. The two components contain the same number of teeth.

- If the clutch initial state is engaged, the initial offset angle must fall in the range

$$-\frac{\delta}{2} \leq \phi_0 \leq +\frac{\delta}{2},$$

where  $\delta$  is the backlash angle between the ring and hub teeth.

The default value is 0 deg. This parameter appears only when you set **Torque transmission model** in the **Clutch** tab to **Dynamic with backlash**.

## Ports

The table summarizes the ports that the block contains.

Port	Description
S	Translational conserving port or physical signal port that represents the shift linkage. The port type depends on the shift linkage variant selected.
X	Physical signal port for sensing the clutch position
R	Rotational conserving port that represents the clutch ring
H	Rotational conserving port that represents the clutch hub

## See Also

Fundamental Friction Clutch | Loaded-Contact Rotational Friction | Torsional Spring-Damper

## Related Examples

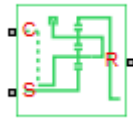
- “Gear Coupling Control with Clutches”

# Double-Pinion Planetary Gear

Planetary gear train with two meshed planet gear sets

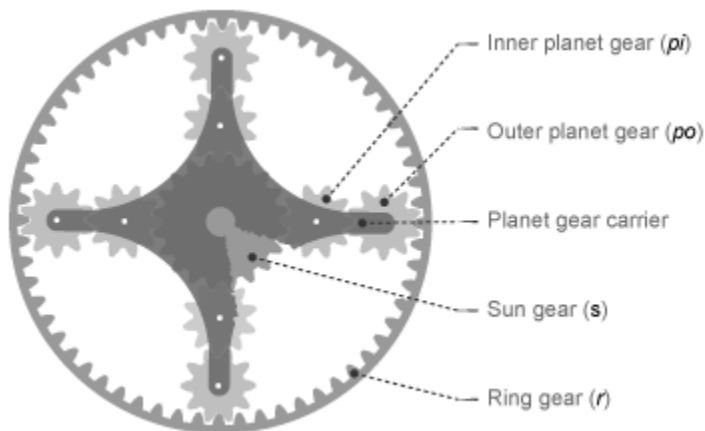
## Library

Gears



## Description

This block represents a planetary gear train with two meshed planet gear sets between the sun gear and the ring gear. A single carrier holds the two planet gear sets at different radii from the sun gear centerline, while allowing the individual gears to rotate with respect to each other. The gear model includes power losses due to friction between meshing gear teeth and viscous damping of the spinning gear shafts.



Structurally, the double-pinion planetary gear resembles a Ravigneaux gear without its second, large, sun gear. The inner planet gears mesh with the sun gear and the outer

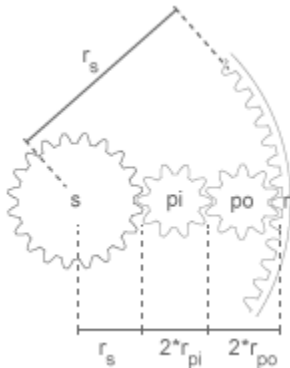
planet gears mesh with the ring gear. Because it contains two planet gear sets, the double-pinion planetary gear reverses the relative rotation directions of the ring and sun gears.

The teeth ratio of a meshed gear pair fixes the relative angular velocities of the two gears in that pair. The dialog box provides two parameters to set the ring-sun and outer planet-inner planet gear teeth ratios. A geometric constraint fixes the remaining teeth ratios—ring-outer planet and inner planet-sun. This geometric constraint requires that the ring gear radius equal the sum of the sun gear radius with the inner and outer planet gear diameters:

$$r_r = r_s + 2 \cdot r_{pi} + 2 \cdot r_{po},$$

where:

- $r_r$  is the ring gear radius
- $r_s$  is the sun gear radius
- $r_{pi}$  is the inner planet gear radius
- $r_{po}$  is the outer planet gear radius



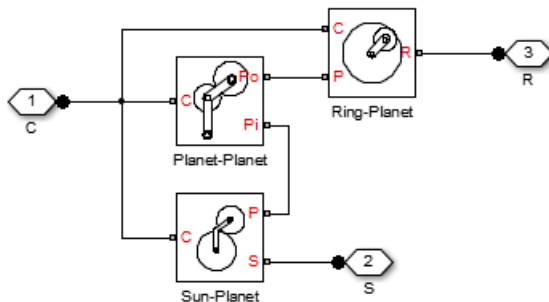
In terms of the ring-sun and outer planet-inner planet teeth ratios, the ring-outer planet teeth ratio is

$$\frac{r_r}{r_{po}} = 2 \cdot \frac{\frac{r_r}{r_s}}{\left(\frac{r_r}{r_s} - 1\right)} \cdot \frac{\left(\frac{r_{po}}{r_{pi}} + 1\right)}{\frac{r_{po}}{r_{pi}}},$$

The inner planet-sun teeth ratio is

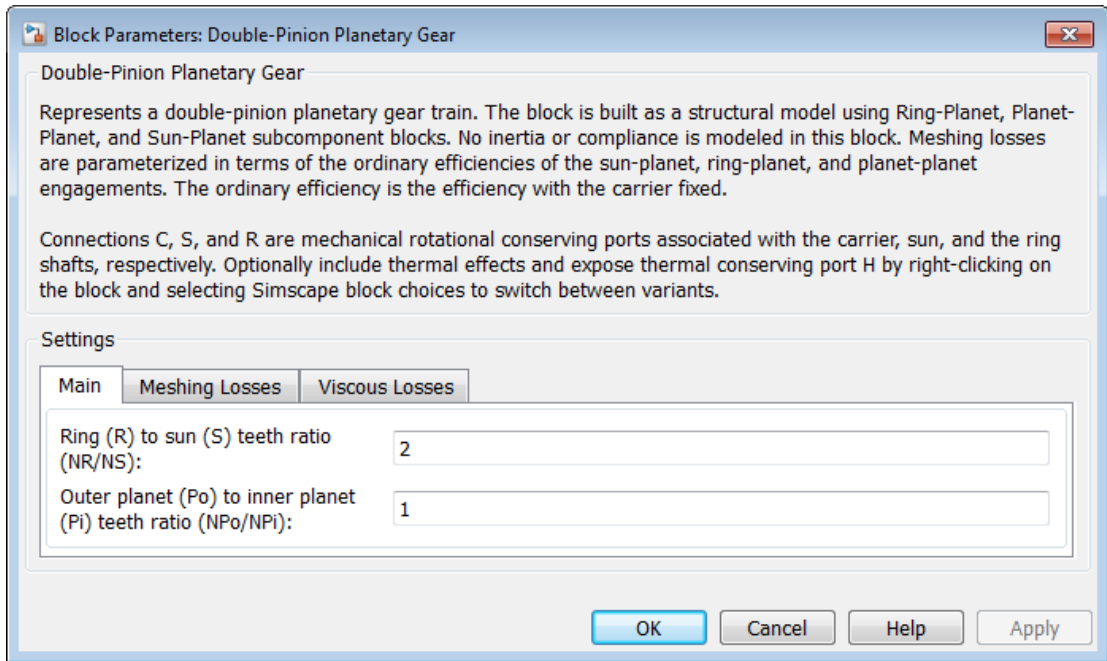
$$\frac{r_{pi}}{r_s} = \frac{\left(\frac{r_r}{r_s} - 1\right)}{2 \left(\frac{r_{po}}{r_{pi}} + 1\right)},$$

The Differential block is a composite component. It contains three underlying blocks—Ring-Planet, Planet-Planet, and Sun-Planet—connected as shown in the figure. Each block connects to a separate drive shaft through a rotational conserving port.



You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Ring (R) to sun (S) teeth ratio (NR/NS)

Teeth ratio between the ring and sun gears. This ratio is the number of teeth in the ring gear divided by the number of teeth in the sun gear. The default value is 2.

#### Outer planet (Po) to inner planet (Pi) teeth ratio (NPo/NPi)

Teeth ratio between the outer-planet and inner-planet gears. This ratio is the number of teeth in the outer planet divided by the number of gear teeth in the inner planet. The default value is 1.

### Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.



## Without Thermal Port

### Friction model

List of friction models at various precision levels for estimating power losses due to meshing.

- **No meshing losses - Suitable for HIL simulation** — Neglect friction between gear cogs. Meshing is ideal.
- **Constant efficiency** — Reduce torque transfer by a constant efficiency factor. This factor falls in the range  $0 < \eta \leq 1$  and is independent of load. Selecting this option exposes additional parameters.

### Sun-planet, ring-planet, and planet-planet ordinary efficiencies

Array of mechanical efficiencies between sun-planet, ring-planet, and planet-planet gear pairs, in that order. The default vector is [0.98 0.98 0.98].

### Sun-carrier, ring-carrier, and planet-carrier power thresholds

Array of power thresholds above which the full efficiency factors apply. Enter the thresholds in the order sun-carrier, ring-carrier, and planet-carrier. A hyperbolic tangent function smooths the efficiency factors from zero when at rest to the full efficiency values at the power thresholds.

As a guideline, the power threshold should be lower than the expected power transmitted during simulation. Higher values might cause the block to underestimate efficiency losses. Very low values might, however, raise the computational cost of simulation. The default vector is [0.001 0.001 0.001] W.

## With Thermal Port

### Temperature

Array of temperatures used to construct 1-D temperature-efficiency lookup tables. The array values must increase left to right. The temperature array must be the same size as the efficiency arrays. The default array is [280 300 320] K.

### Sun-planet efficiency

Array of mechanical efficiencies with power flowing from the sun gear to the planet gears. Each array element is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.75 0.65 0.60].

### Ring-planet efficiency

Array of mechanical efficiencies with power flowing from the ring gear to the planet gears. Each array element is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.50 0.45 0.40].

#### **Planet-planet efficiency**

Array of mechanical efficiencies with power flowing from the inner planet gears to the outer planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.50 0.45 0.40].

#### **Sun-carrier, ring-carrier and planet-carrier power thresholds**

Array of power thresholds above which the full efficiency factors apply. Enter the thresholds in the order sun-carrier, ring-carrier, and planet-carrier. A hyperbolic tangent function smooths the efficiency factors between zero when at rest and the values provided by the temperature-efficiency lookup tables when at the power threshold. The default array is [0.001 0.001 0.001] W.

### **Viscous Losses**

Specify the power losses due to viscous damping of the gear carriers.

#### **Sun-carrier, ring-carrier, and planet-carrier viscous friction coefficients**

Enter a vector with the viscous friction coefficients that dampen sun-carrier, ring-carrier, and planet-carrier motion, in that order. From the drop-down list, select a physical unit. The default vector is [0 0 0] N\*m/(rad/s).

### **Thermal Port**

#### **Thermal mass**

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

#### **Initial temperature**

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Ports

Port	Description
C	Rotational conserving port representing the planet gear carrier
S	Rotational conserving port representing the sun gear
R	Rotational conserving port representing the ring gear
H	Thermal conserving port for thermal modeling

## See Also

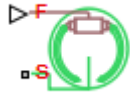
Planetary Gear | Compound Planetary Gear | Ravigneaux Gear

## Double-Shoe Brake

Frictional brake with two pivoted shoes diametrically positioned about rotating drum

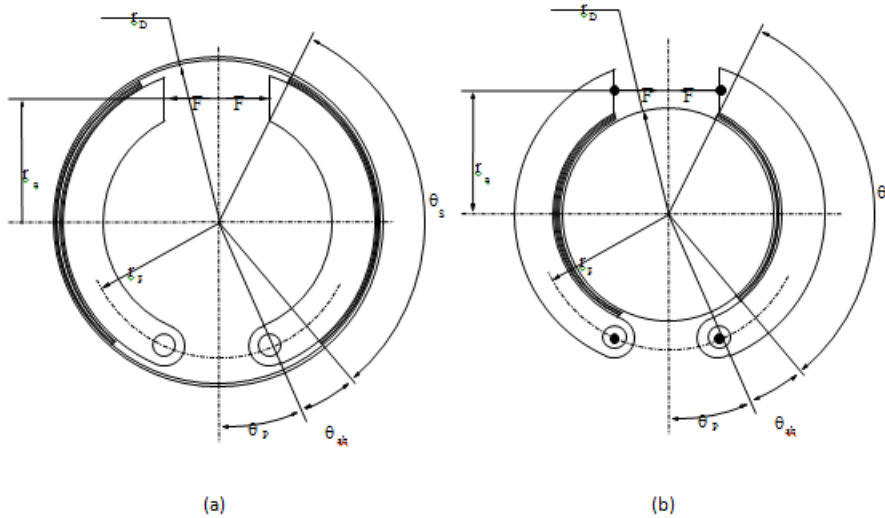
### Library

Brakes & Detents/Rotational



### Description

The block represents a frictional brake with two pivoted rigid shoes that press against a rotating drum to produce a braking action. The rigid shoes sit inside or outside the rotating drum in a diametrically opposed configuration. A positive actuating force causes the rigid shoes to press against the rotating drum. Viscous and contact friction between the drum and the rigid shoe surfaces cause the rotating drum to decelerate. Double-shoe brakes provide high braking torque with small actuator deflections in applications that include motor vehicles and some heavy machinery. The model employs a simple parameterization with readily accessible brake geometry and friction parameters.



In this schematic, a) represents an internal double-shoe brake, and b) represents an external double-shoe brake. In both configurations, a positive actuation force  $F$  brings the shoe and drum friction surfaces into contact. The result is a friction torque that causes deceleration of the rotating drum. Zero and negative forces do not bring the shoe and drum friction surfaces into contact and produce zero braking torque.

The model uses the long-shoe approximation. Contact angles smaller than  $45^\circ$  produce less accurate results. The following formulas provide the friction torque the leading and trailing shoes develop, respectively:

$$T_{LS} = \frac{\mu \cdot p_a \cdot r_D^2 (\cos \theta_{sb} - \cos \theta_s)}{\sin \theta_a}$$

$$T_{TS} = \frac{\mu \cdot p_b \cdot r_D^2 (\cos \theta_{sb} - \cos \theta_s)}{\sin \theta_a}$$

In the formulas, the parameters have the following meaning:

Parameter	Description
$T_{LS}$	Brake torque the leading shoe develops

Parameter	Description
$T_{TS}$	Brake torque the trailing shoe develops
$\mu$	Effective contact friction coefficient
$p_a$	Maximum linear pressure in the leading shoe-drum contact
$p_b$	Maximum linear pressure in the trailing shoe-drum contact
$r_D$	Drum radius
$\theta_{sb}$	Shoe beginning angle
$\theta_s$	Shoe span angle
$\theta_a$	Angle from hinge pin to maximum pressure point  $\theta_a = \begin{cases} \theta_s & \text{if } 0 \leq \theta_s \leq \pi/2 \\ \pi/2 & \text{if } \theta_s \geq \pi/2 \end{cases}$

The model assumes that only Coulomb friction acts at the shoe-drum surface contact. Zero relative velocity between the drum and the shoes produces zero Coulomb friction. To avoid discontinuity at zero relative velocity, the friction coefficient formula employs the following hyperbolic function:

$$\mu = \mu_{Coulomb} \cdot \tanh\left(\frac{4\omega_{shaft}}{\omega_{threshold}}\right)$$

In the formula, the parameters have the following meaning:

Parameter	Description
$\mu$	Effective contact friction coefficient
$\mu_{Coulomb}$	Contact friction coefficient
$\omega_{shaft}$	Shaft velocity
$\omega_{threshold}$	Angular velocity threshold

Balancing the moments that act on each shoe with respect to the pin yields the pressure acting at the shoe-drum surface contact. The following formula provides the balance of moments for the leading shoe.

$$F = \frac{M_N - M_F}{c}$$

In the formula, the parameters have the following meaning:

Parameter	Description
$F$	Actuation Force
$M_N$	Moment acting on the leading shoe due to normal force
$M_F$	Moment acting on the leading shoe due to friction force
$c$	Arm length of the cylinder force with respect to the hinge pin

The following equations give  $M_N$ ,  $M_F$ , and  $c$ , respectively.

$$M_N = \frac{p_a r_p r_D}{\sin \theta_a} \left( \frac{1}{2} [\theta_s - \theta_{sb}] - \frac{1}{4} [\sin 2\theta_s - \sin 2\theta_{sb}] \right)$$

$$M_F = \frac{\mu p_a r_D}{\sin \theta_a} \left( r_D [\cos \theta_{sb} - \cos \theta_s] + \frac{r_p}{4} [\cos 2\theta_s - \cos 2\theta_{sb}] \right)$$

$$c = r_a + r_p \cos \theta_p$$

The parameters have the following meaning:

Parameter	Description
$p_a$	Maximum linear pressure at the shoe-drum contact surface

Parameter	Description
$r_p$	Pin location radius
$\theta_p$	Hinge pin location angle
$r_a$	Actuator location radius

The model does not simulate self-locking brakes. If brake geometry and friction parameters cause a self-locking condition, the model produces a simulation error. A brake self-locks if the friction moment exceeds the moment due to normal forces:  $M_F > M_N$

The following formula provides the balance of moments for the trailing shoe.

$$F = \frac{M_N + M_F}{c}$$

Formulas and parameters for  $M_N$ ,  $M_F$ , and  $c$  share the definition in the leading shoe section.

The net braking torque has the formula:

$$T = T_{LS} + T_{TS} + \mu_{visc}$$

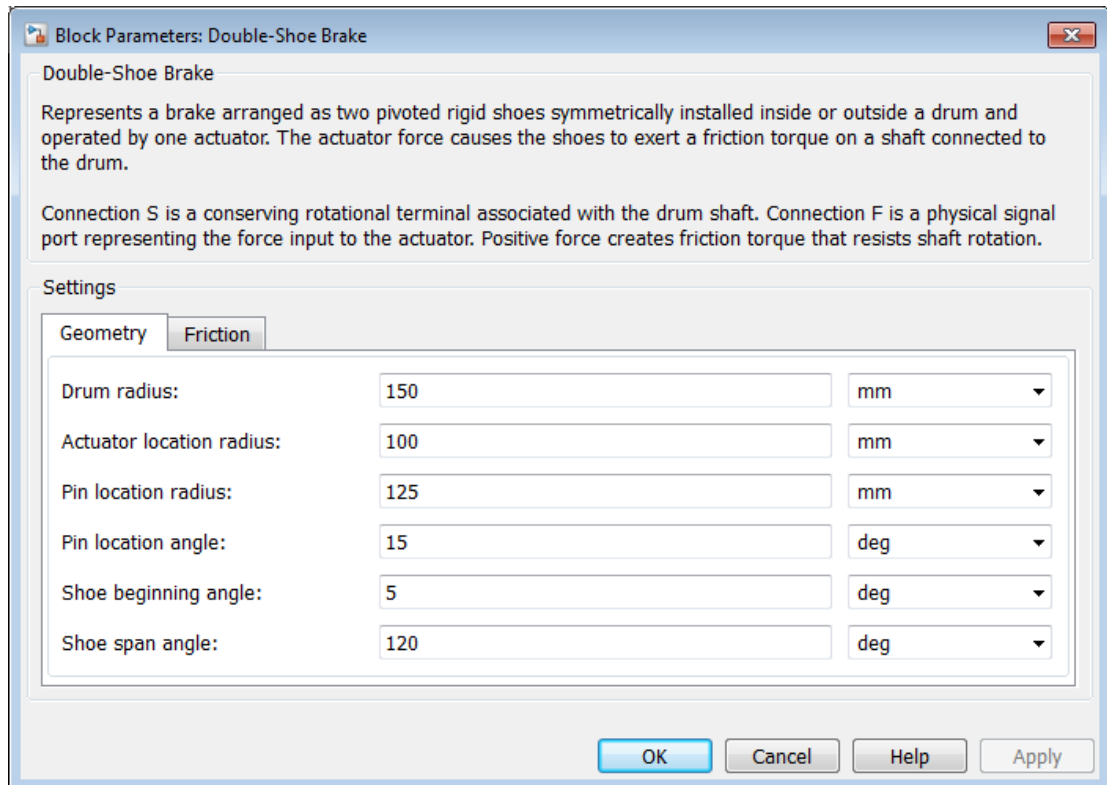
In the formula, parameter  $\mu_{visc}$  is the viscous friction coefficient.

## Assumptions and Limitations

- The brake uses the long-shoe approximation
- The brake geometry does not self-lock
- The model does not account for actuator flow consumption



## Dialog Box and Parameters



### Geometry

#### Drum radius

Radius of the drum contact surface. The parameter must be greater than zero. The default value is 150 mm.

#### Actuator location radius

Distance between the drum center and the force line of action. The parameter must be greater than zero. The default value is 100 mm.

#### Pin location radius

Distance between the hinge pin and drum centers. The parameter must be greater than zero. The default value is 125 mm.

**Pin location angle**

Angular coordinate of the hinge pin location from the brake symmetry axis. The parameter must be greater than or equal to zero. The default value is 15 deg.

**Shoe beginning angle**

Angle between the hinge pin and the beginning of the friction material linen of the shoe. The value of the parameter must be in the range  $0 \leq \theta_{sb} \leq (\pi - \text{pin location angle})$ . The default value is 5 deg.

**Shoe span angle**

Angle between the beginning and the end of the friction material linen on the shoe. The value of the parameter must be in the range  $0 < \theta_{sb} \leq (\pi - \text{pin location angle} - \text{shoe beginning angle})$ . The default value is 130 deg.

**Friction**

**Viscous friction coefficient**

Value of the viscous friction coefficient at the contact surface. The parameter must be greater than or equal to zero. The default value is 0.01 n\*m/(rad/s).

**Contact friction coefficient**

Friction coefficient at the shoe-drum contact surface. The parameter must be greater than zero. The default value is 0.3.

**Angular velocity threshold**

Angular velocity at which the contact friction coefficient practically reaches its steady-state value. The parameter must be greater than zero. the default value is 0.01 rad/s.

**Ports**

Port	Description
F	Physical signal port that represents the brake actuating force
S	Conserving rotational port that represents the rotating drum shaft

**See Also**

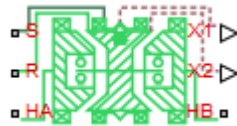
Band Brake | Loaded-Contact Rotational Friction | Rotational Detent

# Double-Sided Synchronizer

Back-to-back dog-cone clutch pairs assembled symmetrically about a translational detent to provide smooth gear engagement

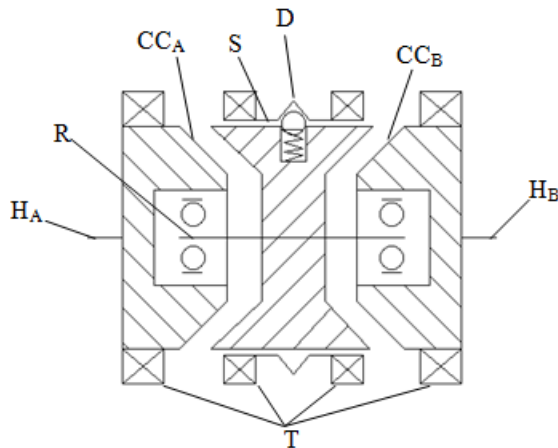
## Library

Clutches

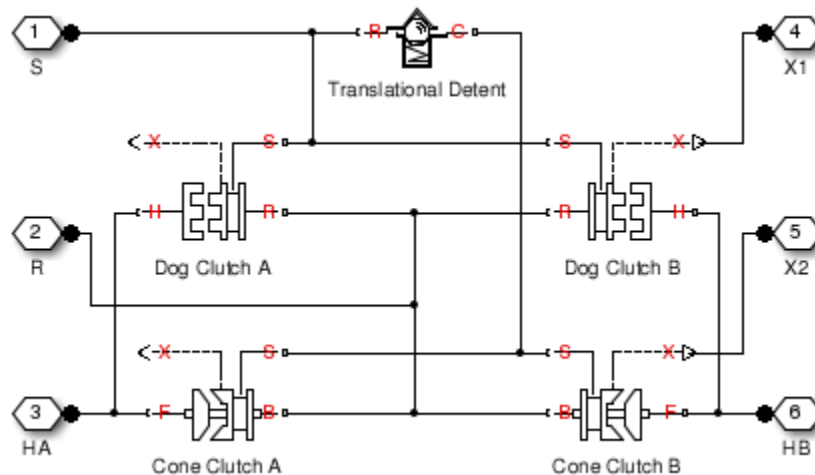


## Description

The block represents a double-sided synchronizer that contains two back-to-back dog clutches, two back-to-back cone clutches, and one translational detent. Shift linkage translation along the negative direction causes the clutches to engage the ring with hub A. Shift linkage translation along the positive direction causes the clutches to engage the ring with hub B. When the magnitude of the shift linkage translation is smaller than the cone clutch ring-hub gap, the synchronizer is in neutral mode and does not transmit torque.



The schematic illustrates a double-sided synchronizer in the disengaged state. In this state, the ring (R) and hub ( $H_A$  and  $H_B$ ) shafts can spin independently at different speeds. As the shift linkage (S) translates in the negative direction, the faces of cone clutch A ( $CC_A$ ) come into contact. The friction in the cone clutch decreases the difference in rotational speed between the shafts. When the force on the shift linkage exceeds the peak force of detent (D), the dog clutch teeth (T) can engage. The detent peak force should be such that the cone clutch has enough time and normal force to bring the shafts to sufficiently similar speeds to allow engagement of the dog clutch. Similarly, translating the shift linkage along the positive direction allows the faces of cone clutch B ( $CC_B$ ) to come into contact, and can allow the shaft of the ring to engage with the shaft of the hub B ( $H_B$ ).



The model implements two **Dog Clutch** blocks, one **Translational Detent**, and two modified **Dog Clutch** blocks. Refer to each block reference page for more information on the corresponding block function.

Connections R,  $H_A$ , and  $H_B$  are mechanical rotational conserving ports that represent the ring (R), hub A ( $H_A$ ), and hub B ( $H_B$ ), respectively. Connection S is a mechanical translational conserving port that represents the ring shifter handle.

Connections X1 and X2 are physical signal ports that output the shift linkage positions of the dog clutches and cone clutches, respectively. The following tables provide the values of X1 and X2 in common clutch engagement cases.

Dog Clutch State	X1
Disengaged	0
Fully engaged with hub A	Negative sum of ring-hub gap and tooth height
Fully engaged with hub B	Positive sum of ring-hub gap and tooth height

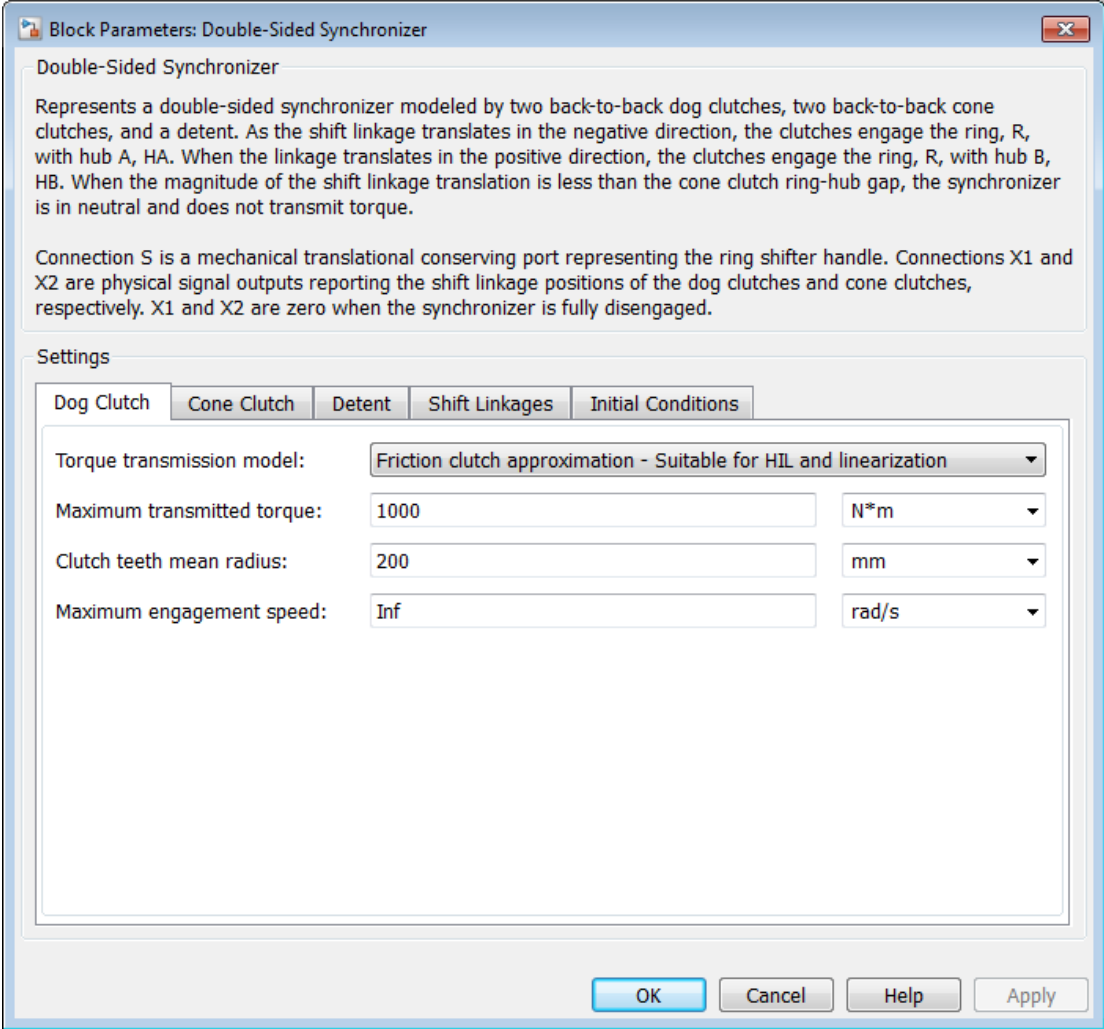
Cone Clutch State	X2
Disengaged	0
Fully engaged with hub A	Negative value of ring-hub gap
Fully engaged with hub B	Positive value of ring-hub gap

The values of X1 and X2 are zero when the synchronizer is fully disengaged. When the dog clutch is fully engaged with hub A, X1 is equal to the negative sum of its ring-hub gap and tooth height. When the dog clutch is fully engaged with hub B, X1 is equal to the positive sum of its ring-hub gap and tooth height. When the cone clutch is fully engaged with hub A, X2 is equal to the negative of its ring-hub gap. When the cone clutch is fully engaged with hub B, X2 is equal to its ring-hub gap.

## Assumptions and Limitations

- The model does not account for inertia effects. You can add a Simscape *Inertia* block at each port to add inertia to the synchronizer model.

# Dialog Box and Parameters



## Dog Clutch

### Torque Transmission Model

Model used to represent torque transmission. The default setting is `Friction clutch approximation - Suitable for HIL and linearization`.

The models provide the following common parameters:

**Clutch teeth mean radius**

Mean radius of the clutch teeth. The parameter must be greater than zero. The default value is 200 mm.

**Maximum engagement speed**

The relative angular speed between the ring and hub shafts above which the dog clutch cannot engage. The value is specific to the specific gearbox or transmission and must be minimized to avoid high dynamic impact during engagement. The default value is `inf rad/s`

**Friction clutch approximation - Suitable for HIL and linearization**

**Maximum transmitted torque**

Maximum expected torque across the clutch. The default value is 1000 Nm.

**Dynamic with Backlash**

**Number of teeth**

Number of teeth in the clutch. The parameter must be greater than or equal to one. The default value is 6.

**Rotational backlash**

Angular play of the ring with respect to the hub. Greater backlash values correspond to wider tooth gaps that makes engagement easier. The parameter must be greater than zero. The default value is 10 deg.

**Torsional stiffness**

Stiffness of the tooth contact. The model assumes deformation due to tooth interaction is elastic. The angular deformation at the contact surface is proportional to the applied torque and the reciprocal of the contact stiffness. The parameter must be greater than zero. The default value is `1e+7 N*m/rad`.

**Torsional damping**

Damping at the tooth contact surface. The value of the parameter is inversely proportional to the number of oscillations following impact. The parameter must be greater than zero. The default value is `2 N*m/(rad/s)`.



**Tooth-tooth friction coefficient**

Friction coefficient for the translational relative motion between the hub and ring teeth. The value of the parameter depends on the tooth material, lubrication, and quality of contacting surfaces. The parameter must be greater than zero. The default value is **0.05**.

**Cone Clutch****Contact surface maximum diameter**

Outer diameter of the friction material lining that lines the cone clutch disks. The parameter must be greater than zero. The default value is **150 mm**.

**Contact surface minimum diameter**

Inner diameter of the friction material lining that lines the cone clutch disks. The parameter must be greater than zero, but smaller than the value of **Contact surface maximum diameter**.

**Cone half angle**

Half angle of the clutch cone. The parameter must be greater than zero and less than or equal to  $90^\circ$ . The default value is **12 deg**.

**Friction model**

Specification method for the kinetic friction coefficient between cone clutch disks in slipping conditions. Options include:

- **Fixed kinetic friction coefficient** — Specify a single value for the kinetic friction coefficient. This value is constant across all clutch relative velocities. Selecting this option exposes an additional parameter, **Kinetic friction coefficient**.
- **Table lookup kinetic friction coefficient** — Specify a lookup table with the kinetic friction coefficient values as a function of the clutch slip velocity. Selecting this option exposes additional parameters for the lookup table values and interpolation/extrapolation methods.

**Kinetic friction coefficient**

Kinetic friction coefficient between the friction surfaces of the cone clutch disks. The parameter must be greater than zero. The default value is **0.3**.

**Kinetic friction coefficient relative velocity vector**

Vector with the clutch slip velocities at which to define the kinetic friction coefficient.

**Kinetic friction coefficient vector**

Vector with the kinetic friction coefficient values corresponding to the clutch slip velocities in **Kinetic friction coefficient relative velocity vector**.

**Friction coefficient interpolation method**

Method for calculating kinetic friction coefficients between lookup-table data points. Options include **Linear** and **Smooth**.

**Friction coefficient extrapolation method**

Method for calculating kinetic friction coefficient values outside of the lookup-table data range. Options include **Linear** and **Nearest**.

**Static friction coefficient**

Static friction coefficient between the friction surfaces of the cone clutch disks. The parameter must be greater than the kinetic friction coefficient. The default value is 0.35.

**Velocity tolerance**

Relative velocity between the cone clutch disks below which the disk friction surfaces lock. Surface locking requires that the torque across the R and H rotational ports be smaller than the product of the effective radius, the static friction coefficient, and the applied normal force. The default value is 0.001 rad/s.

**Threshold force**

Minimum value of the applied normal force for frictional torque transmittal to occur. If the value of the parameter exceeds the value of the applied normal force, no frictional torque is transmitted.

**Detent**

**Peak force**

Peak shear force of the detent. The default value is 500 N.

**Notch width**

Width of the region where the detent exhibits shear force. The default value is 3 mm.

**Viscous friction coefficient**

Viscous friction coefficient at the contact surface of the detent. The parameter must be greater than or equal to zero. The default value is 0.1 N/(m/s).

**Friction to peak force ratio**

Ratio of the kinetic friction to the peak shear force of the detent. The parameter is used to set the value of the kinetic friction. The parameter must be greater than or equal to zero. The default value is 0.01.

#### **Friction velocity threshold**

Velocity required for peak kinetic friction at the contact surface of the detent. The parameter ensures the force is continuous when the travel direction changes, increasing the numerical stability of the simulation. The parameter must be greater than zero. The default value is 0.05 m/s.

## **Shift Linkages**

#### **Ring-hub clearance when dog clutch disengaged**

Distance between ring and dog clutch hub with the ring fully retracted. The parameter specifies the maximum travel distance if engagement requirements are not met. The parameter must be greater than the value of **Ring-hub clearance when cone clutch disengaged**. The default value is 5 mm.

#### **Tooth overlap to engage**

Minimum value of the tooth overlap beyond which the dog clutch is considered engaged. The parameter must be greater than zero. The default value is 3 mm.

#### **Tooth height**

Height of dog clutch teeth. The parameter must be greater than zero. The default value is 10 mm.

#### **Ring-hub clearance when cone clutch disengaged**

Distance between the ring and cone clutch hub when the ring is fully retracted. The cone clutch can begin to engage once the slider has translated this distance. The ring can travel only this distance if the engagement requirements are not satisfied. The parameter must be greater than zero. The default value is 3 mm.

#### **Dog clutch ring stop stiffness**

Stiffness of the hard stops on both sides of the dog clutch ring. The model assumes the ring and stops behave elastically. Contact deformation is proportional to the applied force and the reciprocal of the contact stiffness. The value of the stiffness must be assigned with reference to the parameter **Tooth overlap to engage**. Too low a stiffness could cause the deformation to exceed the required overlap and initiate a false engagement. The parameter must be greater than zero. The default value is 1e+6 N/m.

### **Cone clutch ring stop stiffness**

Stiffness of the hard stops on both sides of the cone clutch ring. The model assumes the ring and stops behave elastically. Contact deformation is proportional to the applied force and the reciprocal of the contact stiffness. The parameter must be greater than zero. The default value is  $1e+6$  N/m.

### **Dog clutch ring stop damping**

Translational contact damping between the dog clutch ring and the hub. The value of the damping is inversely proportional to the number of oscillations that occur after impact. The parameter must be greater than zero. The default value is  $1e+3$  N/(m/s).

### **Cone clutch ring stop damping**

Translational contact damping between the cone clutch ring and the hub. The value of damping is inversely proportional to the number of oscillations that occur after impact. The parameter must be greater than zero. The default value is  $1e+3$  N/(m/s).

### **Viscous friction coefficient**

Viscous friction coefficient for the relative translational motion between the hub and the ring. The value of the parameter depends on lubrication state and quality of contacting surfaces. The coefficient must be greater than or equal to zero. The default value is  $100$  N/(m/s).

## **Initial Conditions**

### **Initial state**

Beginning configuration of cone and dog clutches. Choices include:

- Cone clutch A and dog clutch A locked
- Cone clutch A locked
- All clutches unlocked
- Cone clutch B locked
- Cone clutch B and dog clutch B locked

The default setting is All clutches unlocked.

### **Dog clutch initial shift linkage position**

Initial position of the shift linkage section that attaches to the dog clutch. The value of the parameter has the following restrictions:

Dog Clutch State	Parameter Restriction
Dog clutch A Initially engaged	Negative of the parameter value must be greater than the sum of parameters <b>Ring-hub clearance when dog clutch disengaged</b> and <b>Tooth overlap to engage</b>
Dog clutch A Initially disengaged	Negative of the parameter value must be smaller than the sum of parameters <b>Ring-hub clearance when dog clutch disengaged</b> and <b>Tooth overlap to engage</b>
Dog clutch B Initially engaged	Parameter value must be greater than the sum of parameters <b>Ring-hub clearance when dog clutch disengaged</b> and <b>Tooth overlap to engage</b>
Dog clutch B Initially disengaged	Parameter value must be smaller than the sum of parameters <b>Ring-hub clearance when dog clutch disengaged</b> and <b>Tooth overlap to engage</b>

The default value is 0 mm.

**Cone clutch initial shift linkage position**

Initial position of the shift linkage section that attaches to the cone clutch. The value of the parameter has the following restrictions:

Dog Clutch State	Parameter Restriction
Cone clutch A initially engaged	Negative of parameter must be greater than the value of <b>Ring-hub clearance when cone clutch disengaged</b>
Cone clutch A initially disengaged	Negative of parameter must be smaller than the value of <b>Ring-hub clearance when cone clutch disengaged</b>
Cone clutch B initially engaged	Parameter must be greater than the value of <b>Ring-hub clearance when cone clutch disengaged</b>

Dog Clutch State	Parameter Restriction
Cone clutch B initially disengaged	Parameter must be smaller than the value of <b>Ring-hub clearance when cone clutch disengaged</b>

The default value is 0 mm.

### Initial dog clutch ring-hub offset angle

Initial angle between the ring and hub portions of the dog clutch. To edit the parameter, you must set **Dog Clutch > Torque transmission model** to **Dynamic with backlash**. If the clutch is disengaged, the initial angle must lie in the range  $-\pi/N \leq \theta \leq +\pi/N$ , where  $N$  denotes the number of teeth in the dog clutch. If the clutch is engaged, the initial angle must be in the range  $-\delta/2 \leq \theta \leq +\delta/2$ , where  $\delta$  is the backlash angle. The default value is 0 deg.

## Ports

Port	Description
S	Conserving translational port that represents the shift linkage
R	Conserving rotational port that represents the ring shaft
HA	Conserving rotational port that represents hub shaft A
HB	Conserving rotational port that represents hub shaft B
X1	Physical signal output port that measures the magnitude of the dog clutch translation
X2	Physical signal output port that measures the magnitude of the cone clutch translation

### See Also

Synchronizer | Cone Clutch | Dog Clutch | Translational Detent

# Flexible Shaft

Driveline shaft with torsional compliance

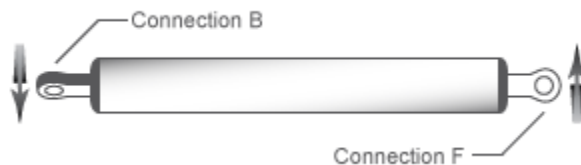
## Library

Couplings & Drives



## Description

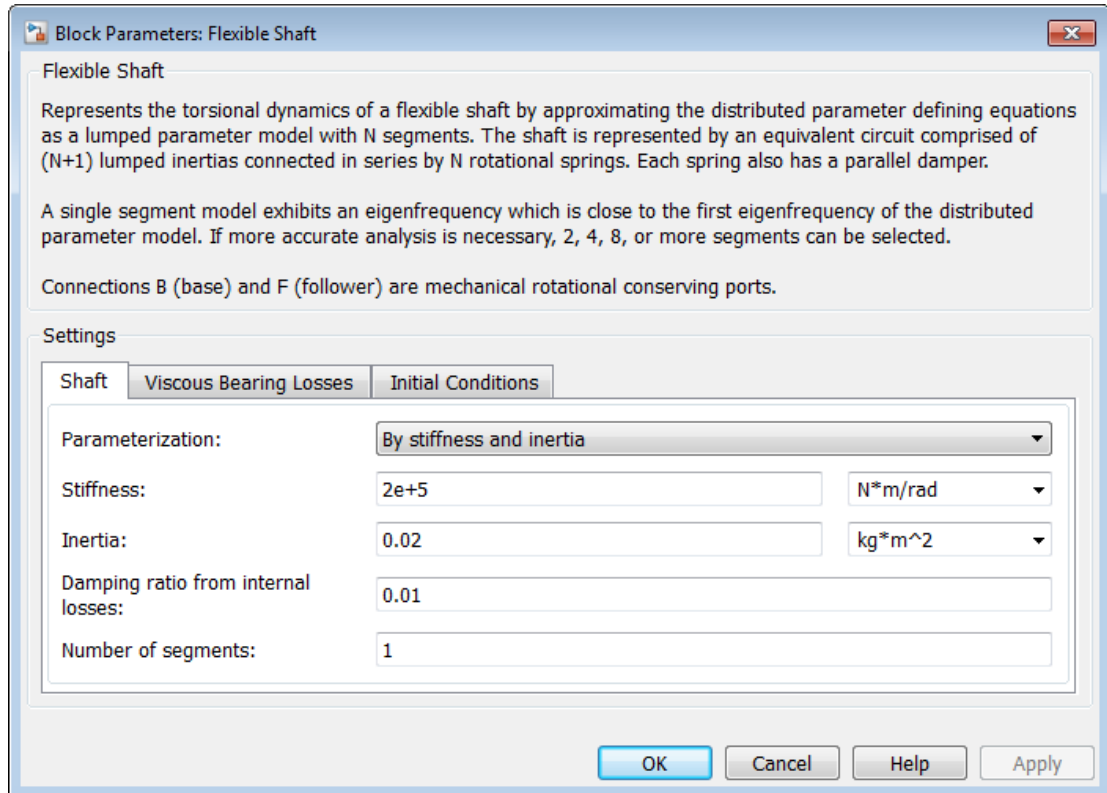
This block represents a driveline shaft with torsional compliance. The shaft consists of a flexible material that twists in response to an applied torque. The twisting action delays power transmission between the shaft ends, altering the dynamic response of the driveline system. The shaft twists but does not bend.



To represent the flexible shaft, the block uses a lumped-parameter model. This model divides the shaft into different elements that interconnect through parallel spring-damper systems. The elements provide the shaft inertia while the spring-damper systems provide the shaft compliance.

You specify the shaft inertia, compliance, and number of shaft elements directly in the block dialog box. Choosing from two parameterizations, you can specify the shaft compliance using stiffness and damping values or, alternatively, the shaft shear modulus. An additional parameter enables you to model the power losses due to viscous friction at the shaft ends.

## Dialog Box and Parameters



## Shaft

### Parameterization

Select how to characterize the flexible shaft. The default is **By stiffness and inertia**.

- **By stiffness and inertia** — Specify shaft characteristics by its inertia and elastic stiffness.

#### **Stiffness and Inertia**

##### **Stiffness**



Stiffness  $k$  of the shaft, the torque per unit angular deflection of the shaft. The default is  $2e+5$ .

From the drop-down list, choose units. The default is newton-meters/radian ( $N \cdot m / rad$ ).

### **Inertia**

Rotational inertia  $J$  of the shaft around its principal axis. The default is  $0.02$ .

From the drop-down list, choose units. The default is kilogram-meters<sup>2</sup> ( $kg \cdot m^2$ ).

- **By material properties** — Specify shaft characteristics by its size and continuum properties. If you select this option, the panel changes from its default.

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### **Shaft Geometry**

Select the geometry of the shaft. The default is **Solid**.

- **Solid** — Specify a solid shaft geometry.

#### **Solid**

##### **Shaft outside diameter**

Diameter  $D$  of the solid shaft. Must be greater than 0. The default is  $0.075$ .

From the drop-down list, choose units. The default is meters (m).

**Annular**— Specify an annular, or hollow, shaft geometry. If you select this option, the panel changes from its default.

#### **Annular**

##### **Shaft outside diameter**

Outside diameter  $D$  of the hollow shaft. Must be greater than 0. The default is  $0.075$ .

From the drop-down list, choose units. The default is meters (m).

##### **Shaft inside diameter**

Inside diameter  $d$  of the hollow shaft. Must be greater than 0. The default is 0.05.

From the drop-down list, choose units. The default is meters (m).

### **Shaft length**

Length  $L$  of the shaft. Must be greater than 0. The default is 1.

From the drop-down list, choose units. The default is meters (m).

### **Material density**

Mass density  $\rho$  of the shaft material. Must be greater than 0. The default is  $7.8e+3$ .

From the drop-down list, choose units. The default is kilograms/meter<sup>3</sup> (kg/m<sup>3</sup>).

### **Shear modulus**

Shear modulus  $G$  of the shaft material. Must be greater than 0. The default is  $7.93e+10$ .

From the drop-down list, choose units. The default is pascals (Pa).

### **Damping ratio from internal losses**

Damping ratio  $c$  for the first flexible torsional mode. The default value is 0.01.

### **Number of segments**

Number  $Nof$  rigid segments into which the shaft is divided. The default is 1.

## **Viscous Bearing Losses**

### **Viscous friction coefficients at base and follower**

Viscous friction coefficients applied at the base and follower, respectively. The default is [0 0].

From the drop-down list, choose units. The default is newton-meters/(radians/second) (N\*m/ (rad/s)).

## **Initial Conditions**

### **Initial shaft angular deflection**

Initial torsional angular deflection of the shaft. The default is 0.

From the drop-down list, choose units. The default is radians (rad).

A positive initial deflection results in a positive torque action from the base (B) to the follower (F) port.

### Initial shaft angular velocity

Initial torsional angular velocity of the shaft. The default is 0.

From the drop-down list, choose units. The default is revolutions/minute (rpm).

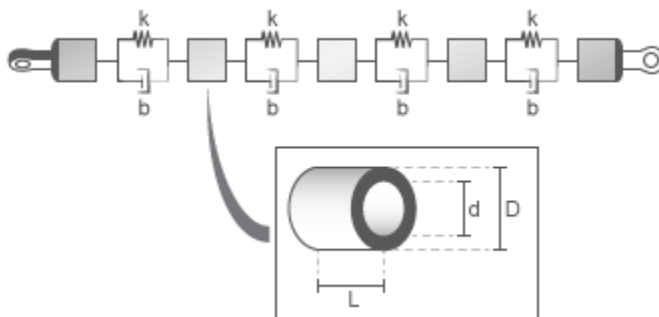
At the start of simulation, the entire shaft rotates collectively at this angular velocity, with no relative motion between the segments.

## Flexible Shaft Model

The Flexible Shaft block approximates the distributed, continuous properties of a shaft by a lumped parameter model. The model contains a finite number,  $N$ , of lumped inertia-damped spring elements in series, plus a final inertia. The result is a series of  $N+1$  inertias connected by  $N$  rotational springs and  $N$  rotational dampers. The block can also include viscous friction at the shaft ends (base and follower ports) to represent bearing losses at these points.

Do not confuse this viscous friction at the shaft ends with the internal material damping which corresponds to losses arising in the shaft material itself.

The Flexible Shaft block model is parameterized in either the shaft stiffness  $k$  and inertia  $J$  or its dimensions and material properties.



## Shaft Characterized by Dimensions and Material Properties

The shaft stiffness and inertia are computed from the shaft dimensions and material properties by the following relationships:

$$J_P = (\pi/32)(D^4 - d^4) ,$$

$$m = (\pi/4)(D^2 - d^2)\rho L ,$$

$$J = (m/8)(D^2 + d^2) = \rho L \cdot J_P ,$$

$$k = J_P \cdot G/L ,$$

where:

$J_P$	Polar moment of inertia		
$D$	Shaft outside diameter		
$d$	Shaft inside diameter		
		For solid shafts:	$d = 0$
		For annular (hollow) shafts:	$d > 0$
$L$	Shaft length		
$m$	Shaft mass		
$J$	Moment of inertia		
$\rho$	Shaft material density		
$G$	Shear modulus of elasticity		
$k$	Shaft rotational stiffness		

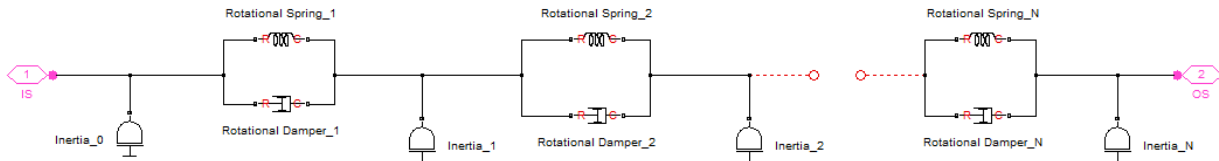
## Internal Material Damping

For either shaft parameterization, the internal material damping is defined by the damping ratio,  $c$ , for a single-segment model. In this case, the damping torque is  $2c/\omega_N$ .  $\omega_N$  is the undamped natural frequency =  $\sqrt{(2k/J)}$ . For an  $N$ -segment model, the damping applied across each of the  $N$  springs is  $2cN/\omega_N$ .

## Equivalent Physical Network

The following figure shows an equivalent physical network constructed from Simscape blocks only. There are  $N$  segments, each consisting for a spring, damper, and inertia. A

segment represents a short section of the driveshaft, the spring representing torsional compliance and the damper representing material damping. The total shaft inertia is split into  $N+1$  parts, and partitioned as shown in the figure.



## Limitations

The distributed parameter model of a continuous torsional shaft is approximated by a finite number,  $N$ , of lumped parameters.

The flexible shaft is assumed to have a constant cross-section along its length.

## Tradeoff Between Accuracy and Speed

A larger number  $N$  of segments increases the accuracy of the model, but reduces its speed. The single-segmented model ( $N=1$ ) exhibits an eigenfrequency which is close to the first eigenfrequency of the continuous, distributed parameter model.

For greater accuracy, you can select 2, 4, 8, or more segments. For example, the four lowest eigenfrequencies are represented with an accuracy of 0.1, 1.9, 1.6, and 5.3 percent, respectively, by a 16-segmented model.

## Ports and Conventions

B and F are rotational conserving ports associated with the shaft input and output sections, respectively.

## References

[1] Bathe, K.-J., *Finite Element Procedures*, Prentice Hall, Inc, 1996.

- [2] Chudnovsky, V., D. Kennedy, A. Mukherjee, and J. Wendlandt, “Modeling Flexible Bodies in SimMechanics and Simulink,” MATLAB Digest 14(3), May 2006.

**See Also**

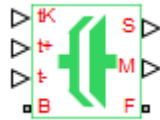
Inertia | Rotational Spring | Rotational Damper | Torsional Spring-Damper

# Fundamental Friction Clutch

Friction clutch with kinetic and static-limit friction torques as inputs

## Library

Clutches



## Description

This block represents a friction clutch, a mechanism that transmits rotational power through friction. The clutch contains two friction plate sets, each rigidly connected to a driveshaft, that come into contact in order to engage. Once in contact, the plates experience frictional torques that enable power to flow between the driveshafts.

The clutch can be bidirectional or unidirectional. A bidirectional clutch can slip in the positive and negative directions. A unidirectional clutch can slip only in the positive direction. The slip direction is positive if the follower shaft spins faster than the base shaft and negative if it spins slower. The block defines the slip velocity as the difference

$$\omega = \omega_F - \omega_B,$$

where:

- $\omega$  is the slip velocity.
- $\omega_F$  is the angular velocity of the follower driveshaft.
- $\omega_B$  is the angular velocity of the base driveshaft.

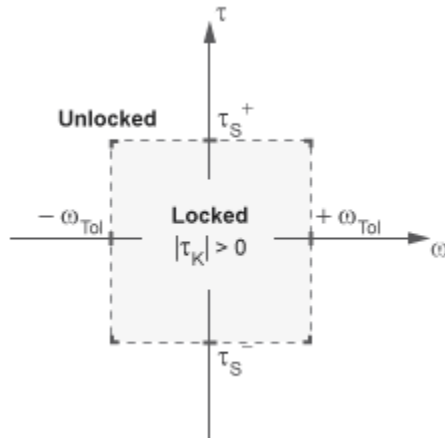
## Clutch States

The clutch can be in three states:

- **Locked** — Real clutch state in which the friction plates spin as a unit. A locked clutch has one rotational degree of freedom. It experiences no power losses due to friction.

- Unlocked — Real clutch state in which the friction plates slip with respect to each other. An unlocked clutch has two rotational degrees of freedom. It experiences power losses equal to the product of the slip velocity and the kinetic friction torque.
- Wait — Virtual clutch state that maintains the motion of the previous state while testing for locking and unlocking. The clutch degrees of freedom and power losses depend on the previous clutch state.

The schematic shows the conditions under which the clutch is locked and unlocked. The clutch is generally locked if the torque it transfers lies between its static friction torque limits and the magnitude of the slip velocity is smaller than its velocity tolerance. The clutch unlocked otherwise.



In the schematic:

- $\tau$  is the torque transferred between the clutch plates.
- $\tau_S^-$  and  $\tau_S^+$  are the static friction torque limits.
- $\tau_K$  is the kinetic friction torque between the clutch plates.
- $\omega_{Tol}$  is the slip velocity tolerance of the clutch.
- $\omega$  is the slip velocity between the clutch plates.

The block identifies the clutch state through physical signal port M using values -1, 0, and +1. The table summarizes the correspondence between the states and the output values.

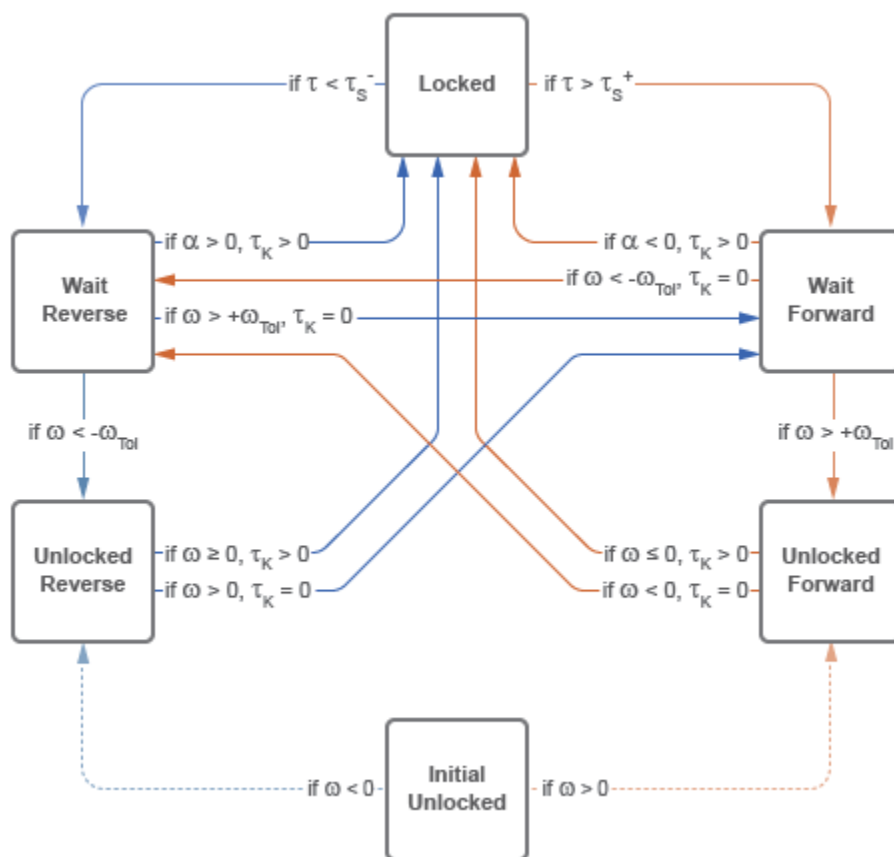


State	Value
Unlocked Forward or Wait Forward	+1
Unlocked Reverse or Wait Reverse	-1
Locked or Unlocked Initial State	0

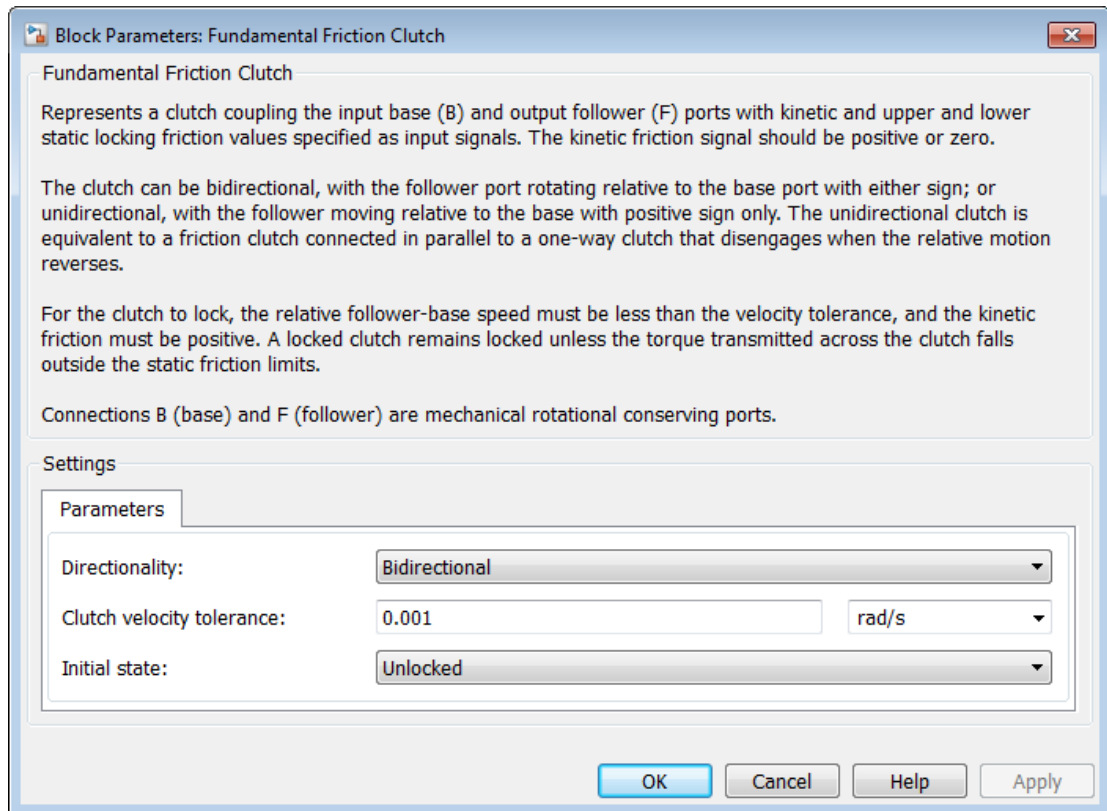
## State Transitions

At the start of simulation, the clutch is in one of two states—locked or initial unlocked. The initial unlocked state is unique in that it lacks a direction of motion. The clutch remains in this state until the clutch slip velocity becomes nonzero. The clutch then transitions to the appropriate state—unlocked reverse or unlocked forward—according to the schematic.

During simulation, the clutch tests various dynamic conditions to determine the appropriate state transitions, if any. The schematic shows the possible transitions, their dynamic conditions, and the resulting states. If the clutch is unidirectional, the schematic reduces to the right half. The variable  $a$  is the slip acceleration between the clutch plates.



## Dialog Box and Parameters



### Directionality

Slip directions the clutch allows between its plates. A bidirectional clutch allows positive and negative slip velocities. A unidirectional clutch allows only positive slip velocities. The default setting is **Bidirectional**.

The unidirectional clutch is equivalent to a friction clutch connected in parallel to a one-way clutch that disengages only when the slip velocity becomes positive. To model a unidirectional clutch with slip in the negative direction, reverse the base and follower port connections.

### Clutch velocity tolerance

Slip velocity below which the clutch can lock. The clutch locks if, after falling below the clutch velocity tolerance, the kinetic friction torque is nonzero and the transferred torque is between the static friction torque limits. The default value is 0.001 rad/s.

## Initial state

Clutch state at the start of simulation. The clutch can be in one of two states, locked and unlocked. A locked clutch constrains the base and follower shafts to spin at the same velocity, i.e., as a single unit. An unlocked clutch allows the two shafts to spin at different velocities, resulting in slip between the clutch plates. The default setting is `Unlocked`.

A clutch that starts simulation unlocked lacks a direction of motion. For this reason, after checking that the unlocked state is valid, the block automatically determines the appropriate direction of motion based on the driveline dynamics. Based on the direction of motion, the clutch then transitions to an `unlocked-reverse` or `unlocked-forward` state.

## Ports

- `B` — Rotational conserving port that represents the base driveshaft
- `F` — Rotational conserving port that represents the follower driveshaft
- `tK` — Physical signal input port for the kinetic friction torque
- `t+` — Physical signal input port for the upper static friction torque limit
- `t-` — Physical signal input port for the lower static friction torque limit
- `S` — Physical signal output port for the clutch slip velocity
- `M` — Physical signal output port for the clutch state

## See Also

Differential | Disk Friction Clutch | Torque Converter | Variable Ratio Transmission

## Related Examples

- “Gear Coupling Control with Clutches”
- Simple Gear

# Generic Engine

Internal combustion engine with throttle and rotational inertia and time lag

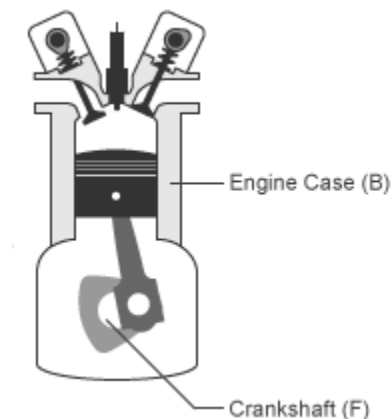
## Library

Engines

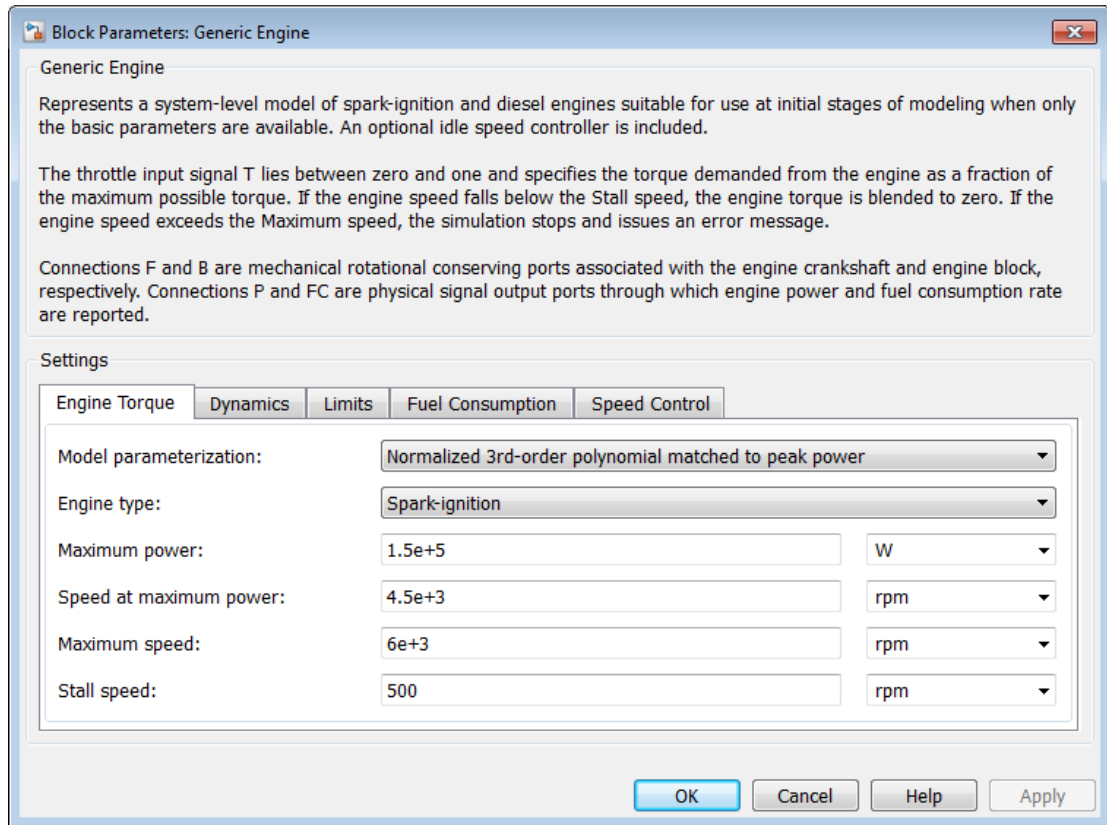


## Description

The block represents a general internal combustion engine. Engine types include spark-ignition and diesel. Speed-power and speed-torque parameterizations are provided. A throttle physical signal input specifies the normalized engine torque. Optional dynamic parameters include crankshaft inertia and response time lag. A physical signal port outputs engine fuel consumption rate based on choice of fuel consumption model. An optional speed controller prevents engine stall and enables cruise control. See “Generic Engine Model” on page 1-128.



## Dialog Box and Parameters



### Engine Torque

#### Model parameterization

Select how to model the engine. The default is Normalized 3rd-order polynomial matched to peak power.

- Normalized 3rd-order polynomial matched to peak power — Parametrize the engine with a power function controlled by power and speed characteristics.

## Normalized Engine Power Polynomial

### Engine type

Choose type of internal combustion engine. The default is Spark-ignition.

### Maximum power

Maximum power  $P_{\max}$  that the engine can output. The default is 150000.

From the drop-down list, choose units. The default is watts (W).

### Speed at maximum power

Engine speed  $\Omega_0$  at which the engine is running at maximum power. The default is 4500.

From the drop-down list, choose units. The default is revolutions per minute (rpm).

### Maximum speed

Maximum speed  $\Omega_{\max}$  at which the engine can generate torque. The default is 6000.

From the drop-down list, choose units. The default is revolutions per minute (rpm).

During simulation, if  $\Omega$  exceeds this maximum, the simulation stops with an error.

---

**Note:** The engine maximum speed  $\Omega_{\max}$  cannot exceed the engine speed at which the engine power becomes negative. For more information, see “Generic Engine Model” on page 1-128.

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### Stall speed

Minimum speed  $\Omega_{\min}$  at which the engine can generate torque. The default is 500.

From the drop-down list, choose units. The default is revolutions per minute (rpm).

During simulation, if  $\Omega$  falls below this minimum, the engine torque is blended to zero.

- **Tabulated torque data** — Engine is parametrized by speed–torque table that you specify. If you select this option, the panel changes from its default.

### **Tabulated Torque Data**

#### **Speed vector**

Vector of values of the engine function's independent variable, the speed  $\Omega$ .

From the drop-down list, choose units. The default is revolutions per minute (rpm).

---

**Note:** In this vector, the first and last speeds are interpreted as the stall speed and the maximum speed, respectively. If the speed falls below the stall speed, engine torque is blended to zero. If the speed exceeds the maximum speed, the simulation stops with an error.

---

#### **Torque vector**

Vector of values of the engine function's dependent variable, the torque  $\tau$ .

From the drop-down list, choose units. The default is newton-meters (N\*m).

#### **Interpolation method**

Method to interpolate the engine speed–torque or speed–power function between discrete relative velocity values within the range of definition. The default is **Linear**.

- **Tabulated power data** — Engine is parametrized by speed–power table that you specify. If you select this option, the panel changes from its default.

### **Tabulated Power Data**

#### **Speed vector**

Vector of values of the engine function's independent variable, the speed  $\Omega$ .

From the drop-down list, choose units. The default is revolutions per minute (rpm).



**Note:** In this vector, the first and last speeds are interpreted as the stall speed and the maximum speed, respectively. If the speed falls below the stall speed, engine torque is blended to zero. If the speed exceeds the maximum speed, the simulation stops with an error.

### **Power vector**

Vector of values of the engine function's dependent variable, the power  $P$ .

From the drop-down list, choose units. The default is watts (W).

### **Interpolation method**

Method to interpolate the engine speed–torque or speed–power function between discrete relative velocity values within the range of definition. The default is **Linear**.

## **Dynamics**

### **Inertia**

Select how to model the rotational inertia of the engine block. The default is **No inertia**.

- **No inertia** — Engine crankshaft is modeled with no inertia.
- **Specify inertia and initial velocity** — Engine crankshaft is modeled with rotational inertia and initial angular velocity. If you select this option, the panel changes from its default.

### **Rotational Inertia and Initial Velocity**

#### **Inertia**

Rotational inertia of the engine crankshaft.

From the drop-down list, choose units. The default is kilograms-meters-squared ( $\text{kg}\cdot\text{m}^2$ ).

#### **Initial velocity**

Initial angular velocity  $\Omega(0)$  of the engine crankshaft. The default is **800**.

From the drop-down list, choose units. The default is revolutions per minute (rpm).

### **Engine time constant**

Select how to model the time lag of the engine response. The default is **No time constant – Suitable for HIL simulation**.

- **No time constant – Suitable for HIL simulation** — Engine reacts with no time lag.
- **Specify engine time constant and initial throttle** — Engine reacts with a time lag. If you select this option, the panel changes from its default.

### **Engine Time Constant and Initial Throttle**

#### **Engine time constant**

Engine time lag. The default is **0.2**.

From the drop-down list, choose units. The default is seconds (s).

#### **Initial normalized throttle**

Initial normalized engine throttle  $T(0)$ , ranging between zero and one. The default is **0**.

## **Limits**

### **Speed threshold**

Width of the speed range over which the engine torque is blended to zero as  $\Omega$  approaches the stall speed. The default is **100**.

From the drop-down list, choose units. The default is revolutions per minute (rpm).

## **Fuel Consumption**

### **Fuel consumption model**

Select model to specify engine fuel consumption. Models range from simple to advanced parameterizations compatible with standard industrial data. The default model is **Constant per revolution**.

**Constant per revolution****Fuel consumption per revolution**

Enter the volume of fuel consumed in one crankshaft revolution. The default value is 25. the default unit is mg/rev.

**Fuel consumption by speed and torque****Speed vector**

Enter vector of engine speeds used in lookup table parameterizations. Vector size must match **Torque vector size**. The default unit is rpm.

**Torque vector**

Enter vector of engine torques used in the lookup table parameterizations. Vector size must match **Speed vector** size. The default unit is N\*m.

**Fuel consumption table**

Enter matrix with fuel consumption rates corresponding to engine speed and torque vectors. The number of rows must equal the number of elements in the **Speed vector**. The number of columns must equal the number of elements in the **Torque vector**. The default unit is g/s.

**Interpolation method**

Select the interpolation method used to calculate fuel consumption at intermediate speed-torque values. Methods are **Linear** and **Smooth**. Outside the data range, fuel consumption is held constant at the last value given in the lookup table.

**Brake specific fuel consumption by speed and torque****Speed vector**

Enter vector of engine speeds used in lookup table parameterizations. Vector size must match **Torque vector size**. The default unit is rpm.

**Torque vector**

Enter vector of engine torques used in the lookup table parameterizations. Vector size must match **Speed vector** size. The default unit is N\*m.

**Brake specific fuel consumption table**

Enter matrix with brake specific fuel consumption (BSFC) rates corresponding to engine speed and torque vectors. BSFC is the ratio of the fuel consumption rate

to the output power. The number of rows must equal the number of elements in the **Speed vector**. The number of columns must equal the number of elements in the **Torque vector**. The default unit is g/s.

**Interpolation method**

Select the interpolation method used to calculate fuel consumption at intermediate speed-torque values. Methods are **Linear** and **Smooth**. Outside the data range, fuel consumption is held constant at the last value given in the lookup table.

**Brake specific fuel consumption by speed and brake mean effective pressure****Displaced volume**

Enter the volume displaced by a piston stroke. The default value is 400. The default unit is cm<sup>3</sup>.

**Revolutions per cycle**

Enter the number of crankshaft revolutions in one combustion cycle — e.g. 2 for a four-stroke engine, or 1 for a two-stroke engine. The default value is 2.

**Speed vector**

Enter vector of speeds used in lookup table parameterizations. The default unit is rpm.

**Brake mean effective pressure vector**

Enter vector of brake mean effective pressure (BMEP) values. The BMEP satisfies the expression:

$$BMEP = T \cdot \left( \frac{2\pi \cdot n_c}{V_d} \right)$$

where:

- $T$  — Output torque
- $n_c$  — Number of cycles per revolution
- $V_d$  — Cylinder displaced volume

**Brake specific fuel consumption table**

Enter the matrix with brake specific fuel consumption (BSFC) rates corresponding to engine speed and brake mean effective pressure (BMEP) vectors. BSFC is the ratio of the fuel consumption rate to the output power. The number of rows must equal the number of elements in the **Speed vector**. The number of columns must equal the number of elements in the **Brake mean effective pressure vector**. The default unit is g/s.

### Interpolation method

Select the interpolation method used to calculate fuel consumption at intermediate speed-torque values. Methods are **linear**, **cubic**, and **spline**. Outside the data range, fuel consumption is held constant at the last value given in the lookup table.

## Speed Control

### Idle speed control

Select speed control model. Options include **No idle speed controller** and **Enable idle speed controller**.

- **No idle speed controller** — Omit idle speed controller. Throttle input is used directly.
- **Enable idle speed controller** — Include idle speed controller to prevent engine stalling. For more information, see “Idle Speed Controller Model” on page 1-130.

### Idle speed reference

Enter the value of the speed reference below which speed increases, and above which speed decreases. The default value is 1000. The default unit is rpm.

### Controller time constant

Enter the value of the time constant associated with an increase or decrease of the controlled throttle. The constant value must be positive. The default value is 1. The default unit is s.

### Controller threshold speed

Parameter used to smooth the controlled throttle value when the engine’s rotational speed crosses the idle speed reference. For more information, see “Idle Speed Controller Model” on page 1-130. Large values decrease controller responsiveness. Small values increase computational cost. This parameter must be positive. The default value is 1. The default unit is rpm.

## Generic Engine Model

By default, the Generic Engine model uses a programmed relationship between torque and speed, modulated by the throttle signal.

### Engine Speed, Throttle, Power, and Torque

The engine model is specified by an *engine power demand* function  $g(\Omega)$ . The function provides the maximum power available for a given engine speed  $\Omega$ . The block parameters (maximum power, speed at maximum power, and maximum speed) normalize this function to physical maximum torque and speed values.

The normalized throttle input signal  $T$  specifies the actual engine power. The power is delivered as a fraction of the maximum power possible in a steady state at a fixed engine speed. It modulates the actual power delivered,  $P$ , from the engine:  $P(\Omega, T) = T \cdot g(\Omega)$ . The engine torque is  $\tau = P/\Omega$ .

### Engine Power Demand

The engine power is nonzero when the speed is limited to the operating range,  $\Omega_{\min} \leq \Omega \leq \Omega_{\max}$ . The absolute maximum engine power  $P_{\max}$  defines  $\Omega_0$  such that  $P_{\max} = g(\Omega_0)$ . Define  $w \equiv \Omega/\Omega_0$  and  $g(\Omega) \equiv P_{\max} p(w)$ . Then  $p(1) = 1$  and  $dp(1)/dw = 0$ . The torque function is:  $\tau = (P_{\max}/\Omega_0) [p(w)/w]$ .

You can derive forms for  $p(w)$  from engine data and models. Generic Engine uses a third-order polynomial form:

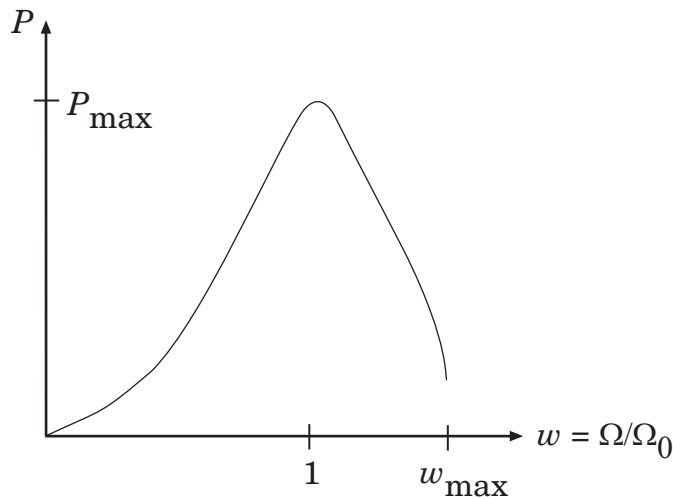
$$p(w) = p_1 \cdot w + p_2 \cdot w^2 - p_3 \cdot w^3$$

satisfying

$$p_1 + p_2 - p_3 = 1, \quad p_1 + 2p_2 - 3p_3 = 0.$$

In typical engines, the  $p_i$  are positive. This polynomial has three zeros, one at  $w = 0$ , and a conjugate pair. One of the pair is positive and physical; the other is negative and unphysical:

$$w_{\pm} = \frac{1}{2} \left( -p_2 \pm \sqrt{p_2^2 - 4p_1 p_3} \right)$$



### Typical Engine Power Demand Function

#### Restrictions on Engine Speed and Power

- For the engine power polynomial, there are restrictions on the polynomial coefficients  $p_i$ , to achieve a valid power-speed curve. These restrictions are detailed below.
- If you use tabulated power or torque data, corresponding restrictions on  $P(\Omega)$  remain.

Set  $w = \Omega/\Omega_0$  and  $p = P(\Omega)/P_0$ , and  $w_{\min} = \Omega_{\min}/\Omega_0$  and  $w_{\max} = \Omega_{\max}/\Omega_0$ . Then:

- The engine speed is restricted to a positive range above the minimum speed and below the maximum speed:  $0 \leq w_{\min} \leq w \leq w_{\max}$ .
- The engine power at minimum speed must be nonnegative:  $p(w_{\min}) \geq 0$ . If you use the polynomial form, this condition is a restriction on the  $p_i$ :  

$$p(w_{\min}) = p_1 w_{\min} + p_2 w_{\min}^2 - p_3 w_{\min}^3 \geq 0$$
- The engine power at maximum speed must be nonnegative:  $p(w_{\max}) \geq 0$ . If you use the polynomial form, this condition is a restriction on  $w_{\max}$ :  $w_{\max} \leq w_+$ .

### Engine Power Forms for Different Engine Types

For the default parametrization, Generic Engine provides two choices of internal combustion engine types, each with different engine power demand parameters.

Power Demand Coefficient	Engine Type:	
	Spark-Ignition	Diesel
$p_1$	1	0.6526
$p_2$	1	1.6948
$p_3$	1	1.3474

## Idle Speed Controller Model

The idle speed controller adjusts the throttle signal to increase engine rotation below a reference speed according to the following expressions:

$$\Pi = \max(\Pi_i, \Pi_c)$$

$$\frac{d(\Pi_c)}{dt} = \frac{0.5 \cdot \left( 1 - \tanh \left( 4 \cdot \frac{\omega - \omega_r}{\omega_t} \right) \right)}{\tau} - \Pi_c$$

where:

- $\Pi$  — Engine throttle
- $\Pi_i$  — Input throttle (port T)
- $\Pi_c$  — Controller throttle
- $\omega$  — Engine speed
- $\omega_e$  — Idle speed reference
- $\omega_t$  — Controller speed threshold
- $\tau$  — Controller time constant

The controlled throttle increases with a first-order lag from zero to one when engine speed falls below the reference speed. When the engine speed rises above the reference speed, the controlled throttle decreases from one to zero. When the difference between engine velocity and reference speed is smaller than the controller speed threshold, the *tanh* function smooths the time derivative of the controlled throttle. The controlled throttle is limited to the range 0–1. The engine uses the larger of the input and controlled



throttle values. If engine time lag is included, the controller changes the input *before* the lag is computed.

## Limitations

This block contains an engine time lag limitation.

## Engine Time Lag

Engines lag in their response to changing speed and throttle. The Generic Engine block optionally supports lag due to a changing throttle only. Time lag simulation increases model fidelity but reduces simulation performance.

## Ports

Port	Description
B	Rotational conserving port representing the engine block
F	Rotational Conserving port representing the engine crankshaft
T	Physical signal input port specifying the normalized engine throttle level
P	Physical signal output port reporting the instantaneous engine power
FC	Physical signal output port reporting the fuel consumption rate

Port T accepts a signal with values in the range 0–1. The signal specifies the engine torque as a fraction of the maximum torque possible in steady state at fixed engine speed. The signal saturates at zero and one. Values below zero are interpreted as zero. Values above one are interpreted as one.

## Examples

These Simscape Driveline example models make use of gasoline engines to power their drivelines:

- `sdl_dual_clutch`
- `sdl_hydraulic_clutch`

- `sdl_manual_transmission`
- `sdl_4wd_dynamics`
- `sdl_vehicle`

## **Related Examples**

- “Complete Vehicle Model”
- “Adjust Model Fidelity”

# Harmonic Drive

High-ratio speed reducer based on elastic deformation of an elliptical gear

## Library

Gears



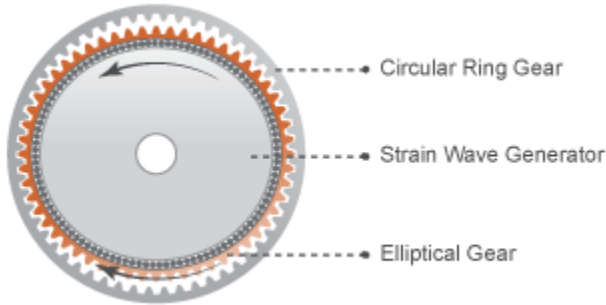
## Description

This block represents a compact, high-ratio, speed reduction mechanism that contains three key components:

- Strain wave generator
- Elliptical gear
- Circular ring gear

The strain wave generator comprises an elliptical plug mated to a raced ball bearing. It sits inside an elastic metal gear, deforming it into a slight elliptical pattern. Rotation of the elliptical pattern in the body of the gear constitutes a strain wave.

The elliptically deformed gear engages the internal teeth of a fixed circular ring gear of only slightly larger diameter. Meshing occurs concurrently at the two elongated ends of the elliptical gear. This design doubles the teeth in mesh, boosting the torque capacity of the drive system.



During normal operation, the base shaft drives the strain wave generator. The elliptical plug spins freely inside the elastic metal gear, propagating the strain wave about the gear rotation axis. This strain wave causes the elliptical gear teeth to progressively engage the internal teeth of the circular ring gear.

The internal meshing between the two gears causes the elliptical gear axis to spin counter to the elliptical strain wave. For every clockwise rotation that the strain wave generator completes, the elliptical gear axis rotates counterclockwise by a small amount.

Large reduction ratios arise from the near-equal gear tooth numbers. The effective gear reduction ratio is:

$$r = \frac{n_E}{n_C - n_E},$$

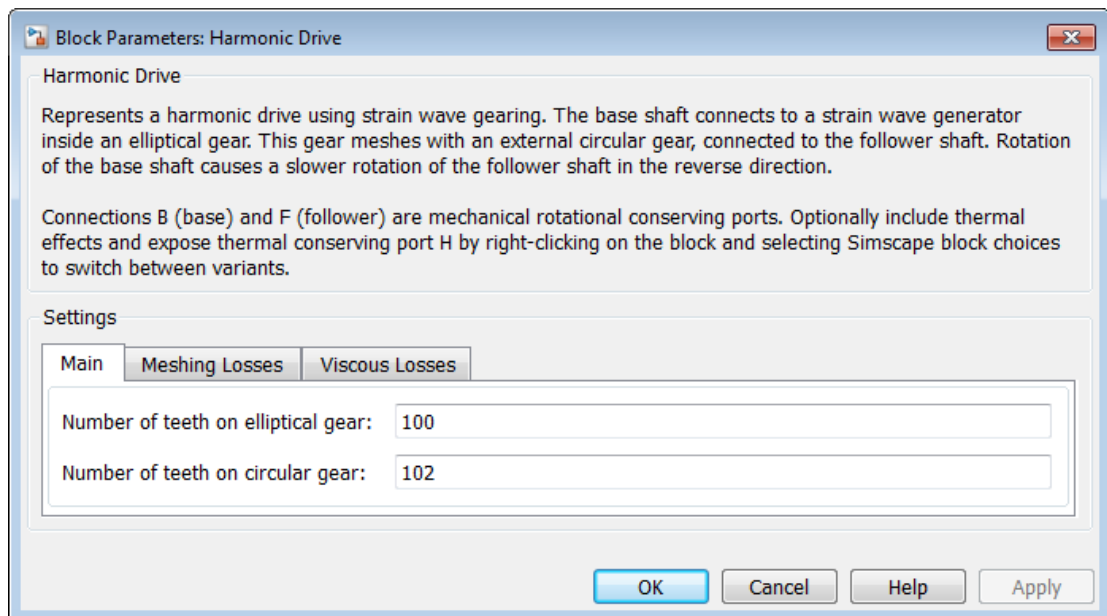
where:

- $r$  is the gear reduction ratio.
- $n_C$  is the tooth number of the circular ring gear.
- $n_E$  is the tooth number of the deformable elliptical gear.

Optional parameters account for power losses due to gear meshing and viscous friction. The Simple Gear block provides the foundation for this block. For more information, see Simple Gear.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Number of teeth on elliptical gear

Total number of teeth protruding outward from the elliptical gear perimeter. This number should be slightly smaller than the number of teeth on the circular ring gear. The ratio of the two gear tooth numbers defines the relative angular velocities of the base and follower shafts. The default value is 100.

#### Number of teeth on circular gear

Number of teeth protruding inward from the circular ring gear perimeter. This number should be slightly larger than the number of teeth on the elliptical gear. The

ratio of the two gear tooth numbers defines the relative angular velocities of the base and follower shafts. The default value is 102.

## Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

### Without Thermal Port

#### Friction model

List of friction models at various precision levels for estimating power losses due to meshing.

- **No meshing losses - Suitable for HIL simulation** — Neglect friction between gear cogs. Meshing is ideal.
- **Constant efficiency** — Reduce torque transfer by a constant efficiency factor. This factor falls in the range  $0 < \eta \leq 1$  and is independent of load. Selecting this option exposes additional parameters.

#### Constant efficiency

##### Efficiency

Torque transfer efficiency ( $\eta$ ) between base and follower shafts. This parameter is inversely proportional to the meshing power losses. Values can range from 0 to 1. The default value is 0.95.

##### Follower power threshold

Absolute value of the follower shaft power above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor from zero when at rest to the full efficiency value at the power threshold.

As a guideline, the power threshold should be lower than the expected power transmitted during simulation. Higher values might cause the block to underestimate efficiency losses. Very low values might, however, raise the computational cost of simulation. The default value is 0.001 W.

- **Load-dependent efficiency** — Reduce torque transfer by a variable efficiency factor. This factor falls in the range  $0 < \eta < 1$  and varies with the torque load. Selecting this option exposes additional parameters.

## Load-Dependent Efficiency

### Input shaft torque at no load

Net torque ( $\tau_{idle}$ ) acting on the input shaft in idle mode, e.g., when torque transfer to the output shaft equals zero. For nonzero values, the power input in idle mode completely dissipates due to meshing losses. The default value is 0.1 N\*m.

### Nominal output torque

Output torque ( $\tau_F$ ) at which to normalize the load-dependent efficiency. The default value is 5 N\*m.

### Efficiency at nominal output torque

Torque transfer efficiency ( $\eta$ ) at the nominal output torque. Efficiency values must fall in the interval [0, 1]. Larger efficiency values correspond to greater torque transfer between the input and output shafts. The default value is 0.95.

### Follower angular velocity threshold

Absolute value of the follower shaft angular velocity above which the full efficiency factor is in effect ( $\omega_F$ ). Below this value, a hyperbolic tangent function smooths the efficiency factor to one, lowering the efficiency losses to zero when at rest.

As a guideline, the angular velocity threshold should be lower than the expected angular velocity during simulation. Higher values might cause the block to underestimate efficiency losses. Very low values might, however, raise the computational cost of simulation.

The default value is 0.01 rad/s.

## With Thermal Port

### Friction model

Choice of model for representing friction. The model can incorporate the temperature and load dependences of friction or just the temperature dependence. The default setting is `Temperature-dependent efficiency`.

### Temperature

Array of temperatures used to construct an efficiency lookup table. The array values must increase from left to right. The temperature array must be the same size as

the efficiency array in temperature-dependent models. It must be the same size as a single row of the efficiency matrix in temperature-and-load-dependent models. The default array is [280 300 320] K.

### **Load at elliptical gear**

Array of elliptical-gear loads used to construct a 2-D temperature-load-efficiency lookup table for temperature-and-load-dependent efficiency models. The array values must increase from left to right. The load array must be the same size as a single column of the efficiency matrix. The default array is [1 5 10] N\*m.

### **Efficiency**

Array of efficiencies used to construct a 1-D temperature-efficiency lookup table for temperature-dependent efficiency models. The array elements are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size.

This parameter appears only when you select a temperature-dependent friction model. The default array is [0.95 0.9 0.85].

### **Efficiency matrix**

Matrix of component efficiencies used to construct a 2-D temperature-load-efficiency lookup table. The matrix elements are the efficiencies at the temperatures in the **Temperature** array and at the loads in the **Load at elliptical gear** array.

The number of rows must be the same as the number of elements in the **Temperature** array. The number of columns must be the same as the number of elements in the **Load at elliptical gear** array.

This parameter appears only when you select a temperature-and-load-dependent efficiency model. The default matrix is [ 0.85 0.8 0.75; 0.95 0.9 0.85; 0.85 0.8 0.7 ].

### **Follower power threshold**

Visible only if you select **Temperature-dependent efficiency** as the friction model. Absolute value of the follower shaft power above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero when at rest and the value provided by the temperature-efficiency lookup table when at the power threshold. The default value is 0.001 W.

### **Follower angular velocity threshold**

Visible only if you select **Temperature and load-dependent efficiency** as the friction model. Absolute value of the follower shaft angular velocity above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function



smooths the efficiency factor to one, lowering the efficiency losses to zero when at rest. The default value is 0.01 rad/s.

## Viscous Losses

### Viscous friction coefficients at base (B) and follower (F)

Two-element array with the viscous friction coefficients in effect at the base and follower shafts. The default array, [0 0], corresponds to zero viscous losses.

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Ports

Port	Description
B	Conserving rotational port representing the base shaft
F	Conserving rotational port representing the follower shaft

## See Also

Cycloidal Drive | Simple Gear | Simple Gear with Variable Efficiency

## Leadscrew

Leadscrew gear set of threaded rotating screw and translating nut, with adjustable thread and friction losses

## Library

Gears/Rotational-Translational

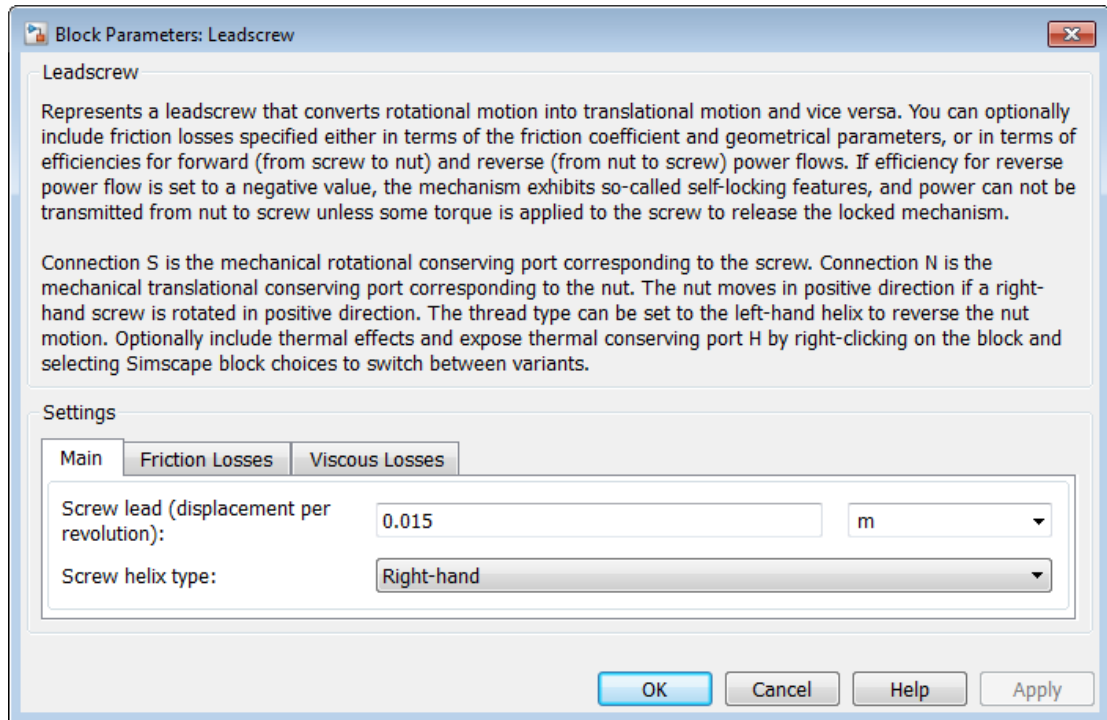


## Description

The Leadscrew block represents a threaded rotational-translational gear that constrains the two connected driveline axes, screw (S) and nut (N), to, respectively, rotate and translate together in a fixed ratio that you specify. You can choose whether the nut axis translates in a positive or negative direction, as the screw rotates in a positive right-handed direction. If the screw helix is right-handed,  $\omega_S$  and  $v_N$  have the same sign. If the screw helix is left-handed,  $\omega_S$  and  $v_N$  have opposite signs. For model details, see “Leadscrew Gear Model” on page 1-144.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Screw lead

Translational displacement  $L$  of the nut per revolution of the screw. The default is 0.015.

From the drop-down list, choose units. The default is meters (m).

#### Screw helix type

Choose the directional sense of screw rotation corresponding to positive nut translation. The default is **Right-hand**.

## Friction Losses

Parameters for friction losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

### Without Thermal Port

#### Friction model

Select how to implement friction losses from nonideal meshing of gear threads. The default is `No friction losses`.

- `No friction losses` – Suitable for HIL simulation — Gear meshing is ideal.
- `Constant efficiency` — Transfer of torque and force between screw and nut is reduced by friction. If you select this option, the panel expands.

#### Constant Efficiency

#### Friction parametrization

Select how to characterize the friction between gear threads. The default is `Friction coefficient and geometrical parameters`.

- `Friction coefficient and geometrical parameters` — Friction is determined by contact friction between surfaces.

#### Lead angle

Thread helix angle  $\lambda = \arctan[L/(\pi d)]$ .  $d$  is the mean thread diameter. Must be greater than zero. The default is `15`.

From the drop-down list, choose units. The default is degrees (`deg`).

#### Acme thread half angle

Half-angle of the acme thread  $\alpha$  in the normal plane. If a square thread is simulated,  $\alpha = 0$ . Must be greater than zero. The default is `14.5`.

From the drop-down list, choose units. The default is degrees (`deg`).

#### Friction coefficient

Dimensionless coefficient of kinetic friction in the thread. Must be greater than zero. The default is `0.08`.

- **Efficiencies** — Friction is determined by constant efficiencies  $0 < \eta < 1$ . If you select this option, the panel changes from its default.

### **Efficiencies**

#### **Screw-nut efficiency**

Efficiency  $\eta_{SN}$  of the power transfer from screw to nut.

#### **Nut-screw efficiency**

Efficiency  $\eta_{NS}$  of the power transfer from nut to screw.

### **Power threshold**

Power threshold above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function smooths the efficiency factor, lowering the efficiency losses to zero when no power is transmitted. The default value is 0.001 W.

## **With Thermal Port**

### **Temperature**

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase from left to right. The temperature array must be the same size as the **Efficiency** array. The default array is [280 300 320] K.

### **Screw-nut efficiency**

Array of component efficiencies with the screw as the driver—that is, with power flowing from the screw to the nut. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.75 0.7 0.65].

### **Nut-screw efficiency**

Array of component efficiencies with the nut as the driver—that is, with power flowing from the nut to the screw. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.5 0.45 0.4].

### **Power threshold**

Power threshold above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

## Viscous Losses

### Viscous friction coefficient

Viscous friction coefficient  $\mu_S$  for the screw. The default is 0.

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (rad/s)$ ).

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Leadscrew Gear Model

### Ideal Gear Constraint and Gear Ratio

Leadscrew imposes one kinematic constraint on the two connected axes:

$$\omega_S L = 2\pi v_N .$$

The transmission ratio is  $R_{NS} = 2\pi/L$ .  $L$  is the screw lead, the translational displacement of the nut for one turn of the screw. In terms of this ratio, the kinematic constraint is:

$$\omega_S = R_{NS} v_N .$$

The two degrees of freedom are reduced to one independent degree of freedom. The forward-transfer gear pair convention is (1,2) = (S,N).

The torque-force transfer is:

$$R_{NS} \tau_S + F_N - F_{\text{loss}} = 0 ,$$

with  $F_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraint and Losses

In the nonideal case,  $F_{\text{loss}} \neq 0$ . For general considerations on nonideal gear modeling, see “Model Gears with Losses”.

### Geometric Surface Contact Friction

In the contact friction case,  $\eta_{\text{SN}}$  and  $\eta_{\text{NS}}$  are determined by:

- The screw-nut threading geometry, specified by lead angle  $\lambda$  and acme thread half-angle  $a$ .
- The surface contact friction coefficient  $k$ .

$$\eta_{\text{SN}} = (\cos a - k \tan a) / (\cos a + k / \tan \lambda) ,$$

$$\eta_{\text{NS}} = (\cos a - k / \tan \lambda) / (\cos a + k \tan a) .$$

### Constant Efficiencies

In the constant efficiency case, you specify  $\eta_{\text{SN}}$  and  $\eta_{\text{NS}}$ , independently of geometric details.

### Self-Locking and Negative Efficiency

$\eta_{\text{NS}}$  has two distinct regimes, depending on lead angle  $\lambda$ , separated by the *self-locking point* at which  $\eta_{\text{NS}} = 0$  and  $\cos a = k / \tan \lambda$ .

- In the *overhauling regime*,  $\eta_{\text{NS}} > 0$ . The force acting on the nut can rotate the screw.
- In the *self-locking regime*,  $\eta_{\text{NS}} < 0$ . An external torque must be applied to the screw to release an otherwise locked mechanism. The more negative is  $\eta_{\text{NS}}$ , the larger the torque must be to release the mechanism.

$\eta_{\text{SN}}$  is conventionally positive.

## Meshing Efficiency

The efficiencies  $\eta$  of meshing between screw and nut are fully active only if the transmitted power is greater than the power threshold.

If the power is less than the threshold, the actual efficiency is automatically regularized to unity at zero velocity.

## Viscous Friction Force

The viscous friction coefficient  $\mu$  controls the viscous friction torque experienced by the screw from lubricated, nonideal gear threads. The viscous friction torque on a screw driveline axis is  $-\mu_S\omega_S$ .  $\omega_S$  is the angular velocity of the screw with respect to its mounting.

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
S	Rotational conserving port representing the screw
N	Translational conserving port representing the nut
H	Thermal conserving port for thermal modeling

## Example

The `sdl_stepping_mechanism` example model uses the Leadscrew gear to translate a load in one direction (ratcheting).

## See Also

Rack & Pinion

## Related Examples

- “Represent and Transfer Driveline Motion and Torque”



# Loaded-Contact Rotational Friction

Loaded-contact friction between two rotating bodies

## Library

Brakes & Detents/Rotational

## Description



The Loaded-Contact Rotational Friction block simulates friction between two rotating bodies loaded with a normal force.

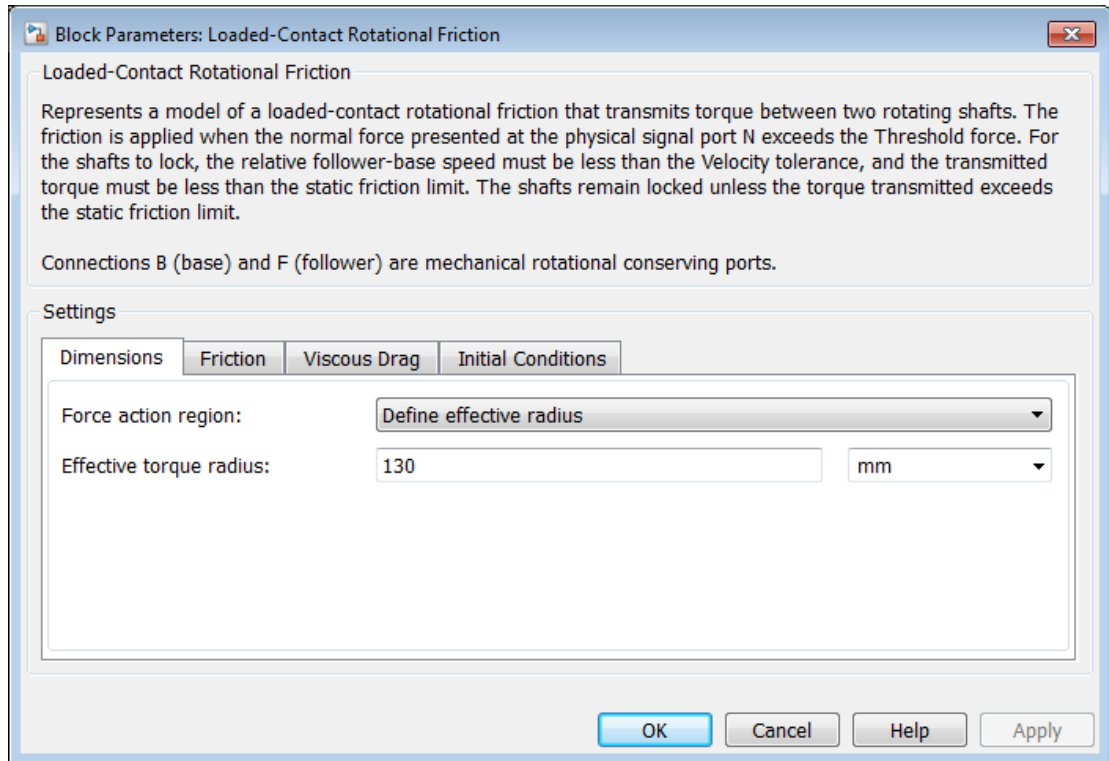
The block is implemented as a structural component based on the Fundamental Friction Clutch block. From the locked state, the clutch unlocks if the friction force exceeds the static friction, as defined by the static coefficient of friction and current normal force. For details on how the locking and unlocking are modeled, see the [Fundamental Friction Clutch](#) block reference page.

Friction torque is transmitted for normal forces larger than the **Threshold force** parameter.

## Ports

B and F are rotational conserving ports associated with the driving and driven shafts, respectively. N is the physical signal terminal through which you import the normal force.

## Dialog Box and Parameters



### Dimensions

#### Force action region

Select how to parameterize the loaded-contact friction. The default is **Define effective radius**.

- **Define effective radius** — Provide a value for the friction effective radius.

#### Effective torque radius

Effective radius  $r_{\text{eff}}$ . Must be greater than zero. The default is 130.

From the drop-down list, choose units. The default is millimeters (mm).

- **Define annular region** — Define the friction effective radius in terms of the inside and outside diameters of the friction disk. If you select this option, the panel changes from its default.

### **Define annular region**

#### **Friction disk outside diameter**

Outside diameter  $r_o$  of the friction disks. Must be greater than zero. The default is 150.

From the drop-down list, choose units. The default is millimeters (mm).

#### **Friction disk inside diameter**

Inside diameter  $r_i$  of the friction disks. Must be greater than zero, but less than the friction disk outside diameter. The default is 100.

From the drop-down list, choose units. The default is millimeters (mm).

## **Friction**

### **Friction model**

Select how to specify the kinetic friction coefficient. The default is **Fixed kinetic friction coefficient**.

- **Fixed kinetic friction coefficient** — Provide a fixed value for the kinetic friction coefficient.

#### **Kinetic friction coefficient**

The kinetic, or Coulomb, friction coefficient. Must be greater than zero. The default is 0.3.

- **Table lookup kinetic friction coefficient** — Define the kinetic friction coefficient by one-dimensional table lookup based on the relative angular velocity between disks. If you select this option, the panel changes from its default.

#### **Table lookup kinetic friction coefficient**

#### **Kinetic friction coefficient relative velocity vector**

Specify the vector of input values for the relative velocity. The input values vector must be strictly increasing. The values can be nonuniformly spaced.

The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values are [0 0.1 0.2 0.3 0.4 0.5 1 2 5 10 100 1000].

From the drop-down list, choose units. The default is radians/second (rad/s).

#### **Kinetic friction coefficient vector**

Specify the vector of output values for kinetic friction coefficient. The kinetic friction coefficient vector must be of the same size as the relative velocity vector. All the values must be positive. The default values are [0.29 0.28 0.26 0.22 0.21 0.2 0.2 0.19 0.19 0.19 0.19 0.19].

#### **Interpolation method**

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the [PS Lookup Table \(1D\)](#) block reference page.

#### **Extrapolation method**

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the [PS Lookup Table \(1D\)](#) block reference page.

#### **Static friction coefficient**

The static, or peak, value of the friction coefficient. Must be greater than the kinetic friction coefficient. The default is 0.35.

#### **Velocity tolerance**

Relative velocity below which the two surfaces can lock. For the surfaces to lock, the torque across the B and F rotational ports must be less than the product of the effective radius, the static friction coefficient, and the applied normal force. The default is 0.001.

From the drop-down list, choose units. The default is radians/second (rad/s).

### **Threshold force**

The normal force applied to the physical signal port N must exceed the **Threshold force** parameter value to be applied to the contact. Forces below the **Threshold force** are not applied, and there is consequently no transmitted frictional torque. The default is 1.

From the drop-down list, choose units. The default is newton (N).

## **Viscous Drag**

### **Viscous drag torque coefficient**

Viscous drag coefficient  $\mu_{\text{visc}}$  for computing the drag torque. The coefficient depends on the type of operating fluid, fluid temperature, and the maximum distance between the disks. The default is 0.

From the drop-down list, choose units. The default is newton-meters/(radians/second) (N\*m/ (rad/s)).

## **Initial Conditions**

### **Initial state**

Select the initial condition applied to the Fundamental Friction Clutch state inside the block:

- **Locked** — Rotational ports B and F are initially locked together. This is the default.
- **Unlocked** — Rotational ports B and F are initially sliding relative to each other.

## **Loaded-Contact Rotational Friction Model**

The block simulates friction between two rotating bodies loaded with a normal force. When the two rotating bodies are not locked, the friction torque is determined with the following equations:

$$\tau_{fr} = N \cdot \mu \cdot r_{eff} \cdot \text{sign}(\omega) + \tau_{visc} ,$$

$$r_{eff} = \frac{2}{3} \cdot \frac{r_o^3 - r_i^3}{r_o^2 - r_i^2} ,$$

$$\tau_{visc} = \mu_{visc} \cdot \omega ,$$

where:

$\tau_{fr}$	Friction torque
$N$	Normal force
$\mu$	Friction coefficient
$r_{eff}$	Effective radius
$r_o$	Disk outside radius
$r_i$	Disk inside radius
$\omega$	Relative angular velocity
$\tau_{visc}$	Viscous drag torque
$\mu_{visc}$	Viscous drag torque coefficient

## Limitations

- The model does not account for inertia. Add inertia terms externally to the B and F ports as required.
- The model computes the torque assuming a uniform distribution of the normal force.

## See Also

Fundamental Friction Clutch | Loaded-Contact Translational Friction

## Related Examples

- “Control Gear Couplings with Clutches”

# Loaded-Contact Translational Friction

Loaded-contact friction between two sliding bodies

## Library

Brakes & Detents/Translational

## Description



The Loaded-Contact Translational Friction block simulates friction between two sliding bodies loaded with a normal force.

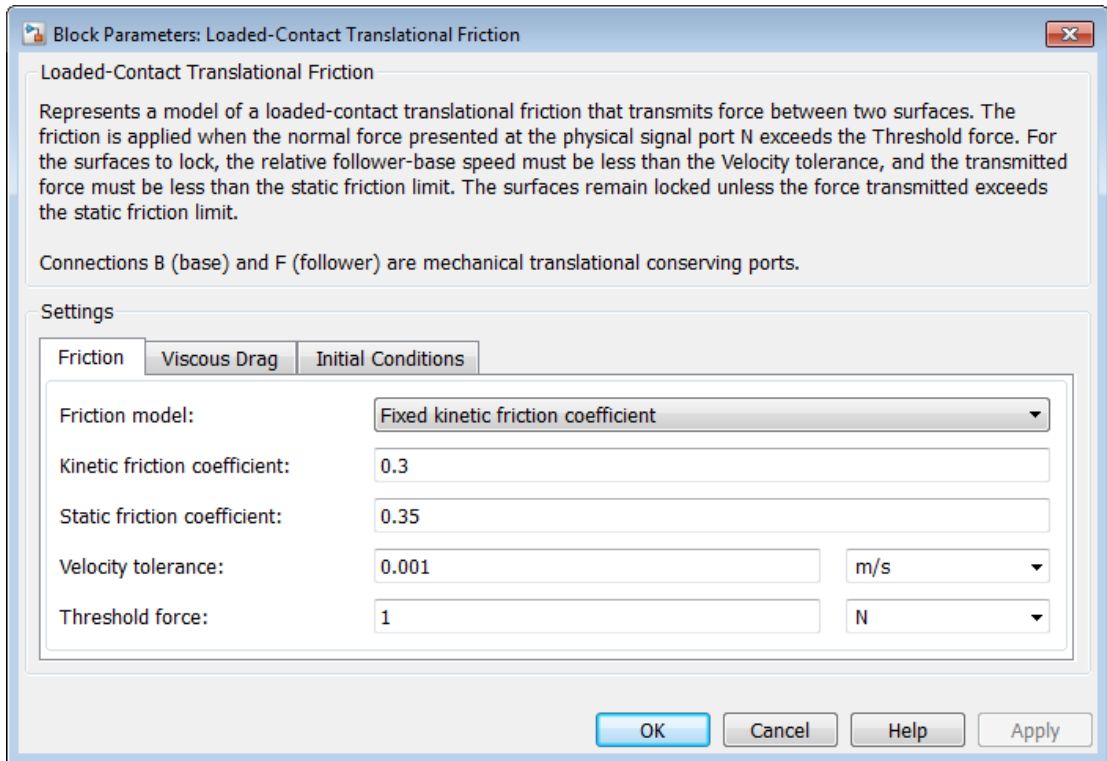
The block is implemented as a structural component based on the Fundamental Friction Clutch block. From the locked state, the clutch unlocks if the friction force exceeds the static friction, as defined by the static coefficient of friction and current normal force. For details on how the locking and unlocking are modeled, see the [Fundamental Friction Clutch](#) block reference page.

Friction force is transmitted for normal forces larger than the **Threshold force** parameter.

## Ports

B and F are translational conserving ports associated with the base and follower, respectively. N is the physical signal terminal through which you import the normal force.

## Dialog Box and Parameters



## Friction

### Friction model

Select how to specify the kinetic friction coefficient. The default is **Fixed kinetic friction coefficient**.

- **Fixed kinetic friction coefficient** — Provide a fixed value for the kinetic friction coefficient.

### Kinetic friction coefficient

The kinetic, or Coulomb, friction coefficient. Must be greater than zero. The default is 0.3.



- **Table lookup kinetic friction coefficient** — Define the kinetic friction coefficient by one-dimensional table lookup based on the relative angular velocity between disks. If you select this option, the panel changes from its default.

### **Table lookup kinetic friction coefficient**

#### **Kinetic friction coefficient relative velocity vector**

Specify the vector of input values for the relative velocity. The input values vector must be strictly increasing. The values can be nonuniformly spaced. The minimum number of values depends on the interpolation method: you must provide at least two values for linear interpolation, at least three values for smooth interpolation. The default values are [0 0.1 0.2 0.3 0.4 0.5 1 2 5].

From the drop-down list, choose units. The default is meters/second (m/s).

#### **Kinetic friction coefficient vector**

Specify the vector of output values for kinetic friction coefficient. The kinetic friction coefficient vector must be of the same size as the relative velocity vector. All the values must be positive. The default values are [0.29 0.28 0.26 0.22 0.21 0.2 0.2 0.19 0.19 0.19 0.19 0.19].

#### **Interpolation method**

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the [PS Lookup Table \(1D\) block reference page](#).

#### **Extrapolation method**

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.

- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the **PS Lookup Table (1D)** block reference page.

### **Static friction coefficient**

The static, or peak, value of the friction coefficient. Must be greater than the kinetic friction coefficient. The default is **0.35**.

### **Velocity tolerance**

Relative velocity below which the two surfaces can lock. For the surfaces to lock, the force across the B and F translational ports must be less than the product of the static friction coefficient and the applied normal force. The default is **0.001**.

From the drop-down list, choose units. The default is meters/second (m/s).

### **Threshold force**

The normal force applied to the physical signal port N must exceed the **Threshold force** parameter value to be applied to the contact. Forces below the **Threshold force** are not applied, and there is consequently no transmitted frictional torque. The default is **1**.

From the drop-down list, choose units. The default is newton (N).

## **Viscous Drag**

### **Viscous drag force coefficient**

Viscous drag coefficient  $\mu_{\text{visc}}$  for computing the drag force. The coefficient depends on the type of operating fluid, fluid temperature, and the maximum distance between the sliding bodies. The default is **0**.

From the drop-down list, choose units. The default is newton/(meters/second) (N/ (m/s)).

## **Initial Conditions**

### **Initial state**

Select the initial condition applied to the Fundamental Friction Clutch state inside the block:

- **Locked** — Translational ports B and F are initially locked together. This is the default.
- **Unlocked** — Translational ports B and F are initially sliding relative to each other.

## Loaded-Contact Translational Friction Model

The block simulates friction between two sliding bodies loaded with a normal force. When the two sliding bodies are not locked, the friction force is determined with the following equations:

$$F_{fr} = N \cdot \mu \cdot \text{sign}(v_{rel}) + F_{visc} ,$$

$$F_{visc} = \mu_{visc} \cdot v_{rel} ,$$

where:

$F_{fr}$	Friction force
$N$	Normal force
$\mu$	Friction coefficient
$v_{rel}$	Relative velocity
$F_{visc}$	Viscous drag force
$\mu_{visc}$	Viscous drag force coefficient

## Limitations

- The model does not account for body mass. Add mass terms externally to the B and F ports as required.
- The model computes the friction force assuming a uniform distribution of the normal force.

## See Also

Fundamental Friction Clutch | Loaded-Contact Translational Friction

## Related Examples

- “Control Gear Couplings with Clutches”

# Nonlinear Rotational Damper

Rotational damper based on polynomial or lookup-table parameterizations

## Library

Couplings & Drives/Springs & Dampers



## Description

The block represents a nonlinear rotational damper. Polynomial and lookup-table parameterizations define the nonlinear relationship between damping torque and relative angular velocity. The damping torque can be symmetric or asymmetric about the zero velocity point. The block applies equal and opposite damping torques on the two rotational conserving ports.

The symmetric polynomial parameterization defines the damping torque for both positive and negative relative velocities according to the expression:

$$T = b_1\omega + \text{sign}(\omega) \cdot b_2\omega^2 + b_3\omega^3 + \text{sign}(\omega) \cdot b_4\omega^4 + b_5\omega^5,$$

where:

- $T$  — Damping torque
- $b_1, b_2, \dots, b_5$  — Damping coefficients
- $\omega$  — Relative angular velocity between ports R and C,  $\omega = \omega_R - \omega_C$
- $\omega_R$  — Absolute angular velocity associated with port R
- $\omega_C$  — Absolute angular velocity associated with port C

Using an odd polynomial ( $b_2, b_4 = 0$ ), eliminates the sign function from the polynomial expression, avoiding zero-crossings that slow down simulation.

The two-sided polynomial parameterization defines the damping torque for both positive and negative relative velocities according to the expression:

$$T = \begin{cases} b_{1p}\omega + b_{2p}\omega^2 + b_{3p}\omega^3 + b_{4p}\omega^4 + b_{5p}\omega^5, & \omega \geq 0 \\ b_{1n}\omega + b_{2n}\omega^2 + b_{3n}\omega^3 + b_{4n}\omega^4 + b_{5n}\omega^5, & \omega < 0 \end{cases},$$

where:

- $b_{1p}, b_{2p}, \dots, b_{5p}$  — Damping coefficients for positive relative velocities
- $b_{1n}, b_{2n}, \dots, b_{5n}$  — Damping coefficients for negative relative velocities

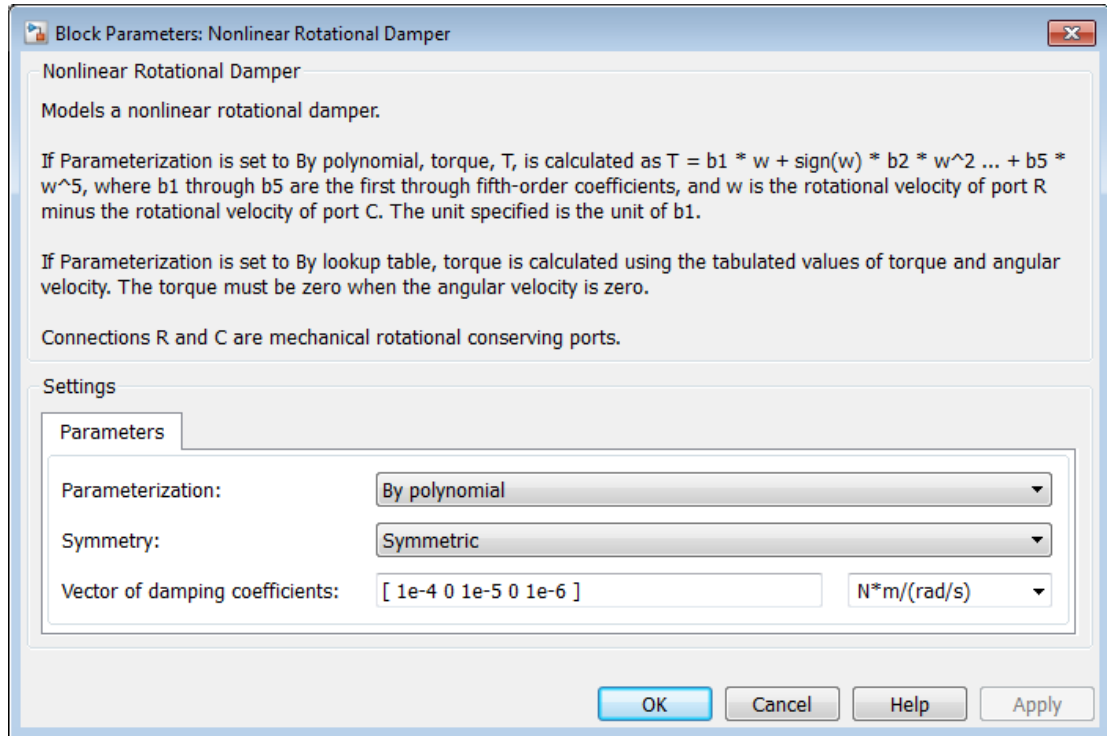
Both polynomial parameterizations use a fifth-order polynomial expression. To use a lower-order polynomial, set the unneeded higher-order coefficients to zero. To use a higher-order polynomial, fit to a lower order polynomial or use the lookup table parameterization.

The lookup table parameterization defines damping torque based on a set of torque and angular velocity vectors. If not specified, the block automatically adds a data point at the origin (zero angular velocity and zero torque).

## Assumptions and Limitations

- Damping is of the viscous type. It depends only on velocity.

## Dialog Box and Parameters



### Parameterization

Select damping parameterization. Options are By polynomial and By lookup table.

#### By polynomial

#### Symmetry

Choose between symmetric and two-sided polynomial parameterizations.

- **Symmetric** — Specify a single set of polynomial coefficients governing damping for both positive and negative relative velocities.

#### Vector of damping coefficients

Enter five-element vector with polynomial damping coefficients. Physical units are for the first coefficient.

The default vector is  $[1e-4 \ 0 \ 1e-5 \ 0 \ 1e-6]$ . The default unit is  $N*m/(rad/s)$ .

- **Two-sided** — Specify two sets of polynomial coefficients governing damping, one for positive relative velocities, the other for negative relative velocities.

#### **Vector of positive rotation damping coefficients**

Enter five-element vector with polynomial damping coefficients for positive relative velocities. Physical units are for the first coefficient.

The default vector is  $[1e-4 \ 0 \ 1e-5 \ 0 \ 1e-6]$ . The default unit is  $N*m/(rad/s)$ .

#### **Vector of negative rotation damping coefficients**

Enter five-element vector with polynomial damping coefficients for negative relative velocities. Physical units are for the first coefficient.

The default vector is  $[0.001 \ -1e-5 \ 1e-4 \ 0 \ 0]$ .

### **By lookup table**

#### **Angular velocity vector**

Enter vector with relative velocity values. The vector requires a minimum number of elements, based on the selected interpolation method — two for **Linear**, and three for **Smooth**. The number of elements must match the torque vector.

The default vector is  $[-1 \ -0.5 \ -0.3 \ -0.1 \ 0.1 \ 0.3 \ 0.5 \ 1]$ . The default unit is  $rad/s$ .

#### **Torque vector**

Enter vector with damping torque values corresponding to velocity vector. The vector requires a minimum number of elements, based on the selected interpolation method — two for **Linear**, three for **Smooth**. The number of elements must match the velocity vector.

The default vector is  $[-0.001 \ -4e-4 \ -2e-4 \ -5e-5 \ 5e-5 \ 2e-4 \ 4e-4 \ 0.001]$ . The unit is  $N*m$ .

### **Interpolation Method**

Select method used to find velocity–torque values between specified data points.

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the **PS Lookup Table (1D)** block reference page.

### **Extrapolation Method**

Select method used to calculate values outside the lookup-table data range.

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the **PS Lookup Table (1D)** block reference page.

## **Ports**

<b>Port</b>	<b>Description</b>
C	Rotational conserving port
R	Rotational conserving port

### **See Also**

Variable Rotational Damper | Nonlinear Translational damper | Variable Translational Damper



# Nonlinear Rotational Spring

Torsional spring based on polynomial or lookup table parameterizations

## Library

Couplings & Drives/Springs & Dampers



## Description

The block represents a torsional spring with nonlinear torque-displacement curve. The spring torque magnitude is a general function of displacement. It need not satisfy Hooke's law. Polynomial and lookup-table parameterizations provide two ways to specify the torque-displacement relationship. The spring torque can be symmetric or asymmetric with respect to zero deformation.

The symmetric polynomial parameterization defines spring torque according to the expression:

$$T = k_1 \theta + \text{sign}(\theta) \cdot k_2 \theta^2 + k_3 \theta^3 + \text{sign}(\theta) \cdot k_4 \theta^4 + k_5 \theta^5,$$

where:

- $T$  — Spring force
- $k_1, k_2, \dots, k_5$  — Spring coefficients
- $\theta$  — Relative displacement between ports R and C,  $\theta = \theta_{\text{init}} + \theta_R - \theta_C$
- $\theta_{\text{init}}$  — Initial spring deformation
- $\theta_R$  — Absolute angular position of port R
- $\theta_C$  — Absolute angular position of port C

At simulation start ( $t=0$ ),  $\theta_R$  and  $\theta_C$  are zero, making  $\theta$  equal to  $\theta_{\text{init}}$ .

Specifying an odd polynomial ( $b_2, b_4 = 0$ ) eliminates the sign function from the polynomial expression. This avoids zero-crossings that slow down simulation.

The two-sided polynomial parameterization defines spring torque according to the expression:

$$T = \begin{cases} k_{1t}\theta + k_{2t}\theta^2 + k_{3t}\theta^3 + k_{4t}\theta^4 + k_{5t}\theta^5, & \theta \geq 0 \\ k_{1c}\theta - k_{2c}\theta^2 + k_{3c}\theta^3 - k_{4c}\theta^4 + k_{5c}\theta^5, & \theta < 0 \end{cases},$$

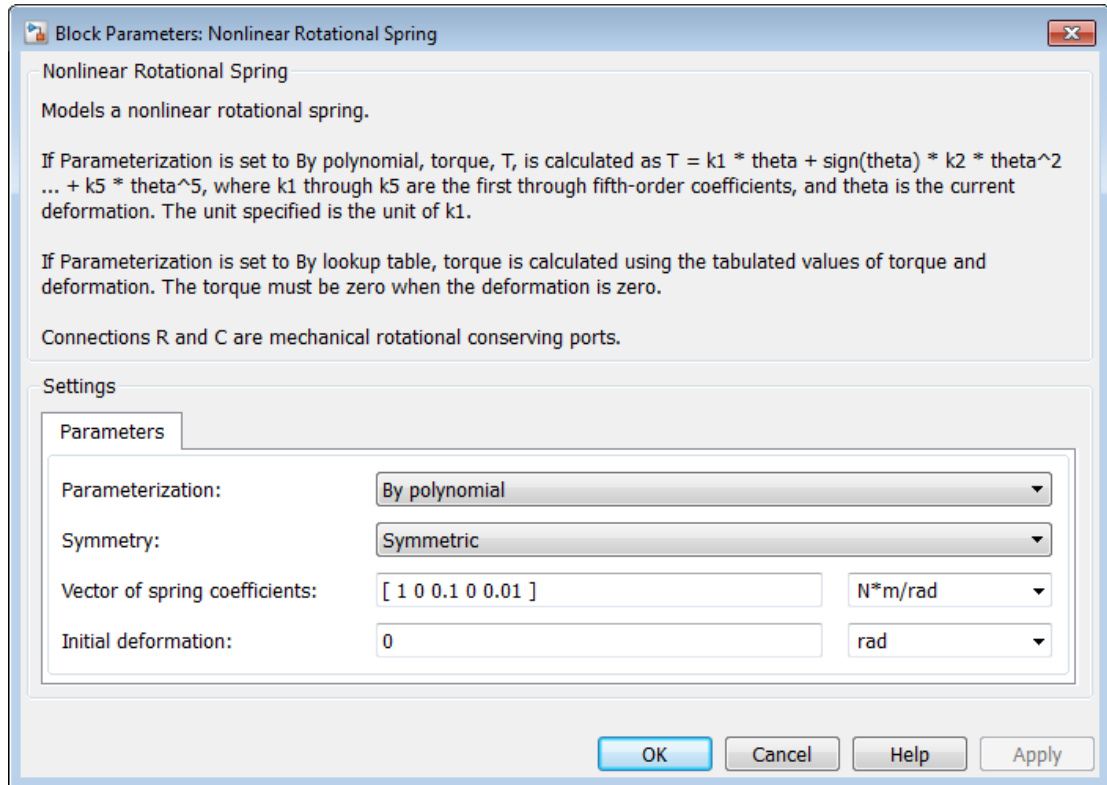
where:

- $k_{1t}, k_{2t}, \dots, k_{5t}$  — Spring tension coefficients
- $k_{1c}, k_{2c}, \dots, k_{5c}$  — Spring compression coefficients

Both polynomial parameterizations use a fifth-order polynomial expression. To use a lower-order polynomial, set the unneeded higher-order coefficients to zero. To use a higher-order polynomial, fit to a lower order polynomial or use the lookup table parameterization.

The lookup table parameterization defines spring torque based on a set of torque and angular velocity vectors. If not specified, the block automatically adds a data point at the origin (zero angular velocity and zero torque).

## Dialog Box and Parameters



### Parameterization

Select spring parameterization. Options are **By polynomial** and **By lookup table**.

#### By Polynomial

Specify nonlinear spring function in terms of polynomial coefficients.

#### Symmetry

Choose between symmetric and two-sided polynomial parameterizations.

- **Symmetric** — Specify one set of polynomial coefficients governing spring torque in both tension and compression.

### **Vector of spring coefficients**

Enter five-element vector with polynomial spring coefficients. The highest non-zero order must be positive. Physical units are for the first coefficient.

The default vector is [ 1 0 0.1 0 0.01 ]. The default unit is N\*m/rad.

- **Two-sided** — Specify two sets of polynomial coefficients governing spring torque, one for positive deformation, the other for negative deformation.

### **Vector of spring tension coefficients**

Enter a five-element vector containing the coefficients of the polynomial spring *tension* function. The highest order non-zero coefficient must be positive. The specified physical unit is the unit of the first polynomial coefficient.

### **Vector of spring compression coefficients**

Enter a five-element vector containing the coefficients of the polynomial spring *compression* function. The highest order non-zero coefficient must be positive. The specified physical unit is the unit of the first polynomial coefficient.

## **By lookup table**

### **Deformation vector**

Enter a vector containing the deformation values used in the lookup table. The vector must contain a minimum number of elements based on the interpolation method: two for **Linear**, and three for **Smooth**. The vector must also contain the same number of elements as the torque vector.

### **Torque vector**

Enter a vector containing the torque values that correspond to the deformation vector values. The vector must contain a minimum number of elements based on the interpolation method: two for **Linear**, and three for **Smooth**. The vector must also contain the same number of elements as the deformation vector. If not included in the vectors, the block automatically adds a point at the (0,0) deformation–torque coordinate.

### **Interpolation method**

Select method used to calculate deformation-torque values between lookup-table data points.

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the [PS Lookup Table \(1D\)](#) block reference page.

### Extrapolation method

Select method used to calculate deformation-torque values outside the lookup-table data range.

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the [PS Lookup Table \(1D\)](#) block reference page.

## Ports

Port	Description
C	Rotational conserving port
R	Rotational conserving port

### See Also

[Variable Rotational Spring](#) | [Nonlinear Translational Spring](#) | [Variable Translational Spring](#)

# Nonlinear Translational Damper

Translational damper based on polynomial or lookup table parameterizations

## Library

Couplings & Drives/Springs & Dampers



## Description

The block represents a nonlinear translational damper. Polynomial and lookup table parameterizations define the nonlinear relationship between damping force and relative linear velocity. The damping force can be symmetric or asymmetric about the zero velocity point. The block applies equal and opposite damping forces on the two translational conserving ports.

The symmetric polynomial parameterization defines the damping force for both positive and negative relative velocities according to the expression:

$$F = b_1 v + \text{sign}(v) \cdot b_2 v^2 + b_3 v^3 + \text{sign}(v) \cdot b_4 v^4 + b_5 v^5,$$

where:

- $F$  — Damping force
- $b_1, b_2, \dots, b_5$  — Damping coefficients
- $v$  — Relative linear velocity between ports R and C,  $v = v_R - v_C$
- $v_R$  — Absolute linear velocity associated with port R
- $v_C$  — Absolute linear velocity associated with port C

Using an odd polynomial ( $b_2, b_4 = 0$ ), eliminates the sign function from the polynomial expression, avoiding zero-crossings that slow down simulation.

The two-sided polynomial parameterization defines the damping force for both positive and negative relative velocities according to the expression:

$$F = \begin{cases} b_{1e}v + b_{2e}v^2 + b_{3e}v^3 + b_{4e}v^4 + b_{5e}v^5, & v \geq 0 \\ b_{1c}v - b_{2c}v^2 + b_{3c}v^3 - b_{4c}v^4 + b_{5c}v^5, & v < 0 \end{cases},$$

where:

- $b_{1e}, b_{2e}, \dots, b_{5e}$  — Damping coefficients for positive relative velocities
- $b_{1c}, b_{2c}, \dots, b_{5c}$  — Damping coefficients for negative relative velocities

Positive relative velocities correspond to damper extension (ports R and C moving away from each other). Negative relative velocities correspond to damper contraction (ports R and C moving towards each other).

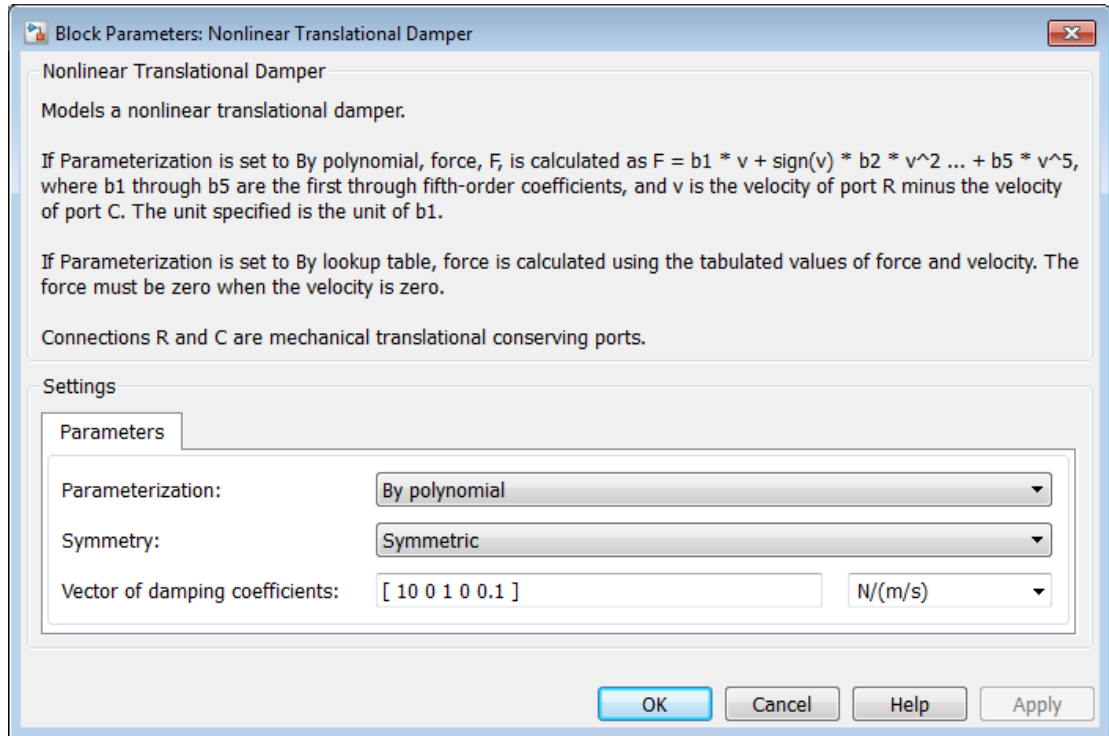
Both polynomial parameterizations use a fifth-order polynomial expression. To use a lower-order polynomial, set the unneeded higher-order coefficients to zero. For polynomials of order greater than five, fit to a polynomial of order smaller than or equal to five, or use the lookup table parameterization.

The lookup table parameterization defines damping force based on a set of velocity and force vectors. If not included in the vectors, the block automatically adds a data point at the origin (zero velocity and zero force).

## Assumptions and Limitations

- The block assumes viscous damping. The damping force depends only on velocity.

## Dialog Box and Parameters



### Parameterization

Select damping parameterization. Options are By polynomial and By lookup table.

#### By polynomial

Specify coefficients of polynomial damping function.

#### Symmetry

Choose between symmetric and two-sided polynomial parameterizations.

- **Symmetric** — Specify a single set of polynomial coefficients governing damping for both positive and negative relative velocities.

#### Vector of damping coefficients



Enter five-element vector with polynomial damping coefficients. Physical units are for the first coefficient.

The default vector is [ 10 0 1 0 0.1 ]. The default unit is N/ (m/s).

- **Two-sided** — Specify two sets of polynomial coefficients governing damping, one for positive relative velocities, the other for negative relative velocities.

#### **Vector of extension damping coefficients**

Enter five-element vector with polynomial damping coefficients for positive relative velocities. Physical units are for the first coefficient.

The default vector is [ 10 0 1 0 0.1 ]. The default unit is N/ (m/s).

#### **Vector of contraction damping coefficients**

Enter five-element vector with polynomial damping coefficients for negative relative velocities. Physical units are for the first coefficient.

The default vector is [ 10 0 1 0 0.1 ]. The default unit is N/ (m/s).

### **By lookup table**

#### **Velocity vector**

Enter vector with relative velocity values. The vector requires a minimum number of elements, based on the selected interpolation method — two for **Linear**, and three for **Smooth**. The number of elements must match the force vector.

The default vector is [ -1 -0.5 -0.3 -0.1 0.1 0.3 0.5 1 ]. The default unit is m/s.

#### **Force vector**

Enter vector with damping force values corresponding to velocity vector. The vector requires a minimum number of elements, based on the selected interpolation method — two for **Linear**, three for **Smooth**. The number of elements must match the velocity vector.

The default vector is [ -100 -40 -20 -5 5 20 40 100 ]. The default unit is N.

#### **Interpolation Method**

Select method used to find intermediate velocity–force values between lookup-table data points.

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the [PS Lookup Table \(1D\)](#) block reference page.

### **Extrapolation Method**

Select method used to calculate values outside the lookup-table data range.

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the [PS Lookup Table \(1D\)](#) block reference page.

## **Ports**

<b>Port</b>	<b>Description</b>
C	Rotational conserving port
R	Rotational conserving port

### **See Also**

[Variable Translational Damper](#) | [Nonlinear Rotational Damper](#) | [Variable Rotational Damper](#)

# Nonlinear Translational Spring

Translational spring based on polynomial or lookup table parameterizations

## Library

Couplings & Drives/Springs & Dampers



## Description

The block represents a translational spring with nonlinear force-displacement curve. The spring force magnitude is a general function of displacement. It need not satisfy Hooke's law. Polynomial and lookup-table parameterizations provide two ways to specify the force-displacement relationship. The spring force can be symmetric or asymmetric with respect to zero deformation.

The symmetric polynomial parameterization defines spring force according to the expression

$$F = k_1 x + \text{sign}(x) \cdot k_2 x^2 + k_3 x^3 + \text{sign}(x) \cdot k_4 x^4 + k_5 x^5,$$

where:

- $F$  — Spring force
- $k_1, k_2, \dots, k_5$  — Spring coefficients
- $x$  — Relative displacement between ports R and C,  $x = x_{init} + x_R - x_C$
- $x_{init}$  — Initial relative displacement
- $x_R$  — Absolute displacement associated with port R
- $x_C$  — Absolute displacement associated with port C

At simulation start ( $t=0$ ),  $x_R$  and  $x_C$  are zero, making  $x$  equal to  $x_{\text{init}}$ .

Specifying an odd polynomial ( $b_2, b_4 = 0$ ) eliminates the sign function from the polynomial expression. This avoids zero-crossings that slow down simulation.

The asymmetric polynomial parameterization defines spring force according to the expression:

$$F = \begin{cases} k_{1t}x + k_{2t}x^2 + k_{3t}x^3 + k_{4t}x^4 + k_{5t}x^5, & x \geq 0 \\ k_{1c}x + k_{2c}x^2 + k_{3c}x^3 + k_{4c}x^4 + k_{5c}x^5, & x < 0 \end{cases},$$

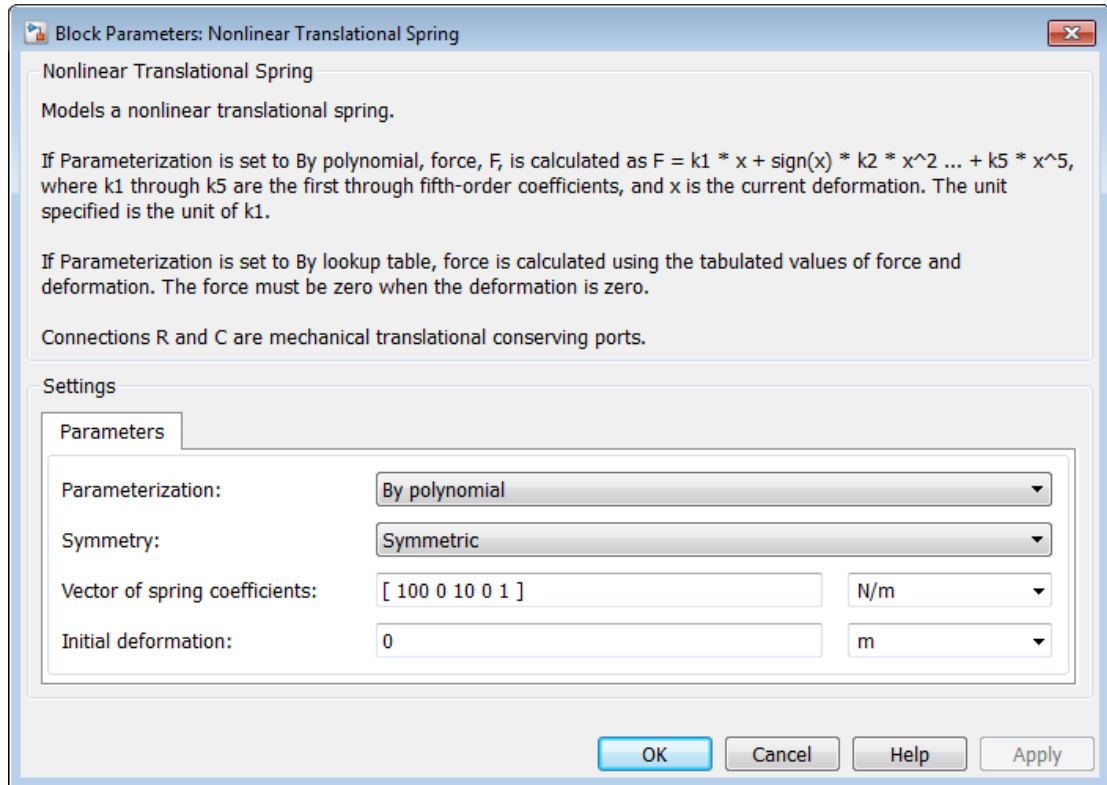
where:

- $k_1, k_2, \dots, k_5$  — Spring tension coefficients
- $k_1, k_2, \dots, k_5$  — Spring compression coefficients

Both polynomial parameterizations use a fifth-order polynomial expression. To use a lower-order polynomial, set the unneeded higher-order coefficients to zero. To use a higher-order polynomial, fit to a lower order polynomial or use the lookup table parameterization.

The lookup table parameterization defines damping torque based on a set of torque and angular velocity vectors. If not specified, the block automatically adds a data point at the origin (zero angular velocity and zero torque).

## Dialog Box and Parameters



### Parameterization

Select spring parameterization. Options are **By polynomial** and **By lookup table**.

#### **By polynomial**

Specify coefficients of polynomial spring function.

#### **Symmetry**

Choose between symmetric and two-sided polynomial parameterizations.

- **Symmetric** — Specify one set of polynomial coefficients governing spring force in both tension and compression.

### Vector of spring coefficients

Enter five-element vector with polynomial spring coefficients. The highest non-zero order must be positive. Physical units are for the first coefficient.

The default vector is [ 100 0 10 0 1 ]. The default unit is N/m.

- **Two-sided** — Specify two sets of polynomial coefficients governing spring force, one for positive relative displacements, the other for negative relative displacements.

### Vector of spring tension coefficients

Enter five-element vector with polynomial spring tension coefficients. Physical units are for the first coefficient.

The default vector is [ 100 0 10 0 1 ]. The default unit is N/m.

### Vector of spring compression coefficients

Enter five-element vector with polynomial spring compression coefficients. Physical units are for the first coefficient.

The default vector is [ 1000 -10 100 0 0 ]. The default unit is N/m.

## By lookup table

### Deformation vector

Enter vector with relative displacement values. the vector requires a minimum number of elements, based on the selected interpolation method — two for **Linear**, and three for **Smooth**. The number of elements must match the force vector. If not included in the vector, the block automatically adds a point at the origin, corresponding to zero displacement and zero force. If the vector includes a zero value, then the force vector must contain a corresponding zero value.

### Force vector

Enter a vector containing the force values that correspond to the deformation vector values. The vector must contain a minimum number of elements based on the interpolation method: two for **Linear**, and three for **Smooth**. The vector must also contain the same number of elements as the deformation vector. If not included in the vectors, the block automatically adds a point at the (0,0) deformation–force coordinate.

### Interpolation Method

Select method used to find intermediate velocity–force values between lookup-table data points.

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the **PS Lookup Table (1D)** block reference page.

### Extrapolation Method

Select method used to calculate values outside the lookup-table data range.

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the **PS Lookup Table (1D)** block reference page.

## Ports

Port	Description
C	Rotational conserving port
R	Rotational conserving port

### See Also

Variable Translational Spring | Nonlinear Rotational Spring | Variable Rotational Spring

# Piston

Piston mechanism of reciprocating combustion engine

## Library

Engines



## Description

This block represents the piston mechanism of a reciprocating combustion engine. The piston model accounts for the instantaneous torque transmitted to the engine crankshaft. The instantaneous torque enables you to model vibrations in the drivetrain due to piston revolution. To model a multipiston engine, use the **Piston Engine** block.

Port B represents the translating piston and port F the rotating crankshaft. The piston force follows from the cylinder pressure and cross-sectional area. The block obtains the combustion pressure from a lookup table parameterized in terms of the crank angle and, optionally, the crank angular velocity and engine throttle level.

The crank torque follows from the piston force and crank angle as well as the crank and connecting rod lengths. In terms of these inputs, the ratio of the piston force and crank torque is

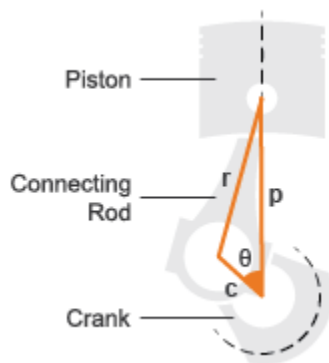
$$\frac{F_B}{T_F} = -c \left( \sin(\theta) + \frac{\sin(2\theta)}{2\sqrt{\frac{r}{c} - \sin^2(\theta)}} \right),$$

where:

- $F_B$  is the instantaneous piston force associated with the base port.



- $T_F$  is the instantaneous crank torque associated with the follower port.
- $c$  is the crank length.
- $\theta$  is the instantaneous crank angle.
- $r$  is the connecting rod length.



### Piston Dimensions

Physical signal port T lets you specify the engine throttle level as a fraction between 0 and 1. This fraction corresponds to the percentage of full power generated. The block uses the physical signal input whenever the pressure lookup table in the block dialog box is parameterized only in terms of the crank angle.

## Dialog Box and Parameters

**Block Parameters: Piston**

**Piston**

Represents a piston and cylinder in a combustion engine. Cylinder pressure resulting from combustion and the flow of gas is specified by table lookups as a function of crank angle, angular velocity, and throttle (T). The piston stroke and rod are used to convert the pressure on the piston to torque applied from the base (B) to the follower (F).

**Settings**

**Parameters**

Cylinder bore:	.10	m
Piston stroke:	.06	m
Piston rod length:	.1	m
Number of strokes per cycle:	4	
Pressure parameterization:	By crank angle	
Crank angle vector:	0.0, -90.0, -30.0, 10.0, 30.0, 90.0, 160.0, 360.0]	deg
Pressure vector (gauge):	[0.0, 3.0, 20.0, 50.0, 20.0, 10.0, 8.0, 0.0]	bar
Bearing viscous friction coefficient:	.001	N*m/(rad/s)
Offset angle:	0	deg
Initial crank angle:	90	deg

OK Cancel Help Apply

### Cylinder bore

Internal diameter of the engine cylinder that the piston travels in. The default value is 0.10 m.

### Piston stroke

Distance between the top dead center and bottom dead center piston positions. The default value is 0.06 m.

### Piston rod length

Length of the connecting rod located between the engine piston and the crankshaft. The default value is 0.10 m.

### **Number of strokes per cycle**

Number of strokes required to complete one engine cycle. One stroke corresponds to a full extension or retraction of the engine piston. A typical automobile engine is based on a four-stroke cycle with induction, compression, power, and exhaust stages. The default value is 4

### **Pressure parameterization**

Engine variables that the cylinder pressure depends on. Options include **By crank angle**, **By crank angle and throttle**, **By crank angle, throttle, and crank velocity**. The default setting is **By crank angle**.

### **Crank angle vector**

$M$ -element vector of crank angles at which to specify the cylinder pressure. A zero angle corresponds to a piston at top dead center. The vector must range from  $-S*180$  to  $+S*180$  degrees, where  $S$  is the number of strokes per cycle. The default vector is an eight-element vector ranging in value from -360 to +360 deg, corresponding to a four-stroke cycle.

### **Throttle vector**

$N$ -element vector of engine throttle settings at which to specify the cylinder pressure. A value of 0 corresponds to no throttle and a value of 1 to full throttle. This parameter is active only when **Pressure parameterization** is set to **By crank angle and throttle** and **By crank angle, throttle, and crank velocity**. The default vector is [0.0, 0.3, 0.8, 1.0].

### **Crank velocity vector**

$L$ -element vector of crankshaft angular velocities at which to specify the cylinder pressure. This parameter is active only when **Pressure parameterization** is set to **By crank angle, throttle, and crank velocity**. The default vector is [0.0, 1000.0, 6000.0] rpm.

### **Pressure vector**

$M$ -element vector of cylinder pressures corresponding to the crank angles specified in the **Crank angle vector** parameter. This parameter is active only when **Pressure parameterization** is set to **By crank angle**.

### **Pressure matrix (gauge)**

$M$ -by- $N$  matrix of cylinder pressures corresponding to the crank angles and throttle settings specified in the **Crank angle vector** and **Throttle vector** parameters.

This parameter is active only when **Pressure parameterization** is set to **By crank angle and throttle**. The default matrix is an 8-by-4 matrix ranging in value from 0 to 50 bar.

### **Pressure matrix 3D (gauge)**

*M*-by-*N*-by-*L* matrix of cylinder pressures corresponding to the crank angles, throttle settings, and crank angular velocity values specified in the **Crank angle vector**, **Throttle vector**, and **Crank velocity vector** parameters. This parameter is active only when **Pressure parameterization** is set to **By crank angle, throttle, and crank velocity**. The default matrix is an 8-by-4-by-3 matrix ranging in value from 0 to 50 bar.

### **Bearing viscous friction coefficient**

Aggregate viscous friction coefficient of the main and rod bearings. The block uses this parameter to compute the viscous power losses between the base and follower shafts. The default value is 0.001 N\*m/(rad/s).

### **Offset angle**

Point in the engine cycle when the piston reaches top dead center. The engine cycle spans in angle from  $-S*180$  to  $+S*180$  degrees, where *S* is the number of strokes per cycle. The default value is 0 deg, corresponding to a zero offset.

### **Initial crank angle**

Crank angle at time zero relative to a top dead center position. The default value is 90 deg.

## **Ports**

- B — Conserving rotational port representing the engine block
- F — Conserving rotational port representing the engine crankshaft
- T — Physical signal input port for specifying the engine throttle setting

## **See Also**

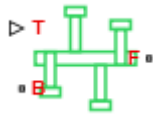
Generic Engine | Piston Engine

# Piston Engine

Reciprocating combustion engine with variable number of pistons

## Library

Engines



## Description

This block represents a reciprocating combustion engine with multiple cylinders. The piston model accounts for the instantaneous torque transmitted to the engine drive shaft. The instantaneous torque enables you to model vibrations in the drivetrain due to piston revolution. To model just the piston mechanism of a combustion engine, use the **Piston** block.

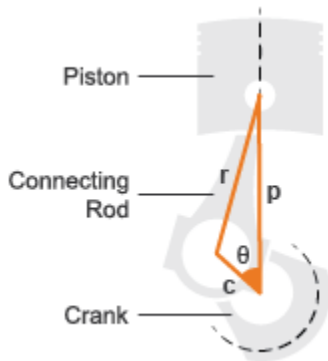
Port B represents the translating piston and port F the rotating crankshaft. The piston force follows from the cylinder pressure and cross-sectional area. The block obtains the combustion pressure from a lookup table parameterized in terms of the crank angle and, optionally, the crank angular velocity and engine throttle level.

The crank torque follows from the piston force and crank angle as well as the crank and connecting rod lengths. In terms of these inputs, the ratio of the piston force and crank torque is

$$\frac{F_B}{T_F} = -c \left( \sin(\theta) + \frac{\sin(2\theta)}{2\sqrt{\frac{r}{c} - \sin^2(\theta)}} \right),$$

where:

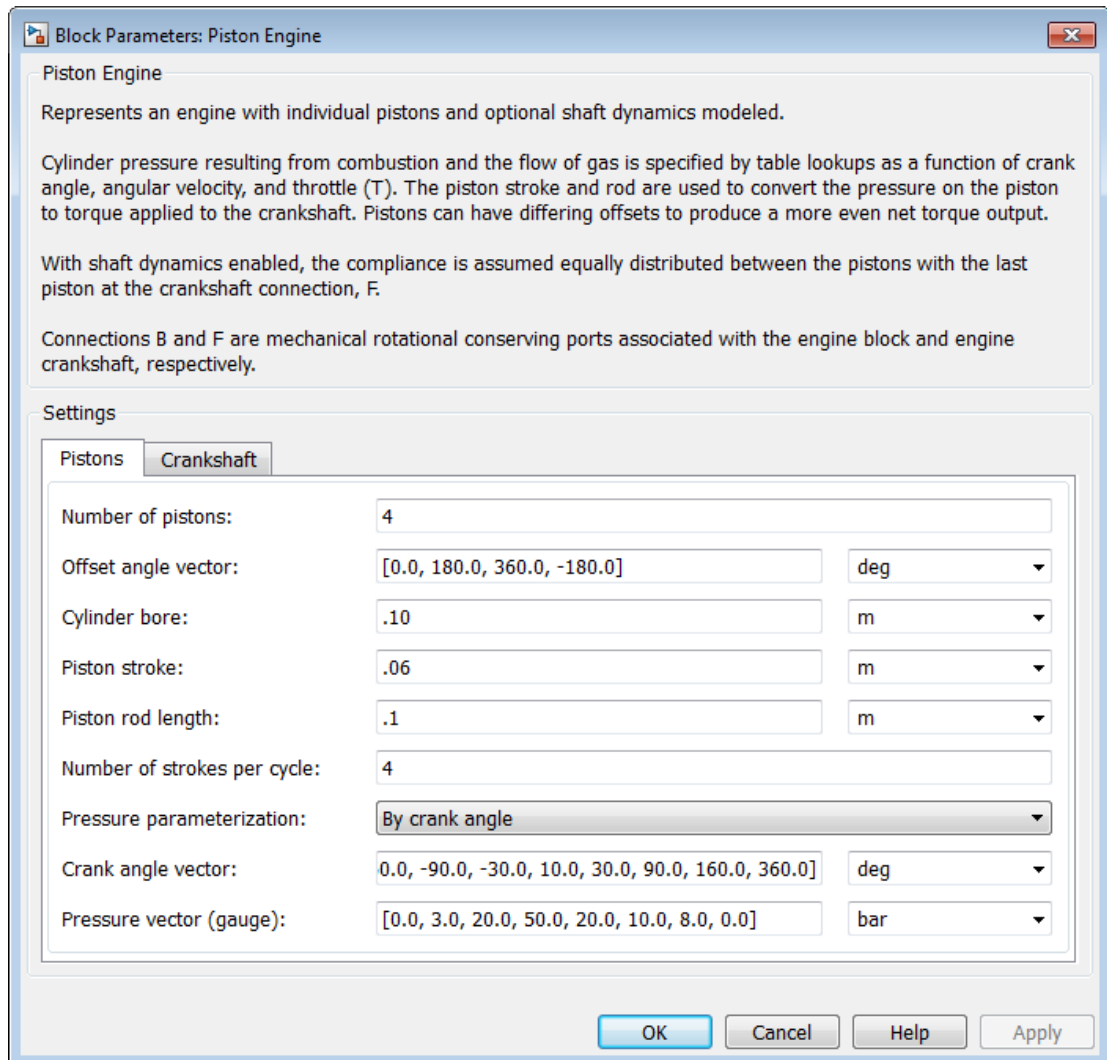
- $F_B$  is the instantaneous piston force associated with the base port.
- $T_F$  is the instantaneous crank torque associated with the follower port.
- $c$  is the crank length.
- $\theta$  is the instantaneous crank angle.
- $r$  is the connecting rod length.



### Piston Dimensions

Physical signal port T lets you specify the engine throttle level as a fraction between 0 and 1. This fraction corresponds to the percentage of full power generated. The block uses the physical signal input whenever the pressure lookup table in the block dialog box is parameterized only in terms of the crank angle.

## Dialog Box and Parameters



### Pistons

#### Number of pistons

Number of pistons in the combustion engine. The default number is 4.

**Offset angle vector**

Vector of piston offset angles. The offset angle specifies the point in the engine cycle when the piston reaches top dead center. The engine cycle spans in angle from  $-S*180$  to  $+S*180$  degrees, where  $S$  is the number of strokes per cycle.

The vector size must be the same as the number of pistons. The default vector is  $[0.0, 180.0, 360.0, -180.0]$ , corresponding to a four-stroke, four-piston engine.

**Cylinder bore**

Internal diameter of the engine cylinder that the piston travels in. The default value is 0.10 m.

**Piston stroke**

Distance between the top dead center and bottom dead center piston positions. The default value is 0.06 m.

**Piston rod length**

Length of the connecting rod located between the engine piston and the crankshaft. The default value is 0.10 m.

**Number of strokes per cycle**

Number of strokes required to complete one engine cycle. One stroke corresponds to a full extension or retraction of the engine piston. A typical automobile engine is based on a four-stroke cycle with induction, compression, power, and exhaust stages. The default value is 4

**Pressure parameterization**

Engine variables that the cylinder pressure depends on. Options include By crank angle, By crank angle and throttle, By crank angle, throttle, and crank velocity. The default setting is By crank angle.

**Crank angle vector**

$M$ -element vector of crank angles at which to specify the cylinder pressure. A zero angle corresponds to a piston at top dead center. The vector must range from  $-S*180$  to  $+S*180$  degrees, where  $S$  is the number of strokes per cycle. The default vector is an eight-element vector ranging in value from -360 to +360 deg, corresponding to a four-stroke cycle.

**Throttle vector**



$N$ -element vector of engine throttle settings at which to specify the cylinder pressure. A value of 0 corresponds to no throttle and a value of 1 to full throttle. This parameter is active only when **Pressure parameterization** is set to **By crank angle and throttle** and **By crank angle, throttle, and crank velocity**. The default vector is [0.0, 0.3, 0.8, 1.0].

### **Crank velocity vector**

$L$ -element vector of crankshaft angular velocities at which to specify the cylinder pressure. This parameter is active only when **Pressure parameterization** is set to **By crank angle, throttle, and crank velocity**. The default vector is [0.0, 1000.0, 6000.0] rpm.

### **Pressure vector**

$M$ -element vector of cylinder pressures corresponding to the crank angles specified in the **Crank angle vector** parameter. This parameter is active only when **Pressure parameterization** is set to **By crank angle**.

### **Pressure matrix (gauge)**

$M$ -by- $N$  matrix of cylinder pressures corresponding to the crank angles and throttle settings specified in the **Crank angle vector** and **Throttle vector** parameters. This parameter is active only when **Pressure parameterization** is set to **By crank angle and throttle**. The default matrix is an 8-by-4 matrix ranging in value from 0 to 50 bar.

### **Pressure matrix 3D (gauge)**

$M$ -by- $N$ -by- $L$  matrix of cylinder pressures corresponding to the crank angles, throttle settings, and crank angular velocity values specified in the **Crank angle vector**, **Throttle vector**, and **Crank velocity vector** parameters. This parameter is active only when **Pressure parameterization** is set to **By crank angle, throttle, and crank velocity**. The default matrix is an 8-by-4-by-3 matrix ranging in value from 0 to 50 bar.

## **Crankshaft**

### **Shaft dynamics**

Optional shaft dynamics parameters. Options include **No shaft dynamics** – Suitable for HIL simulation and **Specify shaft stiffness, damping, and inertia**

### **Stiffness**

Stiffness coefficient of the engine crankshaft. This parameter accounts for resistance to shaft deformation. This parameter is active only when the **Shaft dynamics**

parameter is set to **Specify shaft stiffness, damping, and inertia**. The default value is  $1e6 \text{ N}\cdot\text{m}/\text{rad}$ .

### **Damping**

Damping coefficients of the engine crankshaft. This parameter accounts for energy dissipation due to shaft deformation. This parameter is active only when the **Shaft dynamics** parameter is set to **Specify shaft stiffness, damping, and inertia**. The default value is  $1000 \text{ N}\cdot\text{m}/(\text{rad}/\text{s})$ .

### **Inertia**

Moment of inertia of the crankshaft about its rotational axis. This parameter accounts for resistance to sudden changes in motion. This parameter is active only when the **Shaft dynamics** parameter is set to **Specify shaft stiffness, damping, and inertia**. The default value is  $0.02 \text{ kg}\cdot\text{m}^2$ .

### **Initial angular deflection**

Deflection angle between the base and follower ends of the crankshaft at time zero. The deflection angle measures the angular deformation of the crankshaft due to torsion. This parameter is active only when the **Shaft dynamics** parameter is set to **Specify shaft stiffness, damping, and inertia**. The default value is  $0 \text{ deg}$ .

### **Initial angular velocity**

Angular velocity of the crankshaft at time zero. This parameter is active only when the **Shaft dynamics** parameter is set to **Specify shaft stiffness, damping, and inertia**. The default value is  $0 \text{ rpm}$ .

### **Base and follower bearing viscous friction coefficients**

Two-element vector with the viscous friction coefficients of the base and follower shaft bearings. The block uses viscous friction to account for energy losses between the base and follower shafts. The default vector is  $[0.0, 0.0] \text{ N}\cdot\text{m}/(\text{rad}/\text{s})$ , corresponding to zero damping.

### **Initial crank angle**

Crank angle at time zero relative to a top dead center position. The default value is  $90 \text{ deg}$ .

## **Ports**

- B — Conserving rotational port representing the engine block
- F — Conserving rotational port representing the engine crankshaft

- T — Physical signal input port for specifying the engine throttle setting

### **See Also**

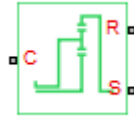
Generic Engine | Piston

# Planetary Gear

Gear train with sun, planet, and ring gears

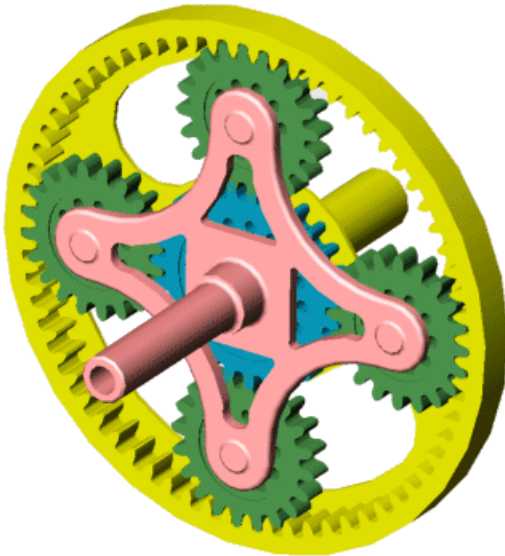
## Library

Gears

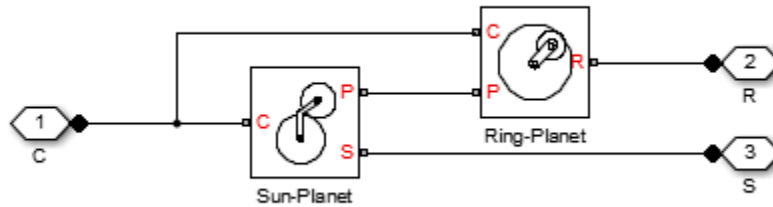


## Description

This block models a gear train with sun, planet, and ring gears. Planetary gears are common in transmission systems, where they provide high gear ratios in compact geometries. A carrier connected to a drive shaft holds the planet gears. Ports C, R, and S represent the shafts connected to the planet gear carrier, ring gear, and sun gear.



The block models the planetary gear as a structural component based on Sun-Planet and Ring-Planet Simscape Driveline blocks. The figure shows the block diagram of this structural component.

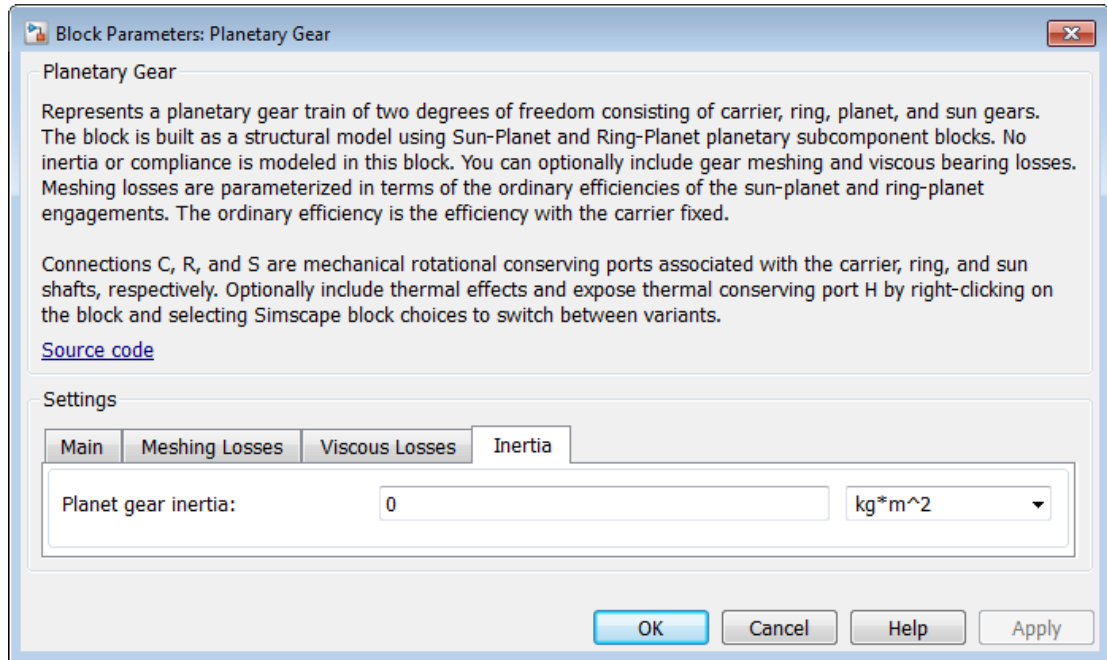


To increase the fidelity of the gear model, you can specify properties such as gear inertia, meshing losses, and viscous losses. By default, gear inertia and viscous losses are assumed negligible. The block enables you to specify the inertias of the internal planet gears only. To model the inertias of the carrier, sun, and ring gears, connect Simscape *Inertia* blocks to ports C, S, and R.

## Modeling Thermal Effects

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Ring (R) to sun (S) teeth ratio ( $N_R/N_S$ )

Ratio  $g_{RS}$  of the ring gear wheel radius to the sun gear wheel radius. This gear ratio must be strictly greater than 1. The default is 2.

### Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

#### Without Thermal Port

##### Friction model

Select how to implement friction losses from nonideal meshing of gear teeth. The default is **No meshing losses**.

- **No meshing losses** – Suitable for HIL simulation — Gear meshing is ideal.
- **Constant efficiency** — Transfer of torque between gear wheel pairs is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

### **Constant Efficiency**

#### **Sun-planet and ring-planet ordinary efficiencies**

Vector of torque transfer efficiencies  $[\eta_{SP} \ \eta_{RP}]$  for sun-planet and ring-planet gear wheel pair meshings, respectively.

#### **Sun-carrier and planet-carrier power thresholds**

Vector of power thresholds  $p_{th}$  above which full efficiency loss is applied, for sun-carrier and planet-carrier, respectively.

## **With Thermal Port**

### **Temperature**

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as each efficiency array. The default array is [280 300 320] K.

### **Sun-planet efficiency**

Array of mechanical efficiencies with power flowing from the sun gear to the planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.95 0.9 0.85].

### **Ring-planet efficiency**

Array of mechanical efficiencies with power flowing from the ring gear to the planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.95 0.9 0.85].

### **Sun-carrier and planet-carrier velocity thresholds**

Array of power thresholds above which the full efficiency factors apply. Enter the thresholds for the sun and planet gears relative to the gear carrier, in this order.

A hyperbolic tangent function smooths the efficiency factors between zero at rest and the values provided by the temperature-efficiency lookup tables at the power thresholds. The default array is [0.001 0.001] W.

## Viscous Losses

### Sun-carrier and planet-carrier viscous friction coefficients

Vector of viscous friction coefficients [ $\mu_S$   $\mu_P$ ] for the sun-carrier and planet-carrier gear motions, respectively. The default is [0 0].

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (rad/s)$ ).

## Inertia

### Planet gear inertia

Moment of inertia of the combined planet gears. This value must be positive or zero. Enter 0 to ignore gear inertia. The default value is  $0 \text{ kg} \cdot \text{m}^2$ .

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Planetary Gear Model

### Ideal Gear Constraints and Gear Ratios

Planetary Gear imposes two kinematic and two geometric constraints on the three connected axes and the fourth, internal gear (planet):



$$r_C \omega_C = r_S \omega_S + r_P \omega_P, \quad r_C = r_S + r_P,$$

$$r_R \omega_R = r_C \omega_C + r_P \omega_P, \quad r_R = r_C + r_P.$$

The ring-sun gear ratio  $g_{RS} = r_R/r_S = N_R/N_S$ .  $N$  is the number of teeth on each gear. In terms of this ratio, the key kinematic constraint is:

$$(1 + g_{RS})\omega_C = \omega_S + g_{RS}\omega_R.$$

The four degrees of freedom reduce to two independent degrees of freedom. The gear pairs are  $(1,2) = (S,P)$  and  $(P,R)$ .

---

**Warning** The gear ratio  $g_{RS}$  must be strictly greater than one.

---

The torque transfer is:

$$g_{RS} \tau_S + \tau_R - \tau_{\text{loss}} = 0,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraints and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . See “Model Gears with Losses”.

## Limitations

- Gears are assumed rigid.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
C	Rotational conserving port that represents the planet gear carrier
R	Rotational conserving port that represents the ring gear
S	Rotational conserving port that represents the sun gear
H	Thermal conserving port for thermal modeling

### **See Also**

Double-Pinion Planetary Gear | Compound Planetary Gear | Ravigneaux Gear

### **Related Examples**

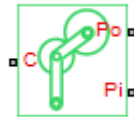
- “Represent and Transfer Driveline Motion and Torque”

# Planet-Planet

Planetary gear set of carrier, inner planet, and outer planet wheels with adjustable gear ratio and friction losses

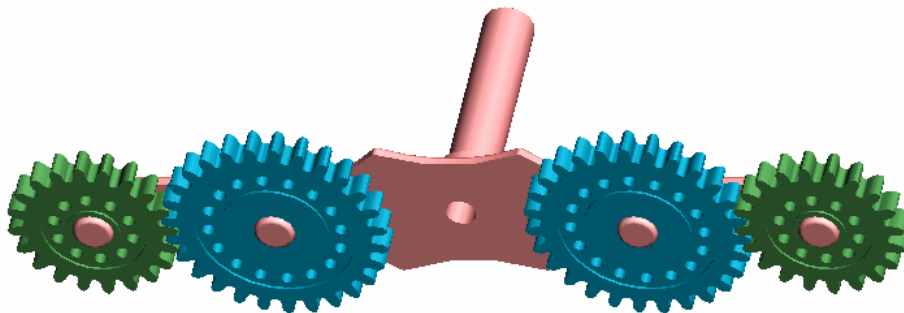
## Library

Gears/Planetary Subcomponents



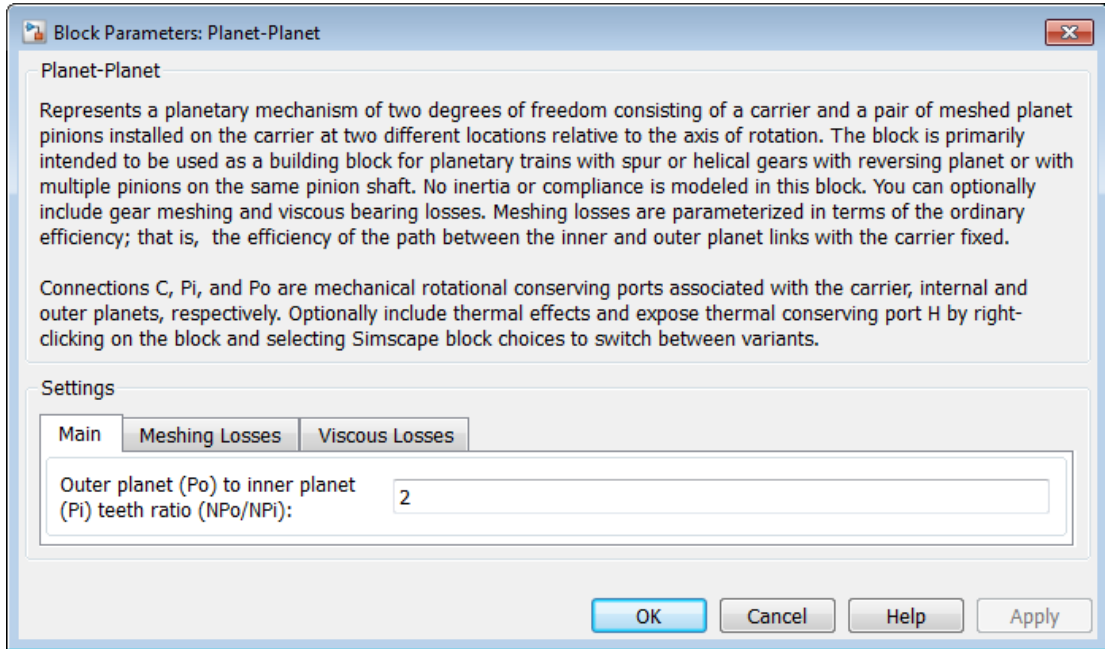
## Description

The Planet-Planet gear block represents a set of carrier, inner planet, and outer planet gear wheels. Both planetary gears are connected to and rotate with respect to the carrier. The planets corotate with a fixed gear ratio that you specify. For model details, see “Planet-Planet Gear Model” on page 1-200.



You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Outer planet (Po) to inner planet (Pi) teeth ratio (NPo/NPi)

Ratio  $g_{oi}$  of the outer planet gear radius wheel to the inner planet gear wheel radius. This gear ratio must be strictly positive. The default is 2.

### Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

#### Without Thermal Port

##### Friction model

Select how to implement friction losses from nonideal meshing of gear teeth. The default is **No meshing losses**.

- No meshing losses – Suitable for HIL simulation — Gear meshing is ideal.
- Constant efficiency — Transfer of torque between gear wheel pairs is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

### Constant Efficiency

#### Ordinary efficiency

Torque transfer efficiency  $\eta_{PP}$  for planet-planet gear wheel pair meshing.

#### Inner planet-carrier power threshold

Power threshold above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function smooths the efficiency factor, lowering the efficiency losses to zero when no power is transmitted. The default value is 0.001 W.

## With Thermal Port

### Temperature

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as the **Efficiency** array. The default array is [280 300 320] K.

### Efficiency

Array of component efficiencies used to construct a 1-D temperature-efficiency lookup table. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.95 0.9 0.85].

#### Inner planet-carrier power threshold

Power threshold above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

## Viscous Losses

### Inner planet-carrier viscous friction coefficient

Viscous friction coefficient  $\mu_{P1}$  for the inner planet-carrier gear motion. The default is 0.

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (\text{rad} / \text{s})$ ).

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Planet-Planet Gear Model

### Ideal Gear Constraints and Gear Ratios

Planet-Planet imposes one kinematic and one geometric constraint on the three connected axes:

$$r_C \omega_C = r_{P_0} \omega_{P_0} + r_{P_i} \omega_{P_i}, \quad r_C = r_{P_0} + r_{P_i}.$$

The outer planet-to-inner planet gear ratio  $g_{oi} = r_{P_0} / r_{P_i} = N_{P_0} / N_{P_i}$ .  $N$  is the number of teeth on each gear. In terms of this ratio, the key kinematic constraint is:

$$(1 + g_{oi}) \omega_C = \omega_{P_i} + g_{oi} \omega_{P_0}.$$

The three degrees of freedom reduce to two independent degrees of freedom. The gear pair is  $(1,2) = (P_i, P_0)$ .

The torque transfer is:

$$g_{oi} \tau_{P_i} + \tau_{P_0} - \tau_{\text{loss}} = 0,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

### Nonideal Gear Constraints and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . See “Model Gears with Losses”.

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
C	Rotational conserving port representing the planet carrier
Po	Rotational conserving port representing the outer planet gear
Pi	Rotational conserving port representing the inner planet gear
H	Thermal conserving port for thermal modeling

## See Also

Planetary Gear | Ravigneaux Gear | Ring-Planet | Sun-Planet | Sun-Planet Bevel

## Related Examples

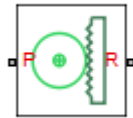
- “Represent and Transfer Driveline Motion and Torque”

## Rack & Pinion

Rack and pinion gear coupling translational and rotational motion, with adjustable pinion radius and friction losses

### Library

Gears/Rotational-Translational



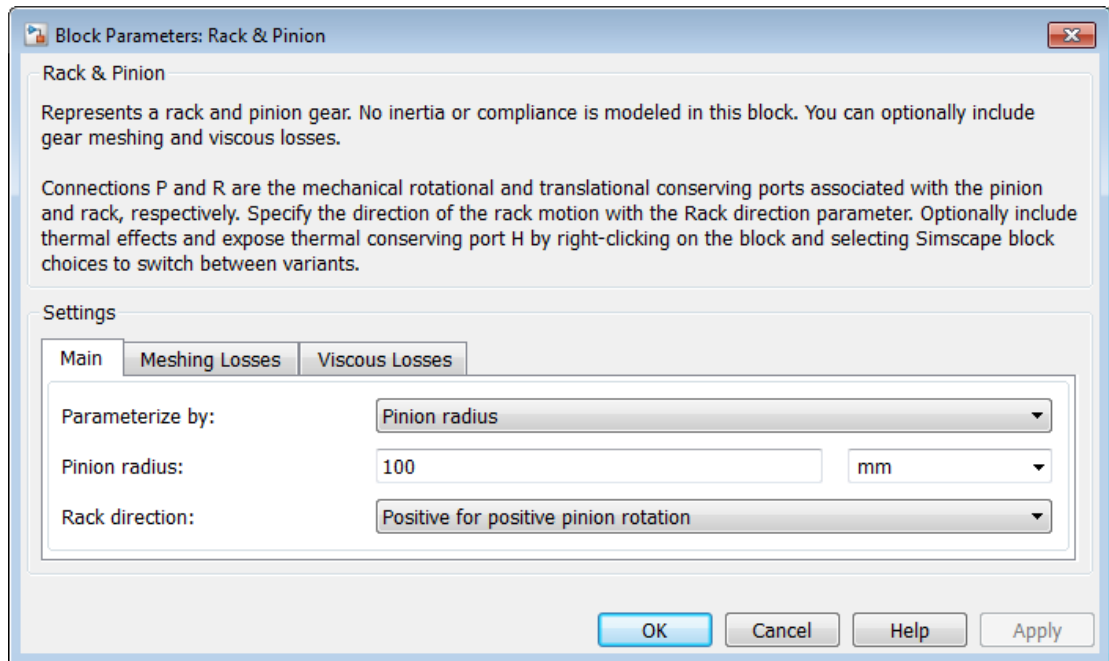
### Description

The Rack & Pinion block represents rack and pinion gear that converts between translational and rotational motion. The rotational-translational gear constrains the pinion (P) and rack (R) to, respectively, rotate and translate together in a fixed ratio that you specify. You can choose whether the rack axis translates in a positive or negative direction, as the pinion rotates in a positive direction, by using the **Rack direction** parameter.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.



## Dialog Box and Parameters



### Main

#### Parameterize by

Select how to parameterize the rack and pinion gear. The default is **Pinion radius**.

- **Pinion radius** — Gear ratio is defined by the effective radius of the pinion.

#### Pinion radius

Effective radius of the pinion  $r_p$ . Must be greater than zero. The default is 100.

From the drop-down list, choose units. The default is millimeters (mm).

- **Tooth parameters** — Gear ratio is defined by the number of teeth on the pinion gear and the rack tooth spacing. If you select this option, the panel changes from its default.

## **Tooth parameters**

### **Number of pinion teeth**

Number of teeth on the pinion  $N_p$ . Must be greater than zero. The default is 20.

### **Rack tooth spacing**

Spacing between the teeth on the rack  $x_R$ . Must be greater than zero. The default is 5.

From the drop-down list, choose units. The default is millimeters (mm).

### **Rack direction**

Choose whether the rack axis translates in a positive or negative direction when the pinion rotates in a positive direction. The default is **Positive for positive pinion rotation**.

## **Meshing Losses**

Parameters for meshing and friction losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

### **Without Thermal Port**

#### **Friction model**

Select how to implement friction losses from nonideal meshing of gear teeth. The default is **No meshing losses**.

- **No meshing losses** — Suitable for HIL simulation — Gear meshing is ideal.
- **Constant efficiency** — Transfer of torque and force between pinion and rack is reduced by constant efficiency  $0 < \eta \leq 1$ . If you select this option, the panel expands.

#### **Constant Efficiency**

##### **Efficiency**

Torque transfer efficiency  $\eta$  for the rack-pinion gear meshing, which is the same for the forward and reverse power flows. Must be greater than zero but less than, or equal to, one. The default is **0.8**.

**Rack power threshold**

Power threshold above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function smooths the efficiency factor, lowering the efficiency losses to zero when no power is transmitted. The default value is 0.001 W.

**With Thermal Port****Temperature**

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as the **Efficiency** array. The default array is [280 300 320] K.

**Efficiency**

Array of component efficiencies used to construct a 1-D temperature-efficiency lookup table. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.95 0.9 0.85].

**Rack power threshold**

Power threshold above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

**Viscous Losses****Pinion rotational viscous friction coefficient**

Viscous friction coefficient  $\mu_P$  for the pinion shaft. The default is 0.

From the drop-down list, choose units. The default is newton-meters/(radians/second) (N\*m/ (rad/s)).

**Rack translational viscous friction coefficient**

Viscous friction coefficient  $\mu_R$  for the rack motion. The default is 0.

From the drop-down list, choose units. The default is newton/(meters/second) (N/ (m/s)).

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Gear Model

### Model Variables

$R_{RP}$	Rack-pinion gear ratio
$\omega_P$	Angular velocity of the pinion shaft
$v_R$	Translational velocity of the rack
$r_P$	Effective radius of the pinion
$N_P$	Number of teeth on the pinion
$x_R$	Rack tooth spacing
$\tau_P$	Pinion shaft torque
$F_R$	Rack force
$F_{\text{loss}}$	Total loss force
$F_{\text{Coul}}$	Friction force
$\eta$	Torque transfer efficiency
$p_{\text{th}}$	Power threshold
$\mu_P$	Viscous friction coefficient for the pinion shaft
$\mu_R$	Viscous friction coefficient for the rack motion

## Ideal Gear Constraint and Gear Ratio

Rack & Pinion imposes one kinematic constraint on the two connected axes:

$$\omega_P = R_{RP} v_R .$$

The transmission ratio is:

$$R_{RP} = 1 / r_P = \omega_P / v_N = \pm 2r / N_P v_R .$$

The two degrees of freedom are reduced to one independent degree of freedom. The forward-transfer gear pair convention is (1,2) = (P,R).

The torque-force transfer is:

$$R_{RP} T_P + F_R - F_{\text{loss}} = 0 ,$$

with  $F_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraint

In the nonideal case,  $F_{\text{loss}} \neq 0$ . For general considerations on nonideal gear modeling, see “Model Gears with Losses”.

In a nonideal pinion-rack pair (P,R), the angular velocity and geometric constraints are unchanged. But the transferred torque, force, and power are reduced by:

- Coulomb friction between teeth surfaces on P and R, characterized by constant efficiency  $\eta$
- Viscous coupling of driveshafts with bearings, parametrized by viscous friction coefficients  $\mu$

## Meshing Efficiency

The efficiency  $\eta$  of meshing between pinion and rack is fully active only if the transmitted power is greater than the power threshold.

If the power is less than the threshold, the actual efficiency is automatically regularized to unity at zero velocity.

Efficiency is assumed equal for both the forward and reverse power flow.

## Viscous Friction Force

The viscous friction coefficients  $\mu_P$  and  $\mu_R$  control the viscous friction torque and force experienced by the rack and pinion from lubricated, nonideal bearings. The viscous friction torque on the pinion axis is  $-\mu_P\omega_P$ . The viscous friction force on the rack motion is  $-\mu_R v_R$ .

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
P	Rotational conserving port representing the pinion
R	Translational conserving port representing the rack
H	Thermal conserving port for modeling heat transfer

P is a rotational conserving port. R is a translational conserving port. They represent the pinion and the rack, respectively.

## See Also

Leadscrew | Simple Gear

## Related Examples

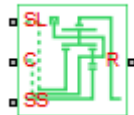
- “Represent and Transfer Driveline Motion and Torque”

# Ravigneaux Gear

Planetary gear with two sun gears and two planet gear sets

## Library

Gears

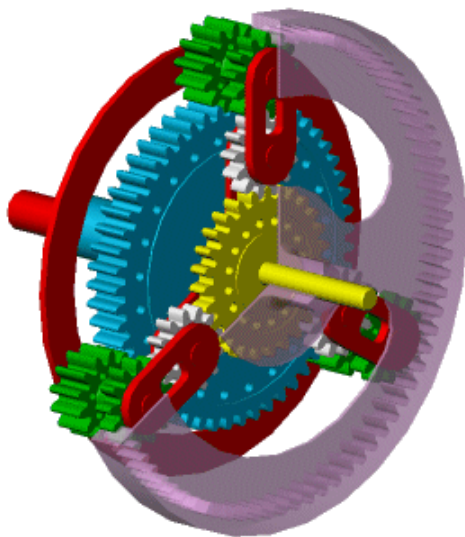


## Description

This block represents a planetary gear train with dual sun and planet gear sets. The two sun gears are centrally located and separated longitudinally along a common rotation axis. The smaller of these gears engages an inner planet gear set, which in turn engages an outer planet gear set. The outer planet gear set, whose length spans the distance between the two sun gears, engages both the larger sun gear and the ring gear.

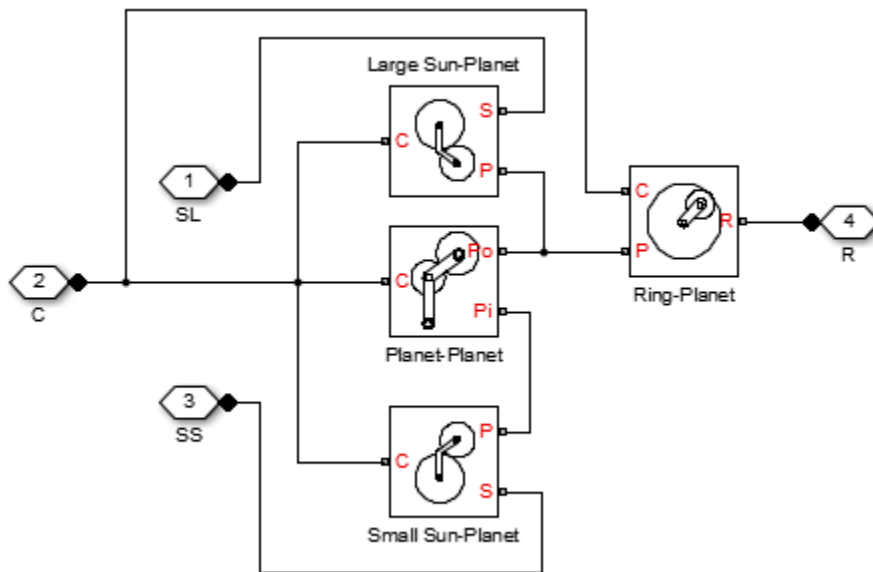
A carrier holds the planet gear sets in place at different radii. The carrier, which rigidly connects to a drive shaft, can spin as a unit with respect to the sun and ring gears. Revolute joints, each located between a planet gear and the carrier, enable the gears to spin about their individual longitudinal axes.

The relative angular velocities of the sun, planet, and ring gears follow from the kinematic constraints between them. For more information, see “Ravigneaux Gear Model” on page 1-215.



The block models the Ravigneaux gear as a structural component based on **Sun-Planet**, **Planet-Planet**, and **Ring-Planet** Simscape Driveline blocks. The figure shows the block diagram of this structural component.

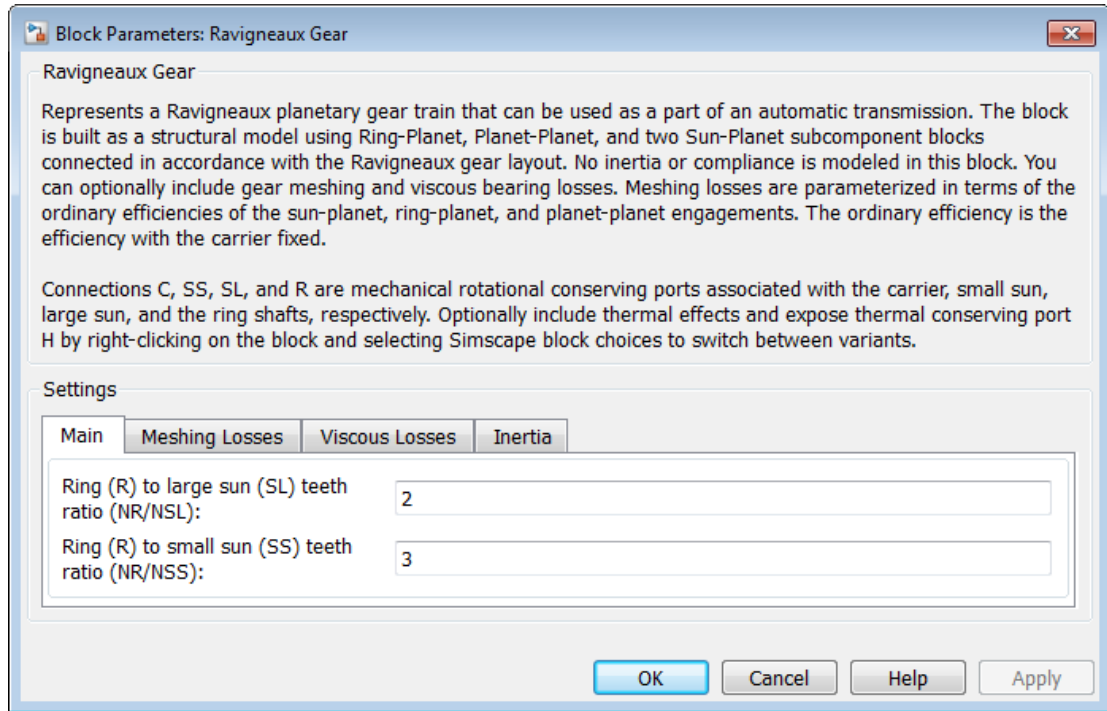




To increase the fidelity of the gear model, you can specify properties such as gear inertia, meshing losses, and viscous losses. By default, gear inertia and viscous losses are assumed negligible. The block enables you to specify the inertias of the internal planet gears only. To model the inertias of the carrier, large sun, small sun, and ring gears, connect Simscape *Inertia* blocks to ports C, SL, SS, and R.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Ring (R) to large sun (SL) teeth ratio (NR/NSL)

Ratio  $g_{RSL}$  of the ring gear wheel radius to the large sun gear wheel radius. This gear ratio must be strictly greater than 1. The default is 2.

#### Ring (R) to small sun (SS) teeth ratio (NR/NSS)

Ratio  $g_{RSS}$  of the ring gear wheel radius to the small sun gear wheel radius. This gear ratio must be strictly greater than the ring-large sun gear ratio. The default is 3.

### Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

## Without Thermal Port

### Friction model

Select how to implement friction losses from nonideal meshing of gear teeth. The default is No meshing losses.

- No meshing losses – Suitable for HIL simulation — Gear meshing is ideal.
- Constant efficiency — Transfer of torque between gear wheel pairs is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

### Constant Efficiency

#### Large sun-planet, small sun-planet, ring-planet, and planet-planet ordinary efficiencies

Vector of torque transfer efficiencies  $[\eta_{LSP} \eta_{SSP} \eta_{RP} \eta_{PP}]$  for large sun-planet, small sun-planet, ring-planet, and planet-planets gear wheel pair meshings, respectively.

#### Large sun-carrier, small sun-carrier, large sun planet-carrier, and small sun planet-carrier power thresholds

Vector of power thresholds  $p_{th}$  above which full efficiency loss is applied, for large sun-carrier, small sun-carrier, large sun planet-carrier, and small sun planet-carrier velocities, respectively. The default is  $[0.001 \ 0.001 \ 0.001 \ 0.001]$  W.

## With Thermal Port

### Temperature

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as each efficiency array. The default array is  $[280 \ 300 \ 320]$  K.

### Large sun-planet efficiency

Array of mechanical efficiencies with power flowing from the large sun gear to the large sun planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is  $[0.95 \ 0.9 \ 0.85]$ .

### Small sun-planet efficiency

Array of mechanical efficiencies with power flowing from the small sun gear to the small sun planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.95 0.9 0.85].

**Ring-planet efficiency**

Array of mechanical efficiencies with power flowing from the ring gear to the large sun planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.95 0.9 0.85].

**Planet-planet efficiency**

Array of mechanical efficiencies with power flowing from the small sun planet gears to the large sun planet gears. Each array value is the ratio of output power to input power at one of the temperatures in the temperature array. The temperature and efficiency arrays must be the same size. The default array is [0.95 0.9 0.85].

**Large sun-carrier, small sun-carrier, large sun planet-carrier and small sun planet-carrier power thresholds**

Array of power thresholds above which the full efficiency factors apply. Enter the thresholds for the large sun gear, small sun gear, large sun planet gears, and small sun planet gears, all relative to the gear carrier, in this order. A hyperbolic tangent function smooths the efficiency factors between zero at rest and the values provided by the temperature-efficiency lookup tables at the power thresholds. The default array is [0.001 0.001 0.001 0.001] W.

**Viscous Losses**

**Large sun-carrier, small sun-carrier, large sun planet-carrier, and small sun planet-carrier viscous friction coefficients**

Vector of viscous friction coefficients [ $\mu_{LS}$   $\mu_{SS}$   $\mu_{LSP}$   $\mu_{SSP}$ ] for the large sun-carrier, small sun-carrier, large sun planet-carrier, and small sun planet-carrier gear motions, respectively. The default is [0 0 0 0].

From the drop-down list, choose units. The default is newton-meters/(radians/second) (N\*m/ (rad/s)).

**Inertia**

**Inner planet gear inertia**

Moment of inertia of the planet gear carrier. This value must be positive or zero.  
Enter 0 to ignore carrier inertia. The default value is  $0 \text{ kg}\cdot\text{m}^2$ .

### Outer planet gear inertia

Moment of inertia of the combined planet gears. This value must be positive or zero.  
Enter 0 to ignore gear inertia. The default value is  $0 \text{ kg}\cdot\text{m}^2$ .

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree.  
The greater the thermal mass, the more resistant the component is to temperature change. The default value is  $50 \text{ J/K}$ .

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is  $300 \text{ K}$ .

# Ravigneaux Gear Model

## Ideal Gear Constraints and Gear Ratios

Ravigneaux imposes four kinematic and four geometric constraints on the four connected axes and the two internal wheels (inner and outer planets):

$$\begin{aligned} r_{Ci}\omega_C &= r_{SS}\omega_{SS} + r_{Pi}\omega_{Pi}, & r_{Ci} &= r_{SS} + r_{Pi}, \\ r_{Co}\omega_C &= r_{SL}\omega_{SL} + r_{Po}\omega_{Po}, & r_{Co} &= r_{SL} + r_{Po}, \\ (r_{Co} - r_{Ci})\omega_C &= r_{Pi}\omega_{Pi} + r_{Po}\omega_{Po}, & r_{Co} - r_{Ci} &= r_{Po} + r_{Pi}, \\ r_R\omega_R &= r_{Co}\omega_C + r_{Po}\omega_{Po}, & r_R &= r_{Co} + r_{Po}. \end{aligned}$$

The ring-small sun ratio  $g_{RSS} = r_R/r_{SS} = N_R/N_{SS}$  and ring-large sun gear ratio  $g_{RSL} = r_R/r_{SL} = N_R/N_{SL}$ .  $N$  is the number of teeth on each gear. In terms of these ratios, the key kinematic constraints are:

$$\begin{aligned} (g_{RSS} - 1)\omega_C &= g_{RSS}\omega_R - \omega_{SS}, \\ (g_{RSL} + 1)\omega_C &= g_{RSL}\omega_R + \omega_{SL}. \end{aligned}$$

The six degrees of freedom reduce to two independent degrees of freedom. The gear pairs are  $(1,2) = (LS,P)$ ,  $(SS,P)$ ,  $(P,R)$ , and  $(P,P)$ .

---

**Warning** The gear ratio  $g_{RSS}$  must be strictly greater than the gear ratio  $g_{RSL}$ . The gear ratio  $g_{RSL}$  must be strictly greater than one.

---

The torque transfers are:

$$g_{RSS}\tau_{SS} + \tau_R - \tau_{\text{loss}}(\text{SS},\text{R}) = 0, \quad g_{RSL}\tau_{SL} + \tau_R - \tau_{\text{loss}}(\text{SL},\text{R}) = 0,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraints and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . See “Model Gears with Losses”.

## Limitations

- Gears are assumed rigid.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Example

The `sdl_Ravigneaux_4_speed` example model uses a Ravigneaux gear as the core of its transmission.

## Ports

Port	Description
C	Rotational conserving port representing the planet gear carrier
R	Rotational conserving port representing the ring gear
SL	Rotational conserving port representing the large sun gear
SS	Rotational conserving port representing the small sun gear

---

Port	Description
H	Thermal conserving port for thermal modeling

### See Also

Compound Planetary Gear | Planet-Planet | Planetary Gear | Ring-Planet | Sun-Planet

### Related Examples

- “Represent and Transfer Driveline Motion and Torque”

## Ring-Planet

Planetary gear set of carrier, planet, and ring wheels with adjustable gear ratio and friction losses

### Library

Gears/Planetary Subcomponents



### Description

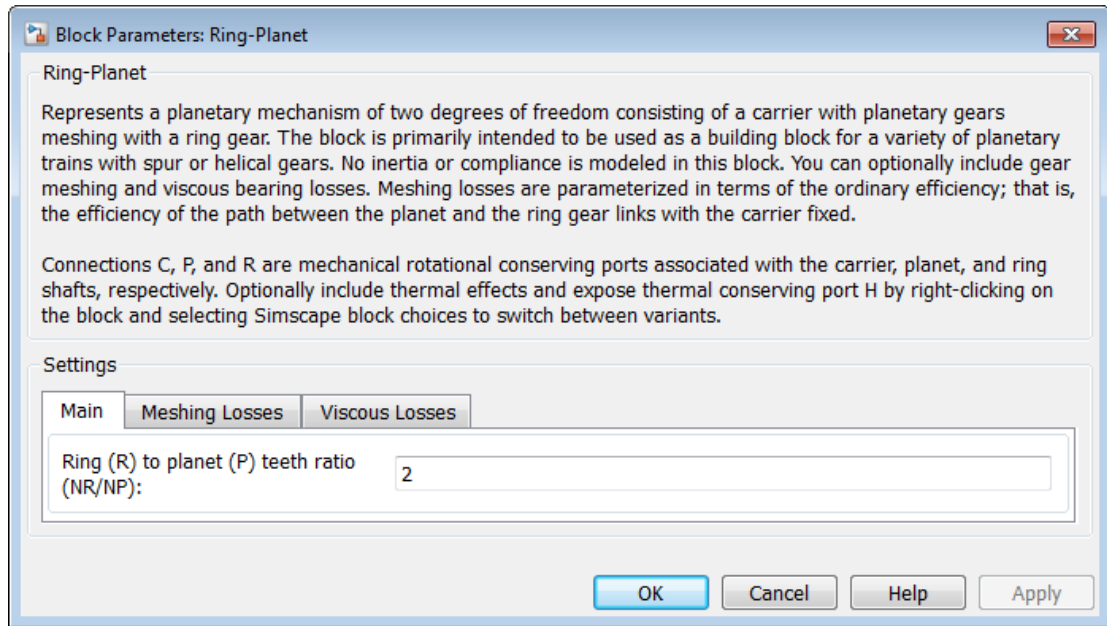
The Ring-Planet gear block represents a set of carrier, planet, and ring gear wheels. The planet is connected to and rotates with respect to the carrier. The planet and ring rotate with a fixed gear ratio that you specify. A ring-planet and a sun-planet gear are basic elements of a planetary gear set. For model details, see “Ring-Planet Gear Model” on page 1-222.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.





## Dialog Box and Parameters



### Main

#### Ring (R) to planet (P) teeth ratio (NR/NP)

Ratio  $g_{RP}$  of the ring gear wheel radius to the planet gear wheel radius. This gear ratio must be strictly greater than 1. The default value is 2.

### Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

#### Without Thermal Port

##### Friction model

Select how to implement friction losses from nonideal meshing of gear teeth. The default is **No meshing losses**.

- No meshing losses – Suitable for HIL simulation — Gear meshing is ideal.
- Constant efficiency — Transfer of torque between gear wheel pairs is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

### Constant Efficiency

#### Ordinary efficiency

Torque transfer efficiency  $\eta_{RP}$  for ring-planet gear wheel pair meshing.

#### Planet-carrier power threshold

Power threshold above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function smooths the efficiency factor, lowering the efficiency losses to zero when no power is transmitted. The default value is 0.001 W.

## With Thermal Port

### Temperature

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as the **Efficiency** array. The default array is [280 300 320] K.

### Efficiency

Array of component efficiencies used to construct a 1-D temperature-efficiency lookup table. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.95 0.9 0.85].

### Planet-carrier power threshold

Power threshold above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

## Viscous Losses

### Planet-carrier viscous friction coefficient

Viscous friction coefficient  $\mu_P$  for the planet-carrier gear motion. The default is 0.

From the drop-down list, choose units. The default is newton-meters/(radians/second) (N\*m/ (rad/s)).

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Ring-Planet Gear Model

### Ideal Gear Constraints and Gear Ratios

Ring-Planet imposes one kinematic and one geometric constraint on the three connected axes:

$$r_R\omega_R = r_C\omega_C + r_P\omega_P, \quad r_R = r_C + r_P.$$

The ring-planet gear ratio  $g_{RP} = r_R/r_P = N_R/N_P$ .  $N$  is the number of teeth on each gear. In terms of this ratio, the key kinematic constraint is:

$$g_{RP}\omega_R = \omega_P + (g_{RP} - 1)\omega_C.$$

The three degrees of freedom reduce to two independent degrees of freedom. The gear pair is (1,2) = (P,R).

---

**Warning** The ring-planet gear ratio  $g_{RP}$  must be strictly greater than one.

---

The torque transfer is:

$$g_{RP}\tau_P + \tau_R - \tau_{\text{loss}} = 0,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraints and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . See “Model Gears with Losses”.

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
C	Rotational conserving port representing the planet carrier
P	Rotational conserving port representing the planet gear
R	Rotational conserving port representing the ring gear
H	Thermal conserving port for thermal modeling

## Example

The `sdl_epicyclic_gearbox` example model uses two Ring-Planet gears to model a nonideal epicyclic gear set.

## See Also

Compound Planetary Gear | Planet-Planet | Planetary Gear | Sun-Planet | Sun-Planet Bevel

## Related Examples

- “Represent and Transfer Driveline Motion and Torque”

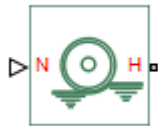
- “Adjust Model Fidelity”

# Rolling Resistance

Model rolling resistance

## Library

Tires & Vehicles/Tire Subcomponents



## Description

The block models the resistance force that acts on the wheel hub due to the rolling resistance at the road-wheel contact surface. The model can use a constant resistance coefficient or the pressure and velocity dependence of the SAE J2452 standard. The resistance force is zero when the normal force acting at the wheel-road surface is less than or equal to zero.

### Constant Resistance Coefficient Model

In the constant coefficient model, the rolling resistance is directly proportional to the resistance coefficient:

$$F = N\mu$$

where parameters represent the following quantities:

- $F$  — Rolling resistance force
- $N$  — Normal Force
- $\mu$  — Rolling resistance coefficient

The rolling resistance coefficient has a hyperbolic form that eliminates discontinuity at  $v_{\text{hub}}=0$ :

$$\mu = \mu_0 \tanh(4v_{\text{hub}}/v_{\text{threshold}})$$

where parameters represent the following quantities:

- $\mu_0$  — Asymptotic rolling resistance coefficient
- $v_{hub}$  — Hub velocity
- $v_{threshold}$  — Threshold velocity

## Pressure and Velocity Dependent Model

The pressure- and velocity-dependent model uses the following formula:

$$F = \left( \frac{P}{P_0} \right)^\alpha \left( \frac{N}{N_0} \right)^\beta N_0 \cdot (A + B|v_{hub}| + Cv_{hub}^2)$$

where parameters represent the following quantities:

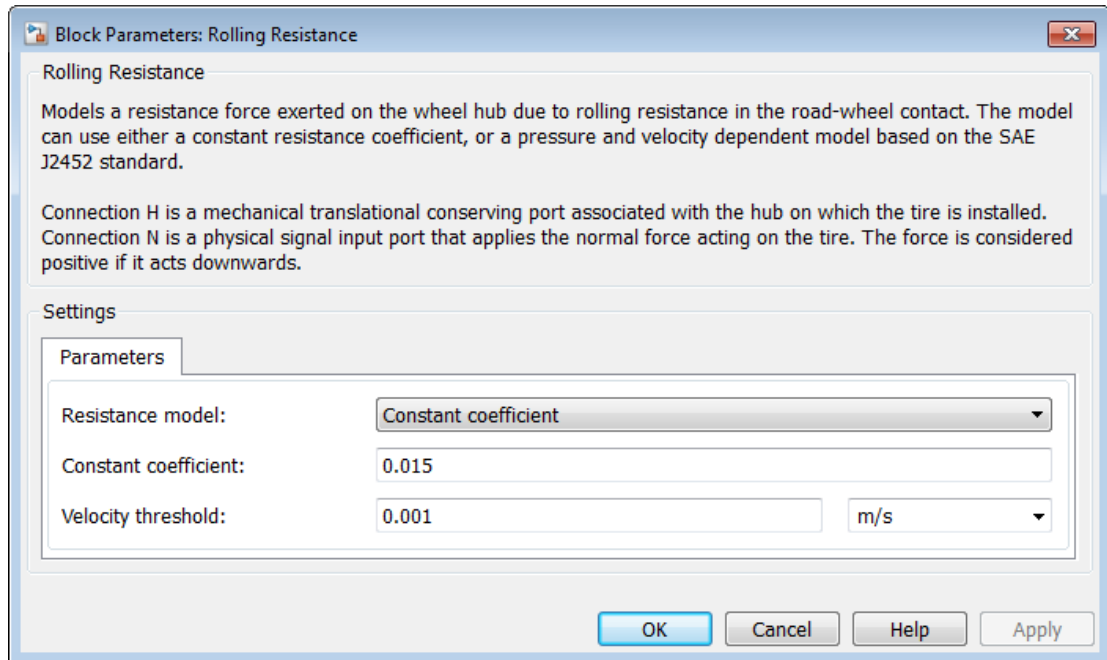
- $P$  — Tire pressure
- $v_{hub}$  — Hub velocity
- $\alpha, \beta, A, B, C$  — Approximating coefficients
- $P_0$  — 1 Pascal (Pa)
- $N_0$  — 1 Newton (N)

In the previous equation, parameters  $P_0$  and  $N_0$  remove the physical units from each exponential expression base.

Connection H is a mechanical translational conserving port that represents the hub of the tire. Connection N is a physical signal input port that represents the normal force acting on the tire. Normal force is positive if it points downward.



## Dialog Box and Parameters



### Resistance Model

Select the model used to compute the rolling resistance on a wheel hub. The parameter provides two options:

- Constant coefficient
- Pressure and velocity dependent

The default value is Constant coefficient.

### Constant Coefficient

Selecting the Constant coefficient option exposes two model parameters: **Constant coefficient** and **Velocity threshold**.

### **Constant Coefficient**

Coefficient that sets the proportionality between the normal force and the rolling resistance force. The parameter must be greater than zero. The default value is 255.

### **Velocity Threshold**

Velocity at which the full rolling resistance force is transmitted to the rolling hub. The parameter ensures the force remains continuous during velocity direction changes, which increases the numerical stability of the simulation. The parameter must be greater than zero. The default value is 0.001 m/s.

## **Pressure and Velocity Dependent**

### **Tire pressure**

Inflation pressure of the tire. The parameter must be greater than zero. The default value is 250e+3 Pa.

### **Alpha**

Exponent of the tire pressure in the model equation. See “Pressure and Velocity Dependent Model” on page 1-226. The default value is -0.003.

### **Beta**

Exponent of the normal force model equation. The default value is 0.97.

### **Coefficient A**

Velocity independent force component in the model equation. The parameter must be greater than zero. The default value is 84e-4.

### **Coefficient B**

Velocity dependent force component in the model equation. The parameter must be greater than zero. The default value is 6.2e-4 s/m.

### **Coefficient C**

Force component that depends on the square of the velocity term in the model equation. The parameter must be greater than zero. The default value is 1.6e-4 s<sup>2</sup>/m<sup>2</sup>.

### **Velocity Threshold**

Velocity at which the full rolling resistance force is transmitted to the rolling hub. The parameter ensures the force remains continuous during velocity direction changes, which increases the numerical stability of the simulation. The parameter must be greater than zero. The default value is 1e-3 m/s.

## Ports

Port	Description
N	Physical signal input port that represents the normal force
H	Conserving translational port that represents the wheel hub

## See Also

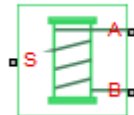
Tire-Road Interaction (Magic Formula) | Tire (Magic Formula) | Tire (Friction Parameterized)

## Rope Drum

Power transmission system with tightly wound rope around cylindrical drum

### Library

Couplings & Drives



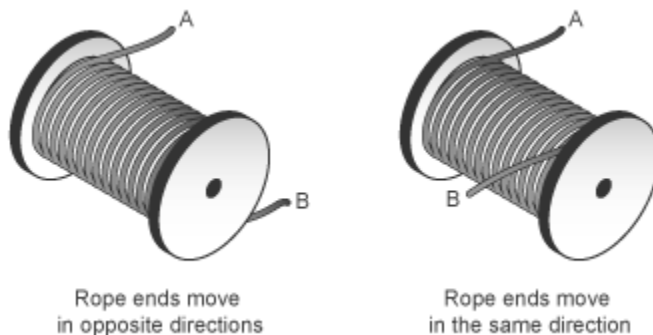
### Description

This block represents a power transmission system with two key components:

- Rope
- Drum

The rope is tightly wound around the cylindrical drum, at a sufficient tension level to prevent slipping between the two components. The rope can be wound such that its ends point in equal or opposite directions. Depending on the rope configuration, the two rope ends can move in equal or opposite directions. These are the rope windup types that you specify in the block dialog box:

- If the rope ends point in the same direction, they translate in opposite directions.
- If the rope ends point in opposite directions, they translate in the same direction.



During normal operation, a driving torque causes the cylindrical drum to rotate about its symmetry axis. The rotating drum transmits a tensile force to the rope ends, which translate with respect to the drum center line. The relative direction of translation between the two rope ends depends on the rope windup type. However, a positive drum rotation always corresponds to a positive translation at rope end A.

The rope drum model assumes that each rope end remains taut during simulation. This assumption is important since slack rope ends do not transmit force. An optional tension warning indicates if this assumption fails. The warning, which appears at the MATLAB command prompt, should prompt careful analysis of the simulation results.

Optional effects in the rope drum model include:

- Drum inertia
- Viscous friction at the drum bearing

The net torque acting on the cylinder satisfies the force balance equation

$$T = F_B \cdot R \cdot \delta - F_A \cdot R + \mu \cdot \omega,$$

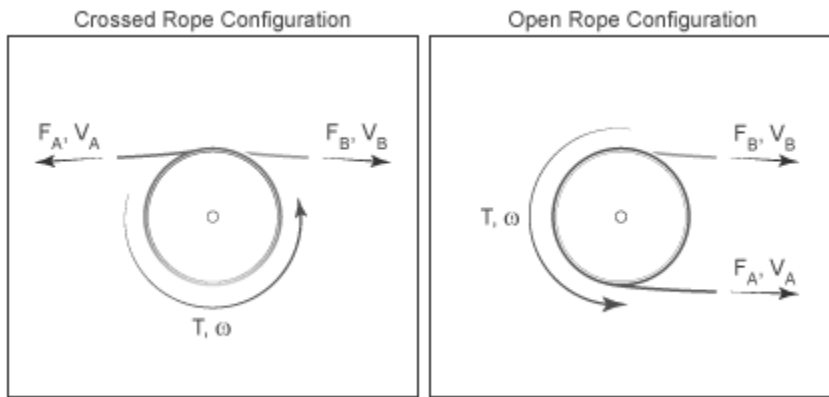
where:

- $T$  is the net torque acting on the drum.
- $F_A$  and  $F_B$  are the external forces pulling on rope ends A and B.
- $R$  is the drum radius.
- $\mu$  is the viscous friction coefficient at the drum bearings.

- $\omega$  is the drum angular velocity.
- $\delta$  is the rope windup type according to the table below.

Rope Windup Type	$\delta$
Ends move in the same direction	-1
Ends move in opposite directions	+1

The figure shows the equation variables.



The translational velocities of the two rope ends are functions of the drum radius and angular velocity. Each translational velocity is equal to the tangential velocity of a point at the drum periphery according to the expressions:

$$V_A = -\omega \cdot R,$$

$$V_B = +\omega \cdot R,$$

where:

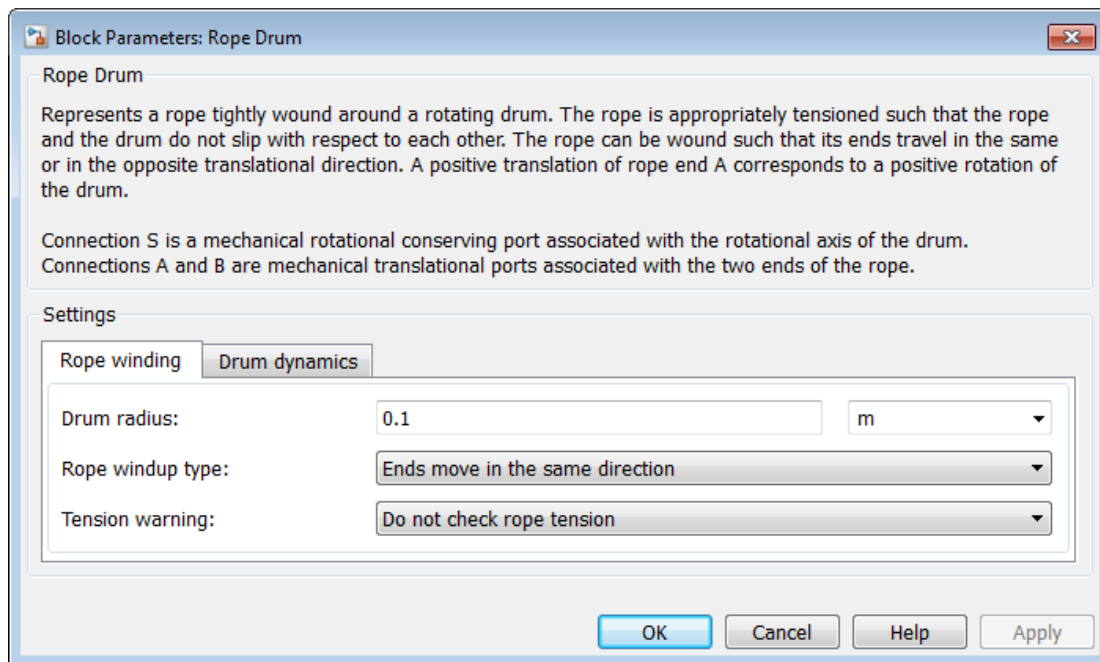
- $V_A$  is the translational velocity of rope end A.
- $V_B$  is the translational velocity of rope end B.

## Assumptions and Limitations

- Slip does not occur at the rope-drum contact surface.

- Rope compliance is ignored.

## Dialog Box and Parameters



## Rope Winding

### Drum radius

Distance between the drum center and its periphery. The drum periphery coincides with the contact surface between the drum and the rope. The default value is 0.1 m.

### Rope windup type

Relative direction of the translation motion of the two rope ends, A and B. Options include:

- The ends move in the same direction
- The ends move in opposite direction

**Tension warning**

Optional warning at the MATLAB command line indicating that at least one rope end has become slack. A rope end becomes slack when the net tensile forces responsible for keeping it taut fall below zero. Since slack cables do not transmit force, you must interpret simulation results carefully if a tension warning appears at the MATLAB command line. Warning options include:

- Do not check rope tension
- Warn if either rope end loses tension

**Drum Dynamics****Bearing viscous friction coefficient**

Linear damping coefficient in effect at the drum bearing. At a given drum angular velocity, this coefficient determines the power losses due to viscous friction. The default value is 0.001 (N\*m)/(rad/s).

**Inertia**

Optional parameter accounting for drum inertia, its resistance to angular acceleration. Options include:

- **No inertia** — Default mode. Keep this mode if drum inertia has a negligible impact on driveline dynamics. Selecting this mode sets drum inertia to zero.
- **Specify drum inertia and initial velocity** — Select this mode if drum inertia has a significant impact on driveline dynamics. Selecting this mode exposes additional parameters enabling you to specify the drum inertia and initial angular velocity.

**Drum inertia**

Moment of inertia of the drum about its rotation axis. In the simple case of a solid cylindrical drum, the moment of inertia is

$$I = \frac{1}{2}MR^2,$$

where  $M$  is the drum mass and  $R$  is the drum radius.

The default value of the drum inertia is 0.01 kg\*m<sup>2</sup>.

**Drum initial velocity**



Angular velocity of the drum at simulation time zero. The default value is 0 rad/s.

## Ports

Port	Description
S	Conserving rotational port associated with the drum shaft
A	Conserving translational port associated with rope end A
B	Conserving translational port associated with rope end B

## Example

Featured example `sdl_power_window` shows an application of the Rope Drum block.

## See Also

Wheel and Axle

## Related Examples

- “Basic Motion, Torque, and Force Modeling”

## Rotational Detent

Double-sided, spring-loaded rotational detent

### Library

Brakes & Detents/Rotational



### Description

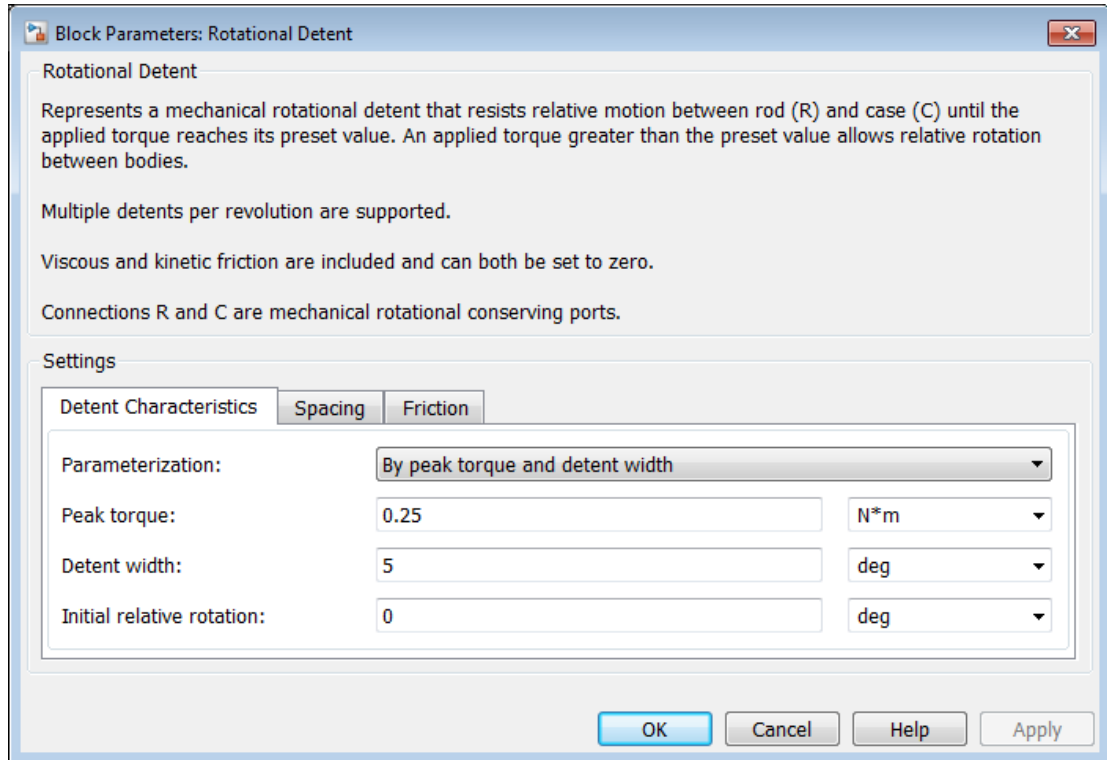
The Rotational Detent block represents a double-sided, spring-loaded rotational detent.

The detent rod rotates over the detent case. The case has notches or magnets that create a net relative torque with the rod as the rod rotates. With the block, you can model rotational detents with peak torque and detent width, or with a lookup table. The model also includes viscous damping and kinetic friction between the rod and case. You can set the friction to zero.

### Ports

R and C are rotational conserving ports associated with the rod and case, respectively.

## Dialog Box and Parameters



## Detent Characteristics

### Parameterization

Select how to specify the detent characteristics. The default is **By peak torque and detent width**.

- **By peak torque and detent width** — Specify detent characteristics by the peak torque and the detent width.

### Peak Torque and Detent Width

#### Peak torque

The peak torque developed inside the detent. The default is 0.25.

From the drop-down list, choose units. The default is newton-meters (N\*m).

### **Detent width**

The width of the region where the torque develops. The default is 5.

From the drop-down list, choose units. The default is degrees (**deg**).

- **By lookup table** — Define the detent characteristics by one-dimensional table lookup based on the relative displacement between the slider and case. If you select this option, the panel changes from its default option.

### **Lookup Table**

#### **Relative rotation vector**

Specify the vector of input relative rotations that correspond to the values in **Torque vector**. These two vectors must be of the same size. The angles must be specified in strictly increasing order. The default values are [ -5.0 -4.0 -3.0 -1.0 1.0 3.0 4.0 5.0 ].

From the drop-down list, choose units. The default is degrees (**deg**).

#### **Torque vector**

Specify the vector of input values for the developed torque that correspond to the values in **Relative rotation vector**. The default values are [ 0 0 -0.25 -0.10 0.10 0.25 0 0 ].

From the drop-down list, choose units. The default is newton-meters (N\*m).

#### **Initial relative rotation**

The relative angle of the rod and case when simulation starts. The default is 0.

From the drop-down list, choose units. The default is degrees (**deg**).

#### **Interpolation method**

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the PS Lookup Table (1D) block reference page.

## Spacing

### Detent spacing

Select how to specify the detent spacing. The default is **Regularly spaced**.

- **Regularly spaced** — Specify detent spacing by regular intervals.

### Regular spacing

#### Number of detents

Specify the number of identical, regularly spaced detents. Must be greater than or equal to 1. The default is 1.

Creates a number of detents evenly spaced from  $-180$  to  $+180$  degrees, with one detent center at 0 degrees. Non-integer values are rounded to the nearest integer.

- **By angle vector** — Specify detent spacing by custom intervals. If you select this option, the panel changes from its default option.

### Custom intervals

#### Vector of detent centers

Specify the locations of the centers of identical detents as a vector of angles. These values must lie between  $-180$  and  $+180$  degrees. The minimum spacing between the detents must be greater than the **Detent width** parameter. The default values are `[-40 0 30 85]`.

From the drop-down list, choose units. The default is degrees (**deg**).

## Friction

### Viscous friction coefficient

Specify the viscous friction coefficient for the rod-case contact. Must be greater than or equal to 0. The default is **0.1**.

From the drop-down list, choose units. The default is newton-meters/(radians/second) (N\*m/ (rad/s)).

**Friction to peak torque ratio**

Specify the kinetic friction coefficient for the rod-case contact. Must be greater than or equal to 0. The default is 0.01.

The kinetic friction is this ratio multiplied by the peak torque.

**Friction velocity threshold**

Specify the relative angular velocity required for peak kinetic friction in the detent. Must be greater than 0. The default is 10.

From the drop-down list, choose units. The default is revolutions/minute (rpm).

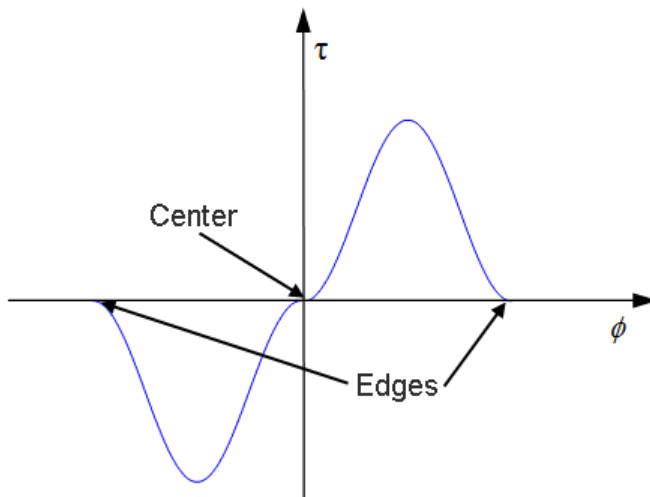
## Rotational Detent Model

As the rod rotates over the case, the relative rotation  $\phi = \phi_R - \phi_C$  causes a torque  $\tau$  to develop. Depending on your choice of parameterization, the torque model is defined by the peak torque and detent width, or by a lookup table specifying relative rotation versus torque.

Regardless of the parameterization, if you specify multiple detents, all detents have the same torque-relative rotation function.

### Peak Torque and Detent Width

If you choose the peak torque and detent width parameterization, the block ensures that the torque-relative rotation curve provides a continuous torque and torque derivative over the detent region. The peak torques are halfway between the detent center and detent edge, as shown in the following figure.



## Lookup Table

With the lookup table parameterization, you can create an arbitrary function relating torque to relative rotation. If you create such a function, consider the following best practices.

### Energy Conservation

If you want to ensure that the detent conserves energy, the total integral of the torque-relative rotation curve (area under the curve) must be zero.

### Simulation Performance

To stabilize simulation of the detent, avoid discontinuities in the torque-relative rotation function.

## Limitations

- The model does not account for inertia. Add inertia terms externally to the R and C ports as required.
- If you use the peak torque-detent width or the lookup table parameterization, the kinetic friction is independent of the detent normal force.

### **See Also**

Loaded-Contact Rotational Friction | Translational Detent | Tire  
(Friction Parameterized)

### **More About**

- “Clutches, Clutch-Like Elements, and Coulomb Friction”

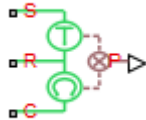


# Rotational Power Sensor

Mechanical sensor used to measure average or instantaneous rotational power

## Library

Sensors



## Description

The block represents a sensor that you can use to measure the rotational power change due to one or more driveline components connected between ports R and C. The power output can be an instantaneous or average value. Three averaging options are available: period, vibration, and revolution averaging.

The instantaneous power is the product of the current angular velocity and torque. Use the instantaneous power to analyze peak power transmission and identify heavily-loaded components.

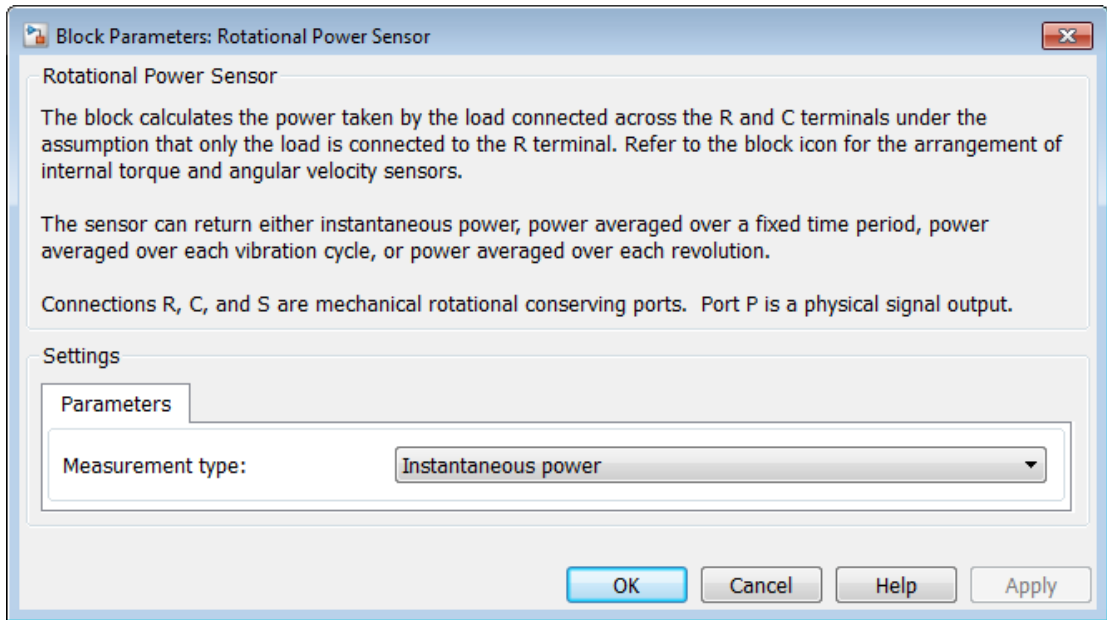
The time-averaged power is the integral of the instantaneous power over one sample period, divided by that period. For simulation times smaller than the sample period, the average power is zero. The power output is constant for each sample period.

The vibration-averaged power is the integral of the power over one vibration period, divided by that period. The vibration period is the time between two consecutive crossings from negative to positive velocity values. The averaging period can change if the vibration has a variable frequency. For simulation times smaller than the vibration period, the average power is zero. The power output is constant for each vibration period.

The revolution-averaged power is the integral of the instantaneous power over one revolution period, divided by that period. The revolution period is defined as the time between two consecutive crossings of zero angular position. The averaging period can

change if the revolution has a variable frequency. For simulation times smaller than the revolution period, the average power is zero. The power output is constant for each revolution period.

## Dialog Box and Parameters



### Measurement Type

Select either instantaneous or average power measurement. The default type is Instantaneous Power.

- **Instantaneous power** — Output the rotational power measured for the current simulation time step.
- **Average power over a specified period** — Output the rotational power averaged over a fixed time period.

### Averaging period

Enter the time period used to compute the average power. Typical values include the cycle length of a rotating device.

The default value is 1. The default unit is s.

- **Average power over a vibration** — Output the rotational power averaged over one vibration period.

#### **Maximum vibration frequency**

Enter the maximum vibration frequency over which the rotational power should be averaged. Very high values can reduce simulation speed. Very low values can result in lower power measurements.

The default value is 1000. The default unit is Hz.

- **Average power over a revolution** — Output the rotational power averaged over one revolution period.

#### **Maximum rotational speed**

Enter the maximum speed over which the rotational power should be averaged. Very high values can reduce simulation speed. Very low values can result in lower power measurements.

The default value is 1000. The default unit is rpm.

## **Ports**

<b>Port</b>	<b>Description</b>
P	Physical signal output port for rotational power
S	Rotational conserving port associated with driving source
C	Rotational conserving port associated with loaded driveline component(s)
R	Rotational conserving port associated with case holding loaded driveline component(s)

## **See Also**

Translational Power Sensor

# Shock Absorber

Mechanism for damping translational vibrations

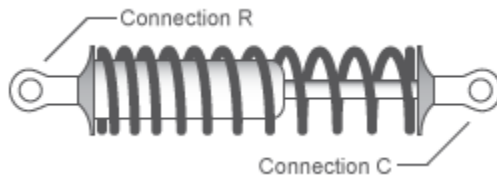
## Library

Couplings & Drives



## Description

The block represents a spring-damper system commonly used to dampen vibration in mechanical systems. An internal force acts between ports R and C. This force is the sum of spring stiffness, damping, Coulomb friction, and hard-stop contributions. All force contributions are optional.



The net internal force satisfies the expression

$$F = F_{spr} + F_d + F_c + F_{HS},$$

where:

- $F$  — Net internal force
- $F_{spr}$  — Spring force,  $F_k = -k \cdot x$
- $F_d$  — Damping force,  $F_d = -b \cdot v$

- $F_c$  — Coulomb friction force,

$$F_c = \begin{cases} -F_k \cdot \text{sign}(v), & \text{when unlocked} \\ -F_s, & \text{when locked} \end{cases},$$

- $F_{HS}$  — Hard stop force,

$$F_{HS} = \begin{cases} -k_{HS} \cdot (x - UB) - b_{HS} \cdot v, & x \geq UB \\ 0 & UB \geq x \geq LB, \\ -k_{HS} \cdot (x - LB) + b_{HS} \cdot v, & LB > x \end{cases}$$

- $k$  — Restoring spring stiffness
- $b$  — Viscous damping coefficient
- $x$  — Relative displacement between ports R and C
- $v$  — Relative velocity between R and C
- $F_k$  — Kinetic friction force
- $F_s$  — Static friction force
- $k_{HS}$  — Hard stop contact stiffness coefficient
- $b_{HS}$  — Hard stop damping coefficient
- $UB$  — Hard stop upper bound
- $LB$  — Hard stop lower bound

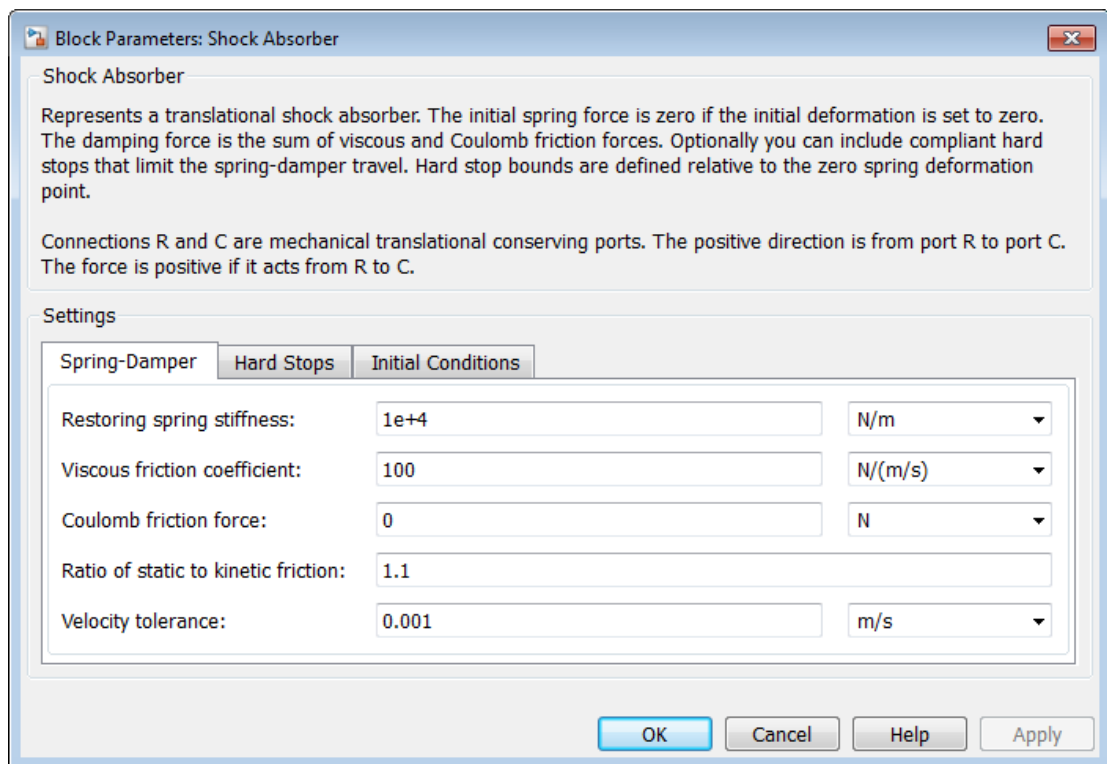
The shock absorber block is based on the blocks listed in the table. For more information, see the corresponding block reference pages.

Block	Library
Loaded-Contact Translational Friction	Simscape Driveline Brakes & Detents/ Translational
Translational Spring	Simscape Foundation Library/Mechanical/ Translational
Translational Damper	
Translational Hard Stop	

## Assumptions and Limitations

- The use of hard-stop and Coulomb friction enhances model fidelity, but reduces simulation speed. See “Improve Performance” in the product documentation.

## Dialog Box and Parameters



### Spring-Damper

#### Restoring spring stiffness

Enter the value of the viscous spring stiffness constant,  $k$ . The value must be greater than or equal to zero.

The default value is  $1e+4$ . the default unit is N/m.

### **Viscous friction coefficient**

Enter the value of the viscous damping constant,  $b$ . The value must be greater than or equal to zero.

The default value is 100. The default unit is m/s.

### **Coulomb friction force**

Enter the value of the Coulomb friction force. The value must be greater than or equal to zero. Setting the value to 0 eliminates the Coulomb friction force contribution. This enhances simulation speed, making the model more suitable for HIL testing.

The default value is 0. The default unit is N.

### **Ratio of static to kinetic friction**

Enter the value of the static/kinetic friction ratio ( $F_s/F_k$ ). The value must be greater than one.

The default value is 1.1.

### **Velocity tolerance**

Enter the value of the relative velocity below which ports R and C lock and translate together. The value must greater than zero.

The default value is 0.001. The default unit is m/s.

## **Hard Stops**

### **Hard stop model**

Select hard stop model. Selecting `No hard-stops – Suitable for HIL simulation` eliminates the hard stop force contribution. This enhances simulation speed.

The default setting is `No hard stops – Suitable for HIL simulation`.

### **Compliant hard stops**

#### **Upper bound**

Upper hard-stop position,  $UB$ . Positive displacement beyond the upper bound activates the hard stop contact force. The value must be greater than the lower bound.

The default value is 0.1. The default unit is m.

**Lower bound**

Lower hard-stop position, *LB*. Negative displacement beyond the lower bound activates the hard stop contact force. The value must be smaller than the upper bound.

The default value is -0.1. The default unit is m.

**Contact stiffness**

Enter the value of the hard stop stiffness constant,  $k_{HS}$ . The value must be greater than zero.

The default value is 1e6. The default unit is N/m.

**Contact damping**

Enter the value of the hard stop damping constant,  $b_{HS}$ . The value must be greater than zero.

The default value is 1e4. The default unit is N/(m/s).

## Initial Conditions

**Initial deformation**

Enter the initial value of the spring deformation.

The default value is 0. The default unit is m.

## Ports

Port	Description
C	Translational conserving port
R	Translational Conserving port

## See Also

Nonlinear Translational Spring | Variable Translational Spring | Variable Translational Damper | Nonlinear Translational Damper

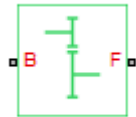


# Simple Gear

Simple gear of base and follower wheels with adjustable gear ratio and friction losses

## Library

Gears

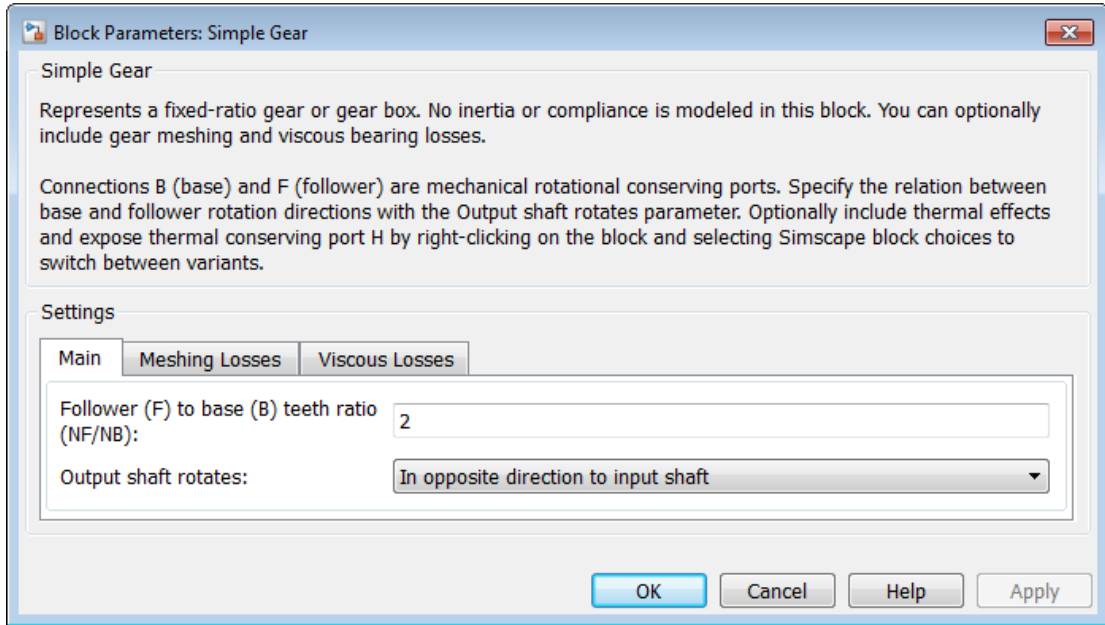


## Description

The Simple Gear block represents a gearbox that constrains the two connected driveline axes, base (B) and follower (F), to corotate with a fixed ratio that you specify. You can choose whether the follower axis rotates in the same or opposite direction as the base axis. If they rotate in the same direction,  $\omega_F$  and  $\omega_B$  have the same sign. If they rotate in opposite directions,  $\omega_F$  and  $\omega_B$  have opposite signs. For model details, see “Simple Gear Model” on page 1-256.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Follower (F) to base (B) teeth ratio (NF/NB)

Fixed ratio  $g_{FB}$  of the follower axis to the base axis. The gear ratio must be strictly positive. The default is 2.

#### Output shaft rotates

Direction of motion of the follower (output) driveshaft relative to the motion of the base (input) driveshaft. The default is In opposite direction to input shaft.

### Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

## Without Thermal Port

### Friction model

List of friction models at various precision levels for estimating power losses due to meshing.

- **No meshing losses - Suitable for HIL simulation** — Neglect friction between gear cogs. Meshing is ideal.
- **Constant efficiency** — Reduce torque transfer by a constant efficiency factor. This factor falls in the range  $0 < \eta \leq 1$  and is independent of load. Selecting this option exposes additional parameters.

#### Constant efficiency

##### Efficiency

Torque transfer efficiency ( $\eta$ ) between base and follower shafts. This parameter is inversely proportional to the meshing power losses. Values can range from 0 to 1. The default value is 0.95.

- **Load-dependent efficiency** — Reduce torque transfer by a variable efficiency factor. This factor falls in the range  $0 < \eta < 1$  and varies with the torque load. Selecting this option exposes additional parameters.

#### Load-Dependent Efficiency

##### Input shaft torque at no load

Net torque ( $\tau_{idle}$ ) acting on the input shaft in idle mode, e.g., when torque transfer to the output shaft equals zero. For nonzero values, the power input in idle mode completely dissipates due to meshing losses. The default value is 0.1 N\*m.

##### Nominal output torque

Output torque ( $\tau_F$ ) at which to normalize the load-dependent efficiency. The default value is 5 N\*m.

##### Efficiency at nominal output torque

Torque transfer efficiency ( $\eta$ ) at the nominal output torque. Efficiency values must fall in the interval [0, 1]. Larger efficiency values correspond to greater torque transfer between the input and output shafts. The default value is 0.95.

##### Follower angular velocity threshold

Absolute value of the follower shaft angular velocity above which the full efficiency factor is in effect ( $\omega_F$ ). Below this value, a hyperbolic tangent function smooths the efficiency factor to one, lowering the efficiency losses to zero when at rest.

As a guideline, the angular velocity threshold should be lower than the expected angular velocity during simulation. Higher values might cause the block to underestimate efficiency losses. Very low values might, however, raise the computational cost of simulation.

The default value is 0.01 rad/s.

### **With Thermal Port**

#### **Friction model**

Choice of model for representing friction. The model can incorporate the temperature and load dependences of friction or just the temperature dependence. The default setting is **Temperature-dependent efficiency**.

#### **Temperature**

Array of temperatures used to construct an efficiency lookup table. The array values must increase from left to right. The temperature array must be the same size as the efficiency array in temperature-dependent models. It must be the same size as a single row of the efficiency matrix in temperature-and-load-dependent models. The default array is [280 300 320] K.

#### **Load at base gear**

Array of base-gear loads used to construct a 2-D temperature-load-efficiency lookup table for temperature-and-load-dependent efficiency models. The array values must increase left to right. The load array must be the same size as a single column of the efficiency matrix. The default array is [1 5 10] N\*m.

#### **Efficiency**

Array of efficiencies used to construct a 1-D temperature-efficiency lookup table for temperature-dependent efficiency models. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size.

This parameter appears only when you select a temperature-dependent friction model. The default array is [0.95 0.9 0.85].

#### **Efficiency matrix**

Matrix of component efficiencies used to construct a 2-D temperature-load-efficiency lookup table. The matrix elements are the efficiencies at the temperatures given by the **Temperature** array and at the loads given by the **Load at base gear** array.

The number of rows must be the same as the number of elements in the **Temperature** array. The number of columns must be the same as the number of elements in the **Load at base gear** array.

This parameter appears only when you select a temperature-and-load-dependent efficiency model. The default matrix is [0.85 0.8 0.75; 0.95 0.9 0.85; 0.85 0.8 0.7].

### **Follower power threshold**

Visible only if you select **Temperature-dependent efficiency** as the friction model. Absolute value of the follower shaft power above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero when at rest and the value provided by the temperature-efficiency lookup table when at the power threshold. The default value is 0.001 W.

### **Follower angular velocity threshold**

Visible only if you select **Temperature and load-dependent efficiency** as the friction model. Absolute value of the follower shaft angular velocity above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function smooths the efficiency factor to one, lowering the efficiency losses to zero when at rest. The default value is 0.01 rad/s.

## **Viscous Losses**

### **Viscous friction coefficients at base (B) and follower (F)**

Two-element array with the viscous friction coefficients in effect at the base and follower shafts. The default array, [0 0], corresponds to zero viscous losses.

## **Thermal Port**

### **Thermal mass**

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### **Initial temperature**

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Simple Gear Model

### Ideal Gear Constraint and Gear Ratio

Simple Gear imposes one kinematic constraint on the two connected axes:

$$r_F \omega_F = r_B \omega_B .$$

The follower-base gear ratio  $g_{FB} = r_F/r_B = N_F/N_B$ .  $N$  is the number of teeth on each gear. The two degrees of freedom reduce to one independent degree of freedom.

The torque transfer is:

$$g_{FB} \tau_B + \tau_F - \tau_{\text{loss}} = 0 ,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

### Nonideal Gear Constraint and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . For general considerations on nonideal gear modeling, see “Model Gears with Losses”.

In a nonideal gear pair (B,F), the angular velocity, gear radii, and gear teeth constraints are unchanged. But the transferred torque and power are reduced by:

- Coulomb friction between teeth surfaces on gears B and F, characterized by efficiency  $\eta$
- Viscous coupling of driveshafts with bearings, parametrized by viscous friction coefficients  $\mu$

#### Constant Efficiency

In the constant efficiency case,  $\eta$  is constant, independent of load or power transferred.

#### Load-Dependent Efficiency

In the load-dependent efficiency case,  $\eta$  depends on the load or power transferred across the gears. For either power flow,  $\tau_{\text{Coul}} = g_{FB} \tau_{\text{idle}} + k \tau_F$ .  $k$  is a proportionality constant.  $\eta$  is related to  $\tau_{\text{Coul}}$  in the standard, preceding form but becomes dependent on load:

$$\eta = \tau_F / [g_{FB} \tau_{idle} + (k + 1) \tau_F] .$$

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
B	Rotational conserving port representing the base shaft
F	Rotational conserving port representing the follower shaft
H	Thermal conserving port for thermal modeling

## Examples

The `sdl_simple_gear` example model gives a basic example of a simple gear.

The `sdl_backlash` example model illustrates a gear with backlash.

The `sdl_gearbox_efficiency` example model measures the efficiency of a nonideal simple gear by comparing output to input power.

## See Also

Variable Ratio Transmission

## Related Examples

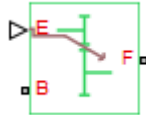
- “Represent and Transfer Driveline Motion and Torque”

# Simple Gear with Variable Efficiency

Gear set with parallel-axis rotation and variable meshing efficiency

## Library

Gears



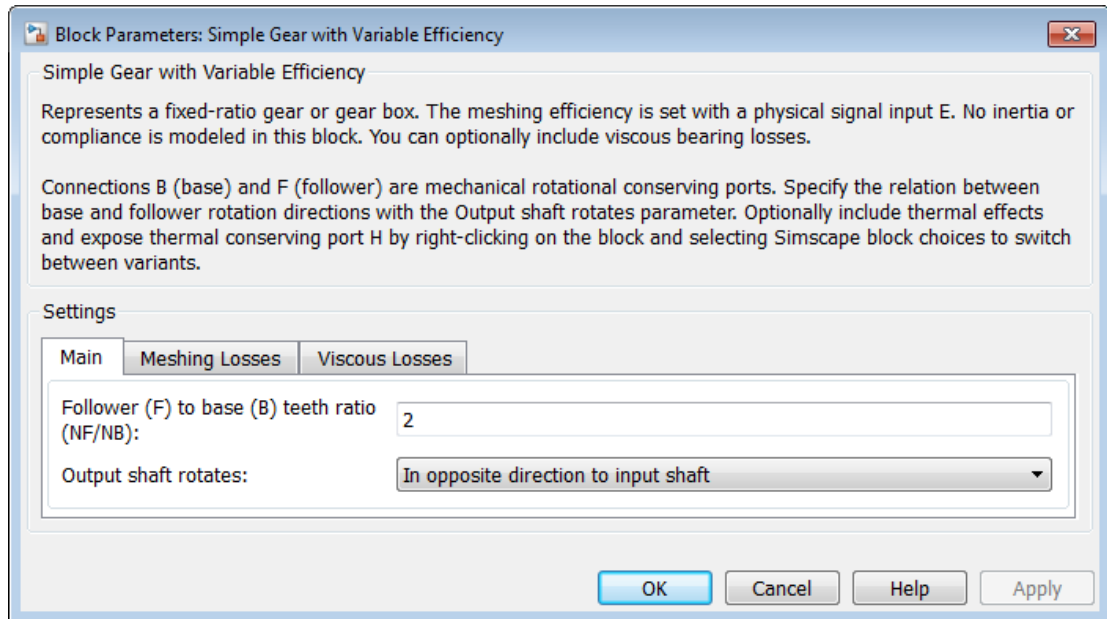
## Description

The block represents a simple gear train with variable meshing efficiency. The gear train transmits torque at a specified ratio between base and follower shafts arranged in a parallel configuration. Shaft rotation can occur in equal or opposite directions. Gear losses are optional. They include meshing and viscous bearing losses. To specify the variable meshing efficiency, the block contains a physical signal port that you can use to input a general time-varying signal. Inertia and compliance effects are ignored.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.



## Dialog Box and Parameters



### Main

#### Follower (F) to base (B) teeth ratio (NF/NB)

Enter the gear ratio. This is the fraction of follower over base gear teeth numbers,  $NF/NB$ . The ratio must be positive. The default value is 2.

#### Output shaft rotates

Select the relative rotation between shafts. This is the rotation direction of the output shaft with respect to the input shaft. Options include equal or opposite directions. The default setting is In opposite direction to input shaft.

### Meshing Losses

#### Minimum efficiency

Enter the smallest efficiency value allowed for the gear. The efficiency is the power ratio between output and input shafts. The physical signal input saturates for values

below the minimum efficiency or above 1. The minimum efficiency must be positive. The default value is 0.01.

### **Follower power threshold**

Enter the follower shaft power above which full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero when at rest and the value provided by the temperature-efficiency lookup table when at the power threshold. The default value is 0.001 W.

## **Viscous Losses**

### **Viscous friction coefficients at base (B) and follower (F)**

Enter a two-element vector with the viscous friction coefficients of the base and follower gears. Coefficients must be positive. The default vector is [0 0]. The default unit is N\*m / (rad/s).

## **Thermal Port**

### **Thermal mass**

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### **Initial temperature**

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## **Simple Gear Model**

### **Ideal Gear Constraint and Gear Ratio**

Simple Gear imposes one kinematic constraint on the two connected axes:

$$r_F \omega_F = r_B \omega_B .$$

The follower-base gear ratio  $g_{FB} = r_F/r_B = N_F/N_B$ .  $N$  is the number of teeth on each gear. The two degrees of freedom reduce to one independent degree of freedom.

The torque transfer is:

$$g_{FB} \tau_B + \tau_F - \tau_{\text{loss}} = 0,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraint and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . For general considerations on nonideal gear modeling, see “Model Gears with Losses”.

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
B	Rotational conserving port representing the base shaft
F	Rotational conserving port representing the follower shaft
H	Thermal conserving port for thermal modeling

## See Also

Simple Gear | Variable Ratio Transmission

## Related Examples

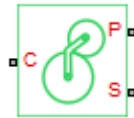
- “Represent and Transfer Driveline Motion and Torque”

## Sun-Planet

Planetary gear set of carrier, planet, and sun wheels with adjustable gear ratio and friction losses

### Library

Gears/Planetary Subcomponents

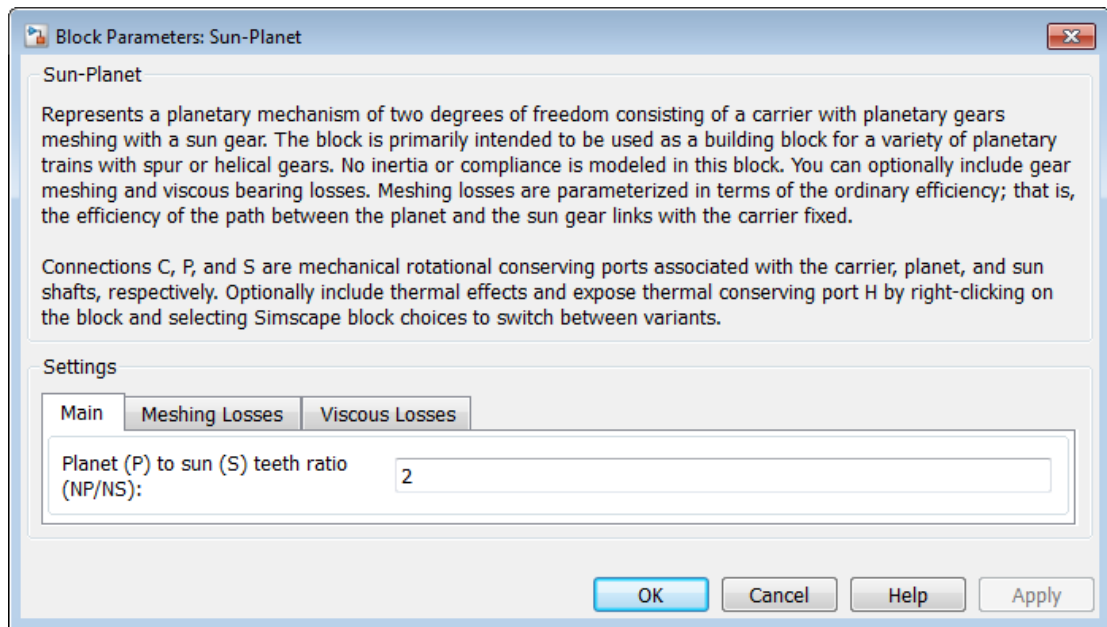


### Description

The Sun-Planet gear block represents a set of carrier, planet, and sun gear wheels. The planet is connected to and rotates with respect to the carrier. The planet and sun corotate with a fixed gear ratio that you specify and in the same direction with respect to the carrier. A sun-planet and a ring-planet gear are basic elements of a planetary gear set. For model details, see “Sun-Planet Gear Model” on page 1-265.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Ring (R) to sun (S) teeth ratio (NP/NS)

Ratio  $g_{RS}$  of the ring gear wheel radius to the sun gear wheel radius. This gear ratio must be strictly greater than 1. The default value is 2.

### Meshing Losses

Parameters for meshing losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

#### Without Thermal Port

##### Friction model

Select how to implement friction losses from nonideal meshing of gear teeth. The default is **No meshing losses**.

- No meshing losses — Suitable for HIL simulation — Gear meshing is ideal.
- Constant efficiency — Transfer of torque between gear wheel pairs is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

### **Constant Efficiency**

#### **Ordinary efficiency**

Torque transfer efficiency  $\eta_{SP}$  for sun-planet gear wheel pair meshing.

#### **Sun-carrier power threshold**

Power threshold above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function smooths the efficiency factor, lowering the efficiency losses to zero when no power is transmitted. The default value is 0.001 W.

### **With Thermal Port**

#### **Temperature**

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as the **Efficiency** array. The default array is [280 300 320] K.

#### **Efficiency**

Array of component efficiencies used to construct a 1-D temperature-efficiency lookup table. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.95 0.9 0.85].

#### **Sun-carrier power threshold**

Power threshold above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

### **Viscous Losses**

#### **Sun-carrier viscous friction coefficient**

Viscous friction coefficient  $\mu_S$  for the sun-carrier gear motion. The default is 0.

From the drop-down list, choose units. The default is newton-meters/(radians/second) (N\*m/ (rad/s)).

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Sun-Planet Gear Model

### Ideal Gear Constraints and Gear Ratios

Sun-Planet imposes one kinematic and one geometric constraint on the three connected axes:

$$r_C \omega_C = r_S \omega_S + r_P \omega_P, \quad r_C = r_P + r_S.$$

The planet-sun gear ratio  $g_{PS} = r_P/r_S = N_P/N_S$ .  $N$  is the number of teeth on each gear. In terms of this ratio, the key kinematic constraint is:

$$\omega_S = -g_{PS} \omega_P + (1 + g_{PS}) \omega_C.$$

The three degrees of freedom reduce to two independent degrees of freedom. The gear pair is (1,2) = (S,P).

---

**Warning** The planet-sun gear ratio  $g_{PS}$  must be strictly greater than one.

---

The torque transfer is:

$$g_{PS} \tau_S + \tau_P - \tau_{\text{loss}} = 0,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraints and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . See “Model Gears with Losses”.

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
C	Rotational conserving port representing the planet carrier
P	Rotational conserving port representing the planet gear
S	Rotational conserving port representing the sun gear
H	Thermal conserving port for thermal modeling

## See Also

Compound Planetary Gear | Planet-Planet | Planetary Gear | Ring-Planet | Sun-Planet Bevel

## Related Examples

- “Represent and Transfer Driveline Motion and Torque”

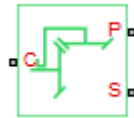


# Sun-Planet Bevel

Planetary gear set of carrier, beveled planet, and sun wheels with adjustable gear ratio, assembly orientation, and friction losses

## Library

Gears/Planetary Subcomponents

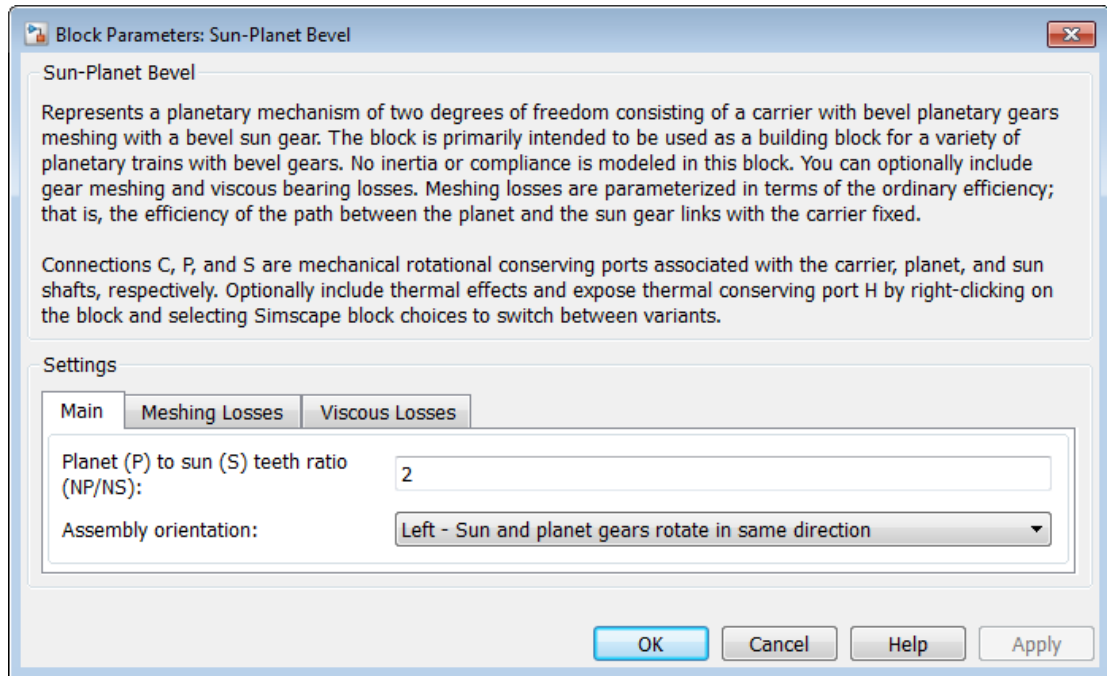


## Description

The Sun-Planet Bevel gear block represents a set of carrier, planet, and sun gear wheels. The planet is connected to and rotates with respect to the carrier. The planet and sun corotate with a fixed gear ratio and in a direction that you specify. You control the direction by setting the assembly orientation, left or right. A sun-planet and a ring-planet gear are basic elements of a planetary gear set. For model details, see “Sun-Planet Bevel Gear Model” on page 1-270.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Planet (P) to sun (S) teeth ratio (NP/NS)

Ratio  $g_{PS}$  of the planet gear wheel radius to the sun gear wheel radius. This gear ratio must be strictly greater than 1. The default value is 2.

#### Assembly orientation

Relative orientation of sun and planet gears, controlling their corotation direction. Left or right orientation imply, respectively, that the gears corotate in the same or opposite direction.

The default is Left – Sun and planet gears rotate in same direction.

## Meshing Losses

Parameters for meshing and friction losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

### Without Thermal Port

#### Friction model

Select how to implement friction losses from nonideal meshing of gear teeth. The default is **No meshing losses**.

- **No meshing losses – Suitable for HIL simulation** — Gear meshing is ideal.
- **Constant efficiency** — Transfer of torque between gear wheel pairs is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

#### Constant Efficiency

##### Ordinary efficiency

Torque transfer efficiency  $\eta_{SP}$  for sun-planet gear wheel pair meshing.

##### Sun-carrier power threshold

Power threshold above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function smooths the efficiency factor, lowering the efficiency losses to zero when no power is transmitted. The default value is 0.001 W.

### With Thermal Port

#### Temperature

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as the **Efficiency** array. The default array is [280 300 320] K.

#### Efficiency

Array of component efficiencies used to construct a 1-D temperature-efficiency lookup table. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.95 0.9 0.85].

### Sun-carrier power threshold

Power threshold above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

## Viscous Losses

### Sun-carrier viscous friction coefficient

Viscous friction coefficient  $\mu_S$  for the sun-carrier gear motion. The default is 0.

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (rad/s)$ ).

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Sun-Planet Bevel Gear Model

### Ideal Gear Constraints and Gear Ratios

Sun-Planet Bevel imposes one kinematic and one geometric constraint on the three connected axes:

$$r_C \omega_C = r_S \omega_S \pm r_P \omega_P, \quad r_C = r_S \pm r_P.$$

The planet-sun gear ratio  $g_{PS} = r_P/r_S = N_P/N_S$ .  $N$  is the number of teeth on each gear. In terms of this ratio, the key kinematic constraint is:

$$\omega_S = \mp g_{PS} \omega_P + (1 \pm g_{PS}) \omega_C.$$

The three degrees of freedom reduce to two independent degrees of freedom. The upper or lower sign applies, respectively, to left-oriented or right-oriented bevel assembly. The gear pair is (1,2) = (S,P).

---

**Warning** The planet-sun gear ratio  $g_{PS}$  must be strictly greater than one.

---

The torque transfer is:

$$g_{PS}\tau_S + \tau_P - \tau_{\text{loss}} = 0 ,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraints and Losses

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . See “Model Gears with Losses”.

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
C	Rotational conserving port representing the gear carrier
P	Rotational conserving port representing the planet gear
S	Rotational conserving port representing the sun gear
H	Thermal conserving port for thermal modeling

## Examples

These Simscape Driveline example models use the Sun-Planet Bevel gear to create custom gear sets:

- `sdl_limited_slip_differential`
- `sdl_custom_planetary_gear`

## See Also

[Differential](#) | [Planet-Planet](#) | [Planetary Gear](#) | [Ring-Planet](#) | [Sun-Planet](#)

## Related Examples

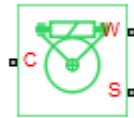
- “Represent and Transfer Driveline Motion and Torque”

# Sun-Planet Worm Gear

Planetary gear set of carrier, worm planet, and sun wheels with adjustable gear ratio, worm thread type, and friction losses

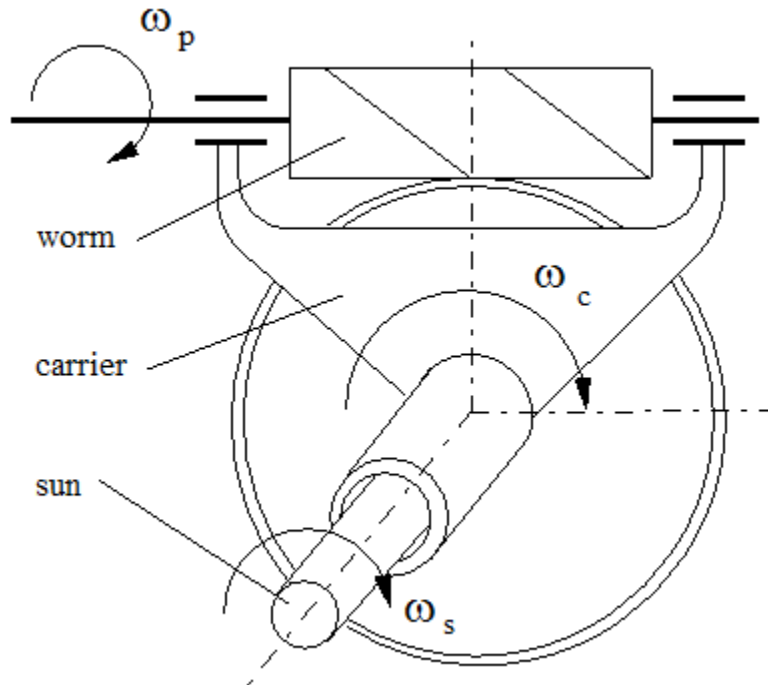
## Library

Gears/Planetary Subcomponents



## Description

The Sun-Planet Worm Gear block represents a two-degree-of-freedom planetary gear built from carrier, sun and planet gears. By type, the sun and planet gears are crossed helical spur gears arranged as a worm-gear transmission, in which the planet gear is a worm. Such transmissions are used in the Torsen type 1 differential. When transmitting power, the sun gear can be independently rotated by the worm (planet) gear, or by the carrier, or both.

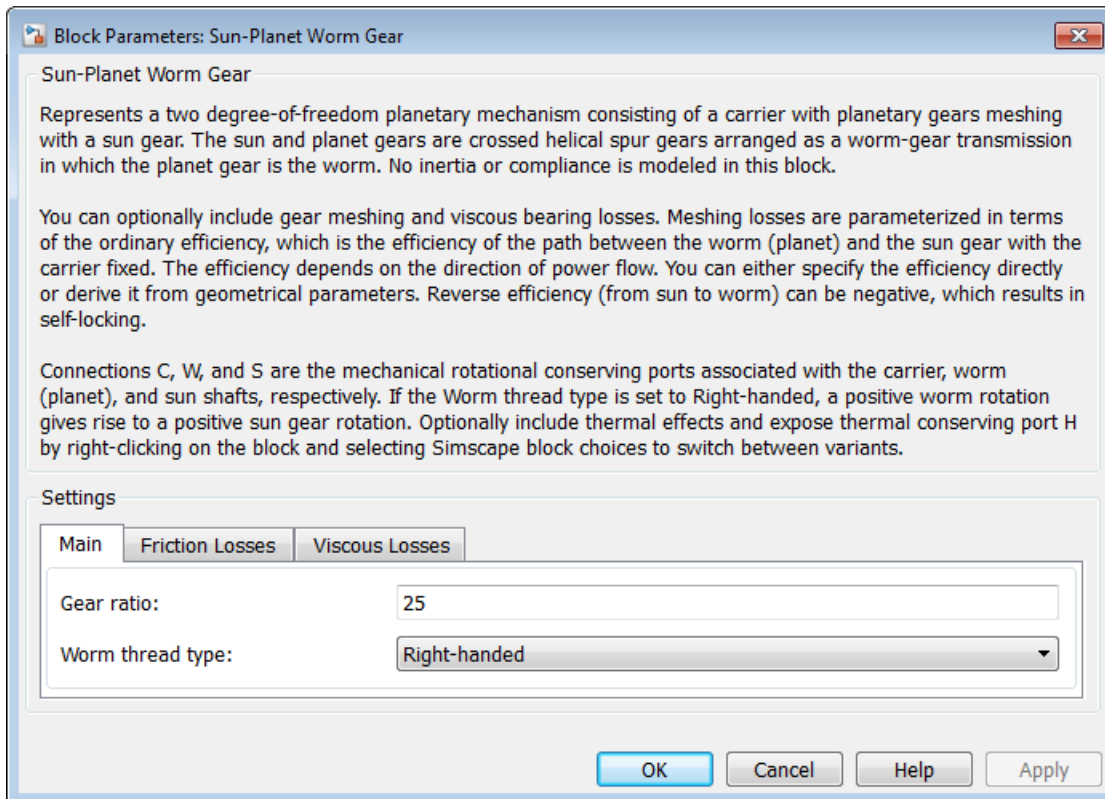


You specify a fixed gear ratio, which is determined as the ratio of the worm angular velocity to the sun gear angular velocity. You control the direction by setting the worm thread type, left-handed or right-handed. Rotation of the right-handed worm in positive direction causes the sun gear to rotate in positive direction too. The positive directions of the sun gear and the carrier are the same.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.



## Dialog Box and Parameters



### Main

#### Gear ratio

Gear or transmission ratio  $R_{WG}$  determined as the ratio of the worm angular velocity to the gear angular velocity. The default is 25.

#### Worm thread type

Choose the directional sense of gear rotation corresponding to positive worm rotation. The default is **Right-handed**. If you select **Left-handed**, rotation of the worm in the generally-assigned positive direction results in the gear rotation in negative direction.

## Friction Losses

Parameters for meshing and friction losses vary with the block variant chosen—one with a thermal port for thermal modeling and one without it.

### Without Thermal Port

#### Friction model

Select how to implement friction losses from nonideal meshing of gear threads. The default is `No friction losses`.

- `No friction losses` — Suitable for HIL simulation — Gear meshing is ideal.
- `Constant efficiency` — Transfer of torque and force between worm and gear is reduced by friction. If you select this option, the panel expands.

#### Constant Efficiency

#### Friction parametrization

Select how to characterize the friction between gear threads. The default is `Friction coefficient and geometrical parameters`.

- `Friction coefficient and geometrical parameters` — Friction is determined by contact friction between surfaces.

#### Normal pressure angle

The thread pressure angle  $a$  in the normal plane. Must be greater than zero and less than 90 degrees. The default is 17.5.

From the drop-down list, choose units. The default is degrees (`deg`).

#### Lead angle

Thread helix angle  $\lambda = \arctan[L/(\pi d)]$ .  $L$  is the worm lead,  $d$  is the worm pitch diameter. Must be greater than zero. The default is 20.

From the drop-down list, choose units. The default is degrees (`deg`).

#### Friction coefficient

Dimensionless coefficient of normal friction in the thread. Must be greater than zero. The default is 0.08.

- **Efficiencies** — Friction is determined by constant efficiencies  $0 < \eta < 1$ . If you select this option, the panel changes from its default.

### **Efficiencies**

#### **Worm-gear efficiency**

Efficiency  $\eta_{WG}$  of the power transfer from worm to gear.

#### **Gear-worm efficiency**

Efficiency  $\eta_{GW}$  of the power transfer from gear to worm.

### **Power threshold**

Power threshold above which the full efficiency factor is in effect. Below this value, a hyperbolic tangent function smooths the efficiency factor, lowering the efficiency losses to zero when no power is transmitted. The default value is 0.001 W.

### **With Thermal Port**

#### **Temperature**

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as the **Efficiency** array. The default array is [280 300 320] K.

#### **Worm-gear efficiency**

Array of component efficiencies with the worm as the driver—that is, with power flowing from the worm to the gear. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.75 0.7 0.65].

#### **Gear-worm efficiency**

Array of component efficiencies with the gear as the driver—that is, with power flowing from the gear to the worm. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.5 0.45 0.4].

### **Power threshold**

Absolute value of the angular velocity above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

## Viscous Losses

### Worm-carrier and sun-carrier viscous friction coefficients

Vector of viscous friction coefficients  $[\mu_{WC} \mu_{SC}]$ , for the worm-carrier and sun-carrier shafts, respectively. The default is  $[0 \ 0]$ .

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (rad/s)$ ).

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Sun-Planet Worm Gear Model

### Model Variables

$R_{WG}$	Gear, or transmission, ratio determined as the ratio of the worm angular velocity to the gear angular velocity. The ratio is positive for the right-hand worm and negative for the left-hand worm.
$\omega_S$	Angular velocity of the sun gear
$\omega_P$	Planet (that is, worm) angular velocity
$\omega_C$	Carrier angular velocity
$\omega_{SC}$	Angular velocity of the sun with respect to the carrier
$a$	Normal pressure angle
$\lambda$	Worm lead angle
$L$	Worm lead

$d$	Worm pitch diameter
$\tau_S$	Torque applied to the sun shaft
$\tau_P$	Torque applied to the planet shaft
$\tau_C$	Torque applied to the carrier shaft
$\tau_{\text{loss}}$	Torque loss due to meshing friction. The loss depends on the device efficiency and the power flow direction. To avoid abrupt change of the friction torque at $\omega_S = 0$ , the friction torque is introduced via the hyperbolic function.
$\tau_{\text{instfr}}$	Instantaneous value of the friction torque added to the model to simulate friction losses
$\tau_{\text{fr}}$	Steady-state value of the friction torque
$k$	Friction coefficient
$\eta_{\text{WG}}$	Efficiency for worm-gear power transfer
$\eta_{\text{GW}}$	Efficiency for gear-worm power transfer
$p_{\text{th}}$	Power threshold
$\mu_{\text{SC}}$	Sun-carrier viscous friction coefficient
$\mu_{\text{WC}}$	Worm-carrier viscous friction coefficient

## Ideal Gear Constraints and Gear Ratio

Sun-planet worm gear imposes one kinematic constraint on the three connected axes:  
 $\omega_S = \omega_P/R_{\text{WG}} + \omega_C$  .

The gear has two independent degrees of freedom. The gear pair is (1,2) = (S,P).

The torque transfer is:

$$R_{\text{WG}}\tau_P + \tau_S - \tau_{\text{loss}} = 0 ,$$

$$\tau_C = -\tau_S,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraints

For general considerations on nonideal gear modeling, see “Model Gears with Losses”.

In a nonideal gear, the angular velocity and geometric constraints are unchanged. But the transferred torque and power are reduced by:

- Coulomb friction between thread surfaces on W and G, characterized by friction coefficient  $k$  or constant efficiencies  $[\eta_{WG}, \eta_{GW}]$
- Viscous coupling of driveshafts with bearings, parametrized by viscous friction coefficients  $\mu_{SC}$  and  $\mu_{WC}$

Because the transmission incorporates a worm gear, the efficiencies are different for the direct and reverse power transfer. The following table shows the value of the efficiency for all combinations of the power transfer.

Driving shaft	Driven shaft		
	Planet	Sun	Carrier
Planet	n/a	$\eta_{WG}$	$\eta_{WG}$
Sun	$\eta_{GW}$	n/a	No loss
Carrier	$\eta_{GW}$	No loss	n/a

### Geometric Surface Contact Friction

In the contact friction case,  $\eta_{WG}$  and  $\eta_{GW}$  are determined by:

- The worm-gear threading geometry, specified by lead angle  $\lambda$  and normal pressure angle  $\alpha$ .
- The surface contact friction coefficient  $k$ .

$$\eta_{WG} = (\cos\alpha - k \tan\lambda) / (\cos\alpha + k/\tan\lambda) ,$$

$$\eta_{GW} = (\cos\alpha - k/\tan\lambda) / (\cos\alpha + k \tan\alpha) .$$

### Constant Efficiencies

In the constant efficiency case, you specify  $\eta_{WG}$  and  $\eta_{GW}$ , independently of geometric details.

### Self-Locking and Negative Efficiency

If you set efficiency for the reverse power flow to a negative value, the train exhibits *self-locking*. Power can not be transmitted from sun gear to worm and from carrier to worm unless some torque is applied to the worm to release the train. In this case, the absolute

value of the efficiency specifies the ratio at which the train is released. The smaller the train lead angle, the smaller the reverse efficiency.

## Meshing Efficiency

The efficiencies  $\eta$  of meshing between worm and gear are fully active only if the transmitted power is greater than the power threshold.

If the power is less than the threshold, the actual efficiency is automatically regularized to unity at zero velocity.

## Viscous Friction Force

The viscous friction coefficients of the worm-carrier and sun-carrier bearings control the viscous friction torque experienced by the carrier from lubricated, nonideal gear threads. For details, see the “Nonideal Gear Constraints” on page 1-279 section.

## Limitations

- Gear inertia is assumed negligible.
- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
C	Rotational conserving port representing the gear carrier
W	Rotational conserving port representing the worm gear
S	Rotational conserving port representing the sun gear
H	Thermal conserving port for thermal modeling

## Example

The `sdl_torsen_differential` example model uses a Sun-Planet Worm gear to model a Torsen differential gear set.

## See Also

Sun-Planet | Sun-Planet Bevel | Worm Gear

## Related Examples

- “Represent and Transfer Driveline Motion and Torque”

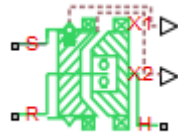


# Synchronizer

Cone clutch, dog clutch, and translational detent assembled to provide smooth gear engagement

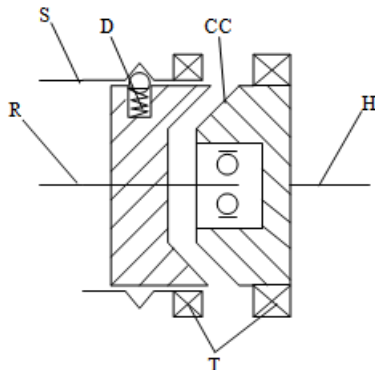
## Library

Clutches



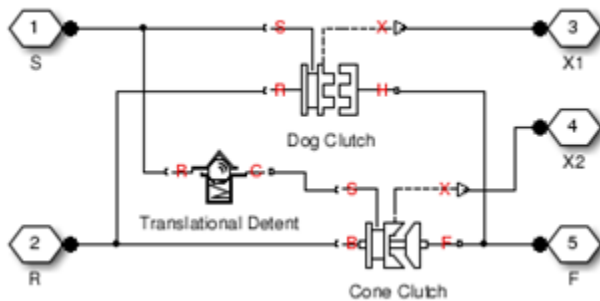
## Description

The block represents a synchronizer that contains a dog clutch, a cone clutch, and a translational detent. The shift linkage first translates to engage the cone clutch. Frictional torque causes the shift linkage and cone clutch shaft to rotate at equal speed. When the force acting on the shift linkage exceeds the detent force, the dog clutch can engage.



The schematic illustrates a synchronizer in the disengaged state. In this state, the ring (R) and hub (H) shafts can spin independently at different speeds. To synchronize ring

and hub shaft speeds, the shift linkage (S) translates toward the hub shaft to engage the cone clutch. The friction surfaces of the cone clutch produce a frictional torque that equalizes the rotational speeds of the ring and hub shafts. The dog clutch teeth (T) can engage when the translational force acting on the shift linkage exceeds the peak detent force. The peak detent force should allow sufficient time and normal force to equalize ring and hub shaft speeds so that the dog clutch can engage.



The model implements **Dog Clutch**, **Translational Detent** and a modified version of **Cone Clutch** blocks. Refer to each block reference page for more information on the corresponding block function. You can use a similar approach to model customized versions of the synchronizer. One example is the **Gearbox (Detailed)** subsystem in the model `sdl_manual_transmission`.

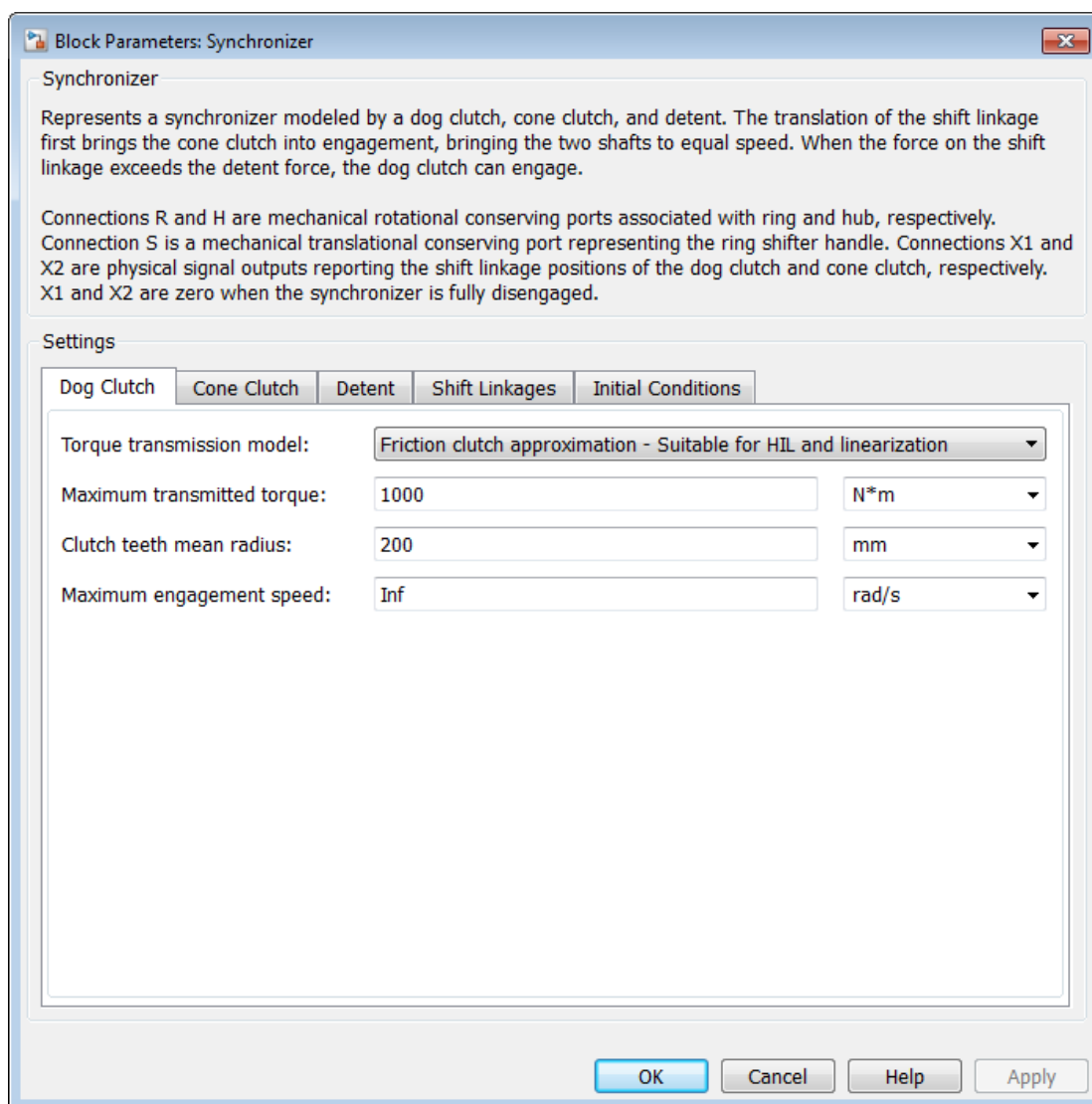
Connections R and H are mechanical rotational conserving ports that represent the ring (R) and hub (H), respectively. Connection S is a mechanical translational conserving port that represents the ring shifter handle.

Connections X1 and X2 are physical signal outputs that report the shift linkage positions of the dog clutch and cone clutch, respectively. The shift linkage positions are zero when the clutch is fully disengaged. When the dog clutch is fully engaged, the dog clutch shift linkage position has a magnitude equal to the sum of the dog clutch ring-hub gap and the tooth height. When cone clutch is fully engaged, the cone clutch shift linkage position has a magnitude equal to the cone clutch ring-hub gap.

## Assumptions and Limitations

- The model does not account for inertia effects. You can add a Simscape **Inertia** block at each port to add inertia to the synchronizer model.

## Dialog Box and Parameters



## Dog Clutch

### Torque Transmission Model

Model used to represent torque transmission. The default setting is `Friction clutch approximation - Suitable for HIL and linearization`.

The models provide the following common parameters:

#### Clutch teeth mean radius

Mean radius of the clutch teeth. The parameter must be greater than zero. The default value is 200 mm.

#### Maximum engagement speed

The relative angular speed between the ring and hub shafts above which the dog clutch cannot engage. The value is specific to the specific gearbox or transmission and must be minimized to avoid high dynamic impact during engagement. The default value is `inf rad/s`

#### Friction clutch approximation - Suitable for HIL and linearization

#### Maximum transmitted torque

Maximum expected torque across the clutch. The default value is 1000 Nm.

#### Dynamic with Backlash

#### Number of teeth

Number of teeth in the clutch. The parameter must be greater than or equal to one. The default value is 6.

#### Rotational backlash

Angular play of the ring with respect to the hub. Greater backlash values correspond to wider tooth gaps that makes engagement easier. The parameter must be greater than zero. The default value is 10 deg.

#### Torsional stiffness

Stiffness of the tooth contact. The model assumes deformation due to tooth interaction is elastic. The angular deformation at the contact surface is proportional to the applied torque and the reciprocal of the contact stiffness. The parameter must be greater than zero. The default value is `1e+7 N*m/rad`.

#### Torsional damping

Damping at the tooth contact surface. The value of the parameter is inversely proportional to the number of oscillations following impact. The parameter must be greater than zero. The default value is 2 N\*m/(rad/s).

#### **Tooth-tooth friction coefficient**

Friction coefficient for the translational relative motion between the hub and ring teeth. The value of the parameter depends on the tooth material, lubrication, and quality of contacting surfaces. The parameter must be greater than zero. The default value is 0.05.

## **Cone Clutch**

#### **Contact surface maximum diameter**

Outer diameter of the friction material lining that lines the cone clutch disks. The parameter must be greater than zero. The default value is 150 mm.

#### **Contact surface minimum diameter**

Inner diameter of the friction material lining that lines the cone clutch disks. The parameter must be greater than zero, but smaller than the value of **Contact surface maximum diameter**.

#### **Cone half angle**

Half angle of the clutch cone. The parameter must be greater than zero and less than or equal to 90°. The default value is 12 deg.

#### **Friction model**

Specification method for the kinetic friction coefficient between cone clutch disks in slipping conditions. Options include:

- **Fixed kinetic friction coefficient** — Specify a single value for the kinetic friction coefficient. This value is constant across all clutch relative velocities. Selecting this option exposes an additional parameter, **Kinetic friction coefficient**.
- **Table lookup kinetic friction coefficient** — Specify a lookup table with the kinetic friction coefficient values as a function of the clutch slip velocity. Selecting this option exposes additional parameters for the lookup table values and interpolation/extrapolation methods.

#### **Kinetic friction coefficient**

Kinetic friction coefficient between the friction surfaces of the cone clutch disks. The parameter must be greater than zero. The default value is 0.3.

**Kinetic friction coefficient relative velocity vector**

Vector with the clutch slip velocities at which to define the kinetic friction coefficient.

**Kinetic friction coefficient vector**

Vector with the kinetic friction coefficient values corresponding to the clutch slip velocities in **Kinetic friction coefficient relative velocity vector**.

**Friction coefficient interpolation method**

Method for calculating kinetic friction coefficients between lookup-table data points. Options include **Linear** and **Smooth**.

**Friction coefficient extrapolation method**

Method for calculating kinetic friction coefficient values outside of the lookup-table data range. Options include **Linear** and **Nearest**.

**Static friction coefficient**

Static friction coefficient between the friction surfaces of the cone clutch disks. The parameter must be greater than the kinetic friction coefficient. The default value is 0.35.

**Velocity tolerance**

Relative velocity between the cone clutch disks below which the disk friction surfaces lock. Surface locking requires that the torque across the R and H rotational ports be smaller than the product of the effective radius, the static friction coefficient, and the applied normal force. The default value is 0.001 rad/s.

**Threshold force**

Minimum value of the applied normal force for frictional torque transmittal to occur. If the value of the parameter exceeds the value of the applied normal force, no frictional torque is transmitted.

**Detent**

**Peak force**

Peak shear force of the detent. The default value is 500 N.

**Notch width**

Width of the region where the detent exhibits shear force. The default value is 3 mm.

**Viscous friction coefficient**

Viscous friction coefficient at the contact surface of the detent. The parameter must be greater than or equal to zero. The default value is 0.1 N/(m/s).

**Friction to peak force ratio**

Ratio of the kinetic friction to the peak shear force of the detent. The parameter is used to set the value of the kinetic friction. The parameter must be greater than or equal to zero. The default value is 0.01.

### **Friction velocity threshold**

Velocity required for peak kinetic friction at the contact surface of the detent. The parameter ensures the force is continuous when the travel direction changes, increasing the numerical stability of the simulation. The parameter must be greater than zero. The default value is 0.05 m/s.

## **Shift Linkages**

### **Linkage travel direction**

Direction the shift linkage must translate along in order to engage the clutch. The default setting is **Positive shift linkage displacement engages clutch**

### **Ring-hub clearance when dog clutch disengaged**

Distance between ring and dog clutch hub with the ring fully retracted. The parameter specifies the maximum travel distance if engagement requirements are not met. The parameter must be greater than the value of **Ring-hub clearance when cone clutch disengaged**. The default value is 5 mm.

### **Tooth overlap to engage**

Minimum value of the tooth overlap beyond which the dog clutch is considered engaged. The parameter must be greater than zero. The default value is 3 mm.

### **Tooth height**

Height of dog clutch teeth. The parameter must be greater than zero. The default value is 10 mm.

### **Ring-hub clearance when cone clutch disengaged**

Distance between the ring and cone clutch hub when the ring is fully retracted. The cone clutch can begin to engage once the slider has translated this distance. The ring can travel only this distance if the engagement requirements are not satisfied. The parameter must be greater than zero. The default value is 3 mm.

### **Hard stop at back of shift linkage**

Hard stop that prevents the shift linkage from traveling beyond the fully disengaged position. Choices include:

- No hard stop when fully disengaged
- Hard stop when fully disengaged

The default setting is **Hard stop when fully disengaged**.

### **Dog clutch ring stop stiffness**

Stiffness of the hard stops on both sides of the dog clutch ring. The model assumes the ring and stops behave elastically. Contact deformation is proportional to the applied force and the reciprocal of the contact stiffness. The value of the stiffness must be assigned with reference to the parameter **Tooth overlap to engage**. Too low a stiffness could cause the deformation to exceed the required overlap and initiate a false engagement. The parameter must be greater than zero. The default value is  $1\text{e}+6$  N/m.

### **Cone clutch ring stop stiffness**

Stiffness of the hard stops on both sides of the cone clutch ring. The model assumes the ring and stops behave elastically. Contact deformation is proportional to the applied force and the reciprocal of the contact stiffness. The parameter must be greater than zero. The default value is  $1\text{e}+6$  N/m.

### **Dog clutch ring stop damping**

Translational contact damping between the dog clutch ring and the hub. The value of the damping is inversely proportional to the number of oscillations that occur after impact. The parameter must be greater than zero. The default value is  $1\text{e}+3$  N/(m/s).

### **Cone clutch ring stop damping**

Translational contact damping between the cone clutch ring and the hub. The value of damping is inversely proportional to the number of oscillations that occur after impact. The parameter must be greater than zero. The default value is  $1\text{e}+3$  N/(m/s).

### **Viscous friction coefficient**

Viscous friction coefficient for the relative translational motion between the hub and the ring. The value of the parameter depends on lubrication state and quality of contacting surfaces. The coefficient must be greater than or equal to zero. The default value is  $100$  N/(m/s).

## **Initial Conditions**

### **Initial state**

Beginning configuration of cone and dog clutches. Choices include:

- **Both clutches unlocked**—Cone and dog clutches transmit zero torque between the ring and hub shafts.



- **Cone clutch locked**—Cone clutch transmits torque between the ring and hub shafts.
- **Both clutches locked**—Cone and dog clutches transmit torque between the ring and hub shafts.

The default value is **Both clutches unlocked**.

### **Dog clutch initial shift linkage position**

Initial position of the shift linkage section that attaches to the dog clutch. The value of the parameter has the following restrictions:

<b>Linkage Travel Direction</b>	<b>Dog Clutch State</b>	<b>Parameter Restriction</b>
Positive shift linkage displacement engages clutch	Initially engaged	Parameter must be greater than the sum of parameters <b>Ring-hub clearance when dog clutch disengaged</b> and <b>Tooth overlap to engage</b>
	Initially disengaged	Parameter must be smaller than the sum of parameters <b>Ring-hub clearance when dog clutch disengaged</b> and <b>Tooth overlap to engage</b>
Negative shift linkage displacement engages clutch	Initially engaged	Negative of the parameter must be greater than the sum of parameters <b>Ring-hub clearance when dog clutch disengaged</b> and <b>Tooth overlap to engage</b>
	Initially disengaged	Negative of the parameter must be smaller than the sum of parameters <b>Ring-hub clearance when dog clutch disengaged</b> and <b>Tooth overlap to engage</b>

The default value is 0 mm.

### **Cone clutch initial shift linkage position**

Initial position of the shift linkage section that attaches to the cone clutch. The value of the parameter has the following restrictions:

Linkage Travel Direction	Dog Clutch State	Parameter Restriction
Positive shift linkage displacement engages clutch	Initially engaged	Parameter must be greater than the value of <b>Ring-hub clearance when cone clutch disengaged</b>
	Initially disengaged	Parameter must be smaller than the value of <b>Ring-hub clearance when cone clutch disengaged</b>
Negative shift linkage displacement engages clutch	Initially engaged	Negative of the parameter must be greater than the value of <b>Ring-hub clearance when dog cone disengaged</b>
	Initially disengaged	Negative of the parameter must be smaller than the value of <b>Ring-hub clearance when dog cone disengaged</b>

The default value is 0 mm.

### Initial dog clutch ring-hub offset angle

Initial angle between the ring and hub portions of the dog clutch. To edit the parameter, you must set **Dog Clutch > Torque transmission model** to **Dynamic with backlash**. If the clutch is disengaged, the initial angle must lie in the range  $-\pi/N \leq \theta \leq +\pi/N$ , where  $N$  denotes the number of teeth in the dog clutch. If the clutch is engaged, the initial angle must be in the range  $-\delta/2 \leq \theta \leq +\delta/2$ , where  $\delta$  is the backlash angle. The default value is 0 deg.

## Ports

Port	Description
S	Conserving translational port that represents the shift linkage

Port	Description
R	Conserving rotational port that represents the ring shaft
H	Conserving rotational port that represents the hub shaft
X1	Physical signal output port that measures the magnitude of the dog clutch translation
X2	Physical signal output port that measures the magnitude of the cone clutch translation

### See Also

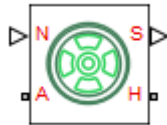
Cone Clutch | Dog Clutch | | Translational Detent

## Tire (Friction Parameterized)

Tire with friction parameterized in terms of static and kinetic coefficients

### Library

Tires & Vehicles



### Description

This block models a tire with friction parameterized in terms of static and kinetic coefficients. The static friction coefficient determines the applied torque at which the tire loses traction and begins to slip. The kinetic friction coefficient determines the amount of torque that the tire transmits to the pavement once it begins to slip. The tire regains traction once its relative velocity over the pavement falls below the traction velocity tolerance specified.

Port A represents the axle on which the tire sits. Port H represents the wheel hub that transmits the thrust generated by the tire to the remainder of the vehicle. Port N accepts a physical signal input of the normal force acting on the tire. The normal force is positive if it acts downward on the tire, pressing it against the pavement. Port S outputs a physical signal with the tire slip measured during simulation.

The block provides two friction variants. The default variant, **Fixed friction coefficients**, accepts the static and kinetic friction coefficients as block parameters. This variant treats the static coefficient as a constant. It treats the kinetic coefficient as a constant or function of tire slip. Use this variant to model tire dynamics under constant pavement conditions.

The alternative variant, **Variable friction coefficients**, accepts the static and kinetic friction coefficients as a physical signal input. Use this variant to model tire dynamics under variable pavement conditions. Selecting this variant exposes physical

signal port M. Use this port to provide the static and kinetic friction coefficients as a two-element vector, specified in this order.

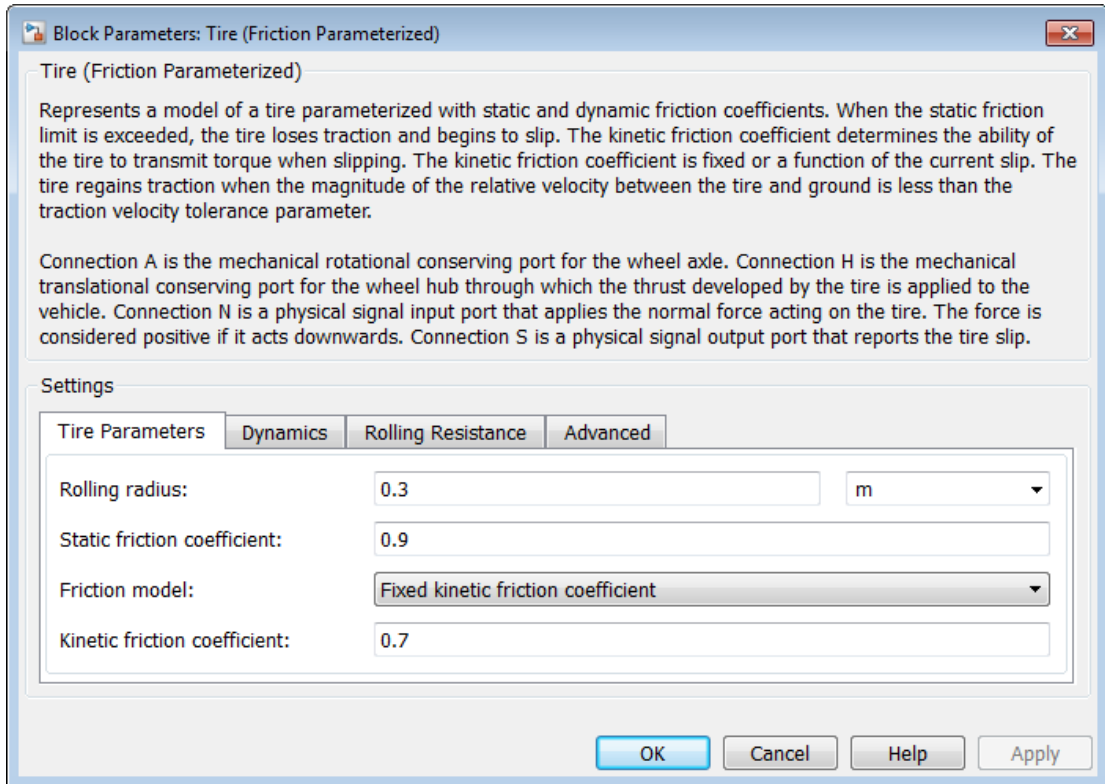
To change block variants:

- 1 Right-click the tire block.
- 2 In the context-sensitive menu, select **Simscape > Block choice**.
- 3 Select the desired block variant.

To increase the fidelity of the tire model, the block enables you to specify properties such as tire compliance, inertia, and rolling resistance. However, these properties increase the complexity of the tire model and can slow down simulation. Consider ignoring tire compliance and inertia if simulating the model in real time or if preparing the model for Hardware-in-Loop (HIL) simulation.

The traction state model of this block is based on that of the **Fundamental Friction Clutch** block. For more information on the state model, see “Clutch State, Transition, and Variable Summary”.

## Dialog Box and Parameters



### Tire Parameters

Use the **Tire Parameters** pane to specify characteristics of the tire, such as the rolling radius or static friction coefficient.

#### Rolling radius

Distance between the pavement and the center of the tire. This distance must be positive. The default value is 0.30 m.

#### Static friction coefficient

Ratio of the allowable longitudinal force to the normal force allowed before the tire begins to slip ( $\mu_s$ ). The parameter must be greater than either the kinetic friction

coefficient or the largest value in the kinetic friction coefficient vector. The default is 0.9.

This parameter is visible when the block variant is set to `Fixed friction coefficients`. For more information about the block variants, see the block description.

### Friction model

Parameterization through which to specify the kinetic friction coefficient. Options include:

- `Fixed kinetic friction coefficient` — (Default) Uses a constant kinetic function coefficient. Exposes **Kinetic friction coefficient** parameter.
- `Table lookup kinetic friction coefficient` — Uses a function of slip. Exposes **Tire slip vector** and **Kinetic friction coefficient vector** parameters.

This parameter is visible when the block variant is set to `Fixed friction coefficients`. For more information about the block variants, see the block description.

### Kinetic friction coefficient

Ratio of the transmitted longitudinal force to the normal force allowed during tire slip ( $\mu_k$ ). The ratio must be greater than zero. Default 0.7.

This parameter is visible when the tire variant is set to `Fixed friction coefficients` and the **Friction model** parameter is set to `Fixed kinetic friction coefficient`. For more information about the block variants, see the block description.

### Tire slip vector

Vector that contains values of tire slip that correspond to the kinetic friction coefficients in the **Kinetic friction coefficient vector** parameter. The vectors must be the same size. If the **Tire slip vector** parameter contains only nonnegative values, the slip versus friction function is assumed to be symmetric about the slip axis. Default vector is [0 0.02 0.06 0.15 0.6 1].

This parameter is visible when the tire variant is set to `Fixed friction coefficients` and the **Friction model** parameter is set to `Table lookup kinetic friction coefficient`. For more information about the block variants, see the block description.

### Kinetic friction coefficient vector

Vector that contains kinetic friction coefficients that correspond to the tire slip values specified in the **Tire slip vector** parameter. The vectors must be the same size.

Default vector is [0.89 0.88 0.8 0.75 0.7 0.7].

This parameter is visible when the tire variant is set to **Fixed friction coefficients** and the **Friction model** parameter is set to **Table lookup kinetic friction coefficient**. For more information about the block variants, see the block description.

### Interpolation method

Interpolation method for the lookup table to use for processing the tire slip-kinetic friction coefficient characteristic. Interpolation options include:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the **PS Lookup Table (1D)** block reference page.

This parameter is visible when the tire variant is set to **Fixed friction coefficients** and the **Friction model** parameter is set to **Table lookup kinetic friction coefficient**. For more information about the block variants, see the block description.

### Extrapolation method

Extrapolation method for the lookup table to use for processing the tire slip-kinetic friction coefficient characteristic.

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the **PS Lookup Table (1D)** block reference page.

This parameter is visible when the tire variant is set to **Fixed friction coefficients** and the **Friction model** parameter is set to **Table lookup kinetic friction coefficient**. For more information about the block variants, see the block description.



## Dynamics

### Compliance

Specifies whether the model includes longitudinal stiffness and damping.

- **No compliance - Suitable for HIL simulation** — (Default) Does not include longitudinal stiffness and damping.
- **Specify stiffness and damping** — Includes longitudinal stiffness and damping. Exposes the **Longitudinal stiffness** and **Longitudinal damping** parameters.

### Longitudinal stiffness

The longitudinal stiffness of the tire. The parameter must be greater than zero. Default is  $1e+6$  N/m.

The **Longitudinal stiffness** parameter appears if the **Compliance** parameter is **Specify stiffness and damping**.

### Longitudinal damping

The longitudinal damping of the tire. The parameter must be greater than zero. Default is  $1000$  N/(m/s).

The **Longitudinal damping** parameter appears if the **Compliance** parameter is **Specify stiffness and damping**.

### Inertia

Specifies whether the model the model includes tire inertia.

- **No inertia** — (Default) Does not include tire inertia.
- **Specify inertia and initial velocity** — Includes tire inertia and initial velocity. Exposes the **Tire inertia** and **Initial velocity** parameters.

### Tire inertia

The rotational inertia of the tire. The parameter must be greater than zero. Default is  $1$  kg\*m<sup>2</sup>.

The **Tire inertia** parameter appears if the **Inertia** parameter is **Specify inertia and initial velocity**.

### Initial velocity

The initial rotational velocity of the tire. Default is  $0$  rad/s.

The **Initial velocity** parameter appears if the **Inertia** parameter is **Specify inertia and initial velocity**.

## Rolling Resistance

### Rolling resistance

Option to turn on and off rolling resistance modeling in the tire. Settings you can select include:

- **No rolling resistance** — Ignore the effects of rolling resistance.
- **Specify rolling resistance** — Model the effects of rolling resistance using the selected parameterization. Selecting this setting causes the block to expose the **Resistance model** parameter.

### Resistance model

Parameterization with which to model rolling resistance in the tire. Options include **Constant coefficient** and **Pressure and velocity dependent**. The default setting is **Constant coefficient**.

### Constant coefficient

#### Constant Coefficient

Coefficient that sets the proportionality between the normal force and the rolling resistance force. The parameter must be greater than zero. The default value is 255.

### Velocity Threshold

Velocity at which the full rolling resistance force is transmitted to the rolling hub. The parameter ensures the force remains continuous during velocity direction changes, which increases the numerical stability of the simulation. The parameter must be greater than zero. The default value is 0.001 m/s.

### Pressure and velocity dependent

#### Tire pressure

Inflation pressure of the tire. The parameter must be greater than zero. The default value is 250e+3 Pa.

#### Alpha

Exponent of the tire pressure in the model equation. See “Pressure and Velocity Dependent Model” on page 1-226. The default value is -0.003.

**Beta**

Exponent of the normal force model equation. The default value is **0.97**.

**Coefficient A**

Velocity independent force component in the model equation. The parameter must be greater than zero. The default value is **84e-4**.

**Coefficient B**

Velocity dependent force component in the model equation. The parameter must be greater than zero. The default value is **6.2e-4 s/m**.

**Coefficient C**

Force component that depends on the square of the velocity term in the model equation. The parameter must be greater than zero. The default value is **1.6e-4 s<sup>2</sup>/m<sup>2</sup>**.

**Velocity Threshold**

Velocity at which the full rolling resistance force is transmitted to the rolling hub. The parameter ensures the force remains continuous during velocity direction changes, which increases the numerical stability of the simulation. The parameter must be greater than zero. The default value is **1e-3 m/s**.

**Advanced**

Use the **Advanced** tab to specify parameters that the state machine uses to determine the model of the tire.

**Traction velocity tolerance**

The magnitude of the relative velocity between the tire and ground at which the tire regains traction. Setting this value too low prevents the tire from entering a state where it has traction. Setting it too high can cause the tire to suddenly change velocity when the tire gains traction, and can result in an unstable simulation. The parameter must be greater than zero. Default is **0.01 m/s**.

**Engagement threshold force**

Normal force values below the **Engagement threshold force** are not applied to the tire. Setting this value too low can cause the tire to gain and lose traction rapidly. Setting this value too high can give unrealistically low static and dynamic friction forces. The parameter must be greater than zero. Default is **10 N**.

**Initial traction state**

Specifies whether the tire is initially in traction or slipping.

- Tire is initially slipping — (Default)
- Tire is initially in traction

## Ports

Port	Description
A	Conserving mechanical rotational port associated with the axle of the tire
H	Conserving mechanical translational port associated with the hub of the tire
N	Physical signal input port associated with the normal force on the tire
M	Physical signal input associated with the static and kinetic friction coefficients of the tire
S	Physical signal output port associated with the relative slip between the tire and road

## Example

The `sdl_4wd_dynamics` example model shows the use of the Tire (Friction Parameterized) block.

## See Also

Fundamental Friction Clutch | Tire (Simple) | Tire (Magic Formula) | Tire-Road Interaction (Magic Formula)

## More About

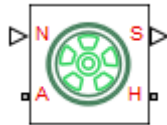
- “Clutch State, Transition, and Variable Summary”

# Tire (Magic Formula)

Tire with longitudinal behavior given by magic formula coefficients

## Library

Tires & Vehicles



## Description

This block models a tire with longitudinal behavior given by the magic formula, an empirical equation based on four fitting coefficients. The longitudinal direction of the tire is the same as its direction of motion as it rolls on pavement. This block is a structural component based on the **Tire-Road Interaction (Magic Formula)** block.

Port A represents the axle on which the tire sits. Port H represents the wheel hub that transmits the thrust generated by the tire to the remainder of the vehicle. Port N accepts a physical signal input of the normal force acting on the tire. The normal force is positive if it acts downward on the tire, pressing it against the pavement. Port S outputs a physical signal with the tire slip measured during simulation.

The block provides two friction variants. The default variant, **Fixed friction coefficients**, accepts the magic formula coefficients as block parameters. This variant treats the coefficients as constants or load-dependent parameters. Use this variant to model tire dynamics under constant pavement conditions.

The alternative variant, **Variable friction coefficients**, accepts the magic formula coefficients as a physical signal input. Use this variant to model tire dynamics under variable pavement conditions. Selecting this variant exposes physical signal port M. Use this port to provide the magic formula coefficients as a four-element vector, specified in the order  $[b, c, d, e]$ .

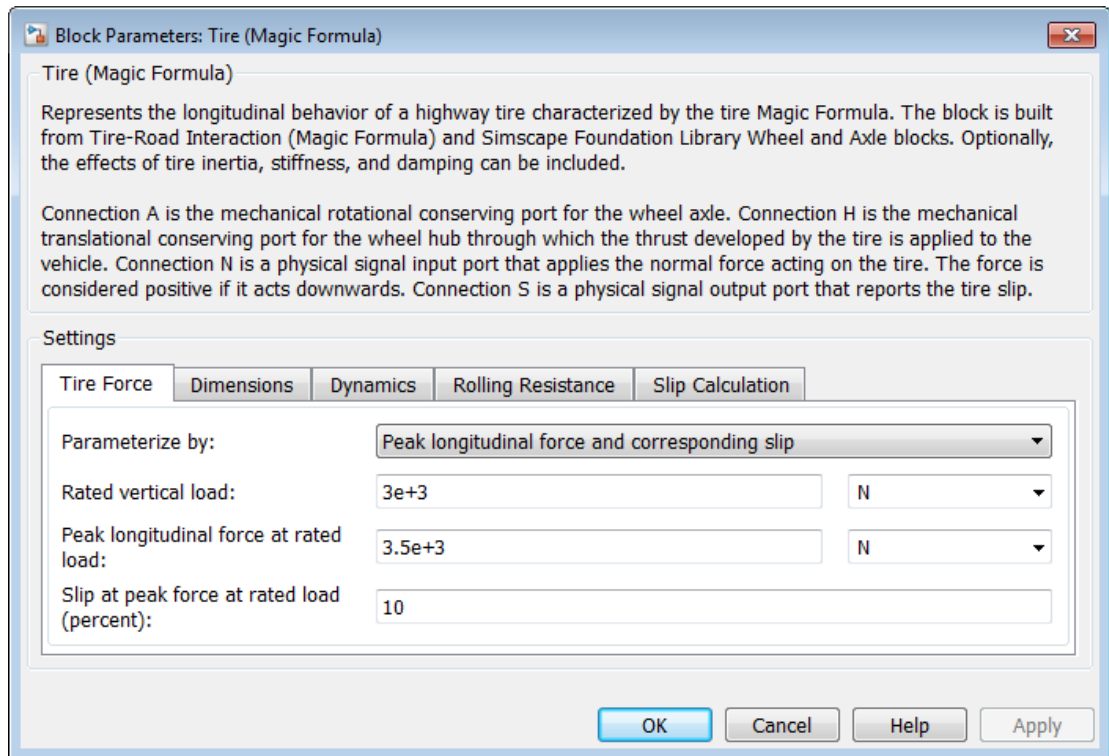
To change block variants:

- 1 Right-click the tire block.

- 2 In the context-sensitive menu, select **Simscape > Block choice**.
- 3 Select the desired block variant.

To increase the fidelity of the tire model, the block enables you to specify properties such as tire compliance, inertia, and rolling resistance. However, these properties increase the complexity of the tire model and can slow down simulation. Consider ignoring tire compliance and inertia if simulating the model in real time or if preparing the model for Hardware-in-Loop (HIL) simulation.

## Dialog Box and Parameters



### Tire Force

#### Parameterize by

Select how to use the Magic Formula to model the tire-road interaction. The default is **Peak longitudinal force and corresponding slip**. This tab appears only when the block variant is set to **Fixed friction coefficients**. For more information about the block variants, see the block description.

- **Peak longitudinal force and corresponding slip** — Parametrize the Magic Formula with physical characteristics of the tire.

### **Peak Force and Corresponding Slip**

#### **Rated vertical load**

Rated vertical load force  $F_{z0}$ . The default is **3e+3**.

From the drop-down list, choose units. The default is newtons (N).

#### **Peak longitudinal force at rated load**

Maximum longitudinal force  $F_{x0}$  that the tire exerts on the wheel when the vertical load equals its rated value  $F_{z0}$ . The default is **3500**.

From the drop-down list, choose units. The default is newtons (N).

#### **Slip at peak force at rated load (percent)**

The value of the contact slip  $\kappa'_0$ , in percent (%), when the longitudinal force equals its maximum value  $F_{x0}$  and the vertical load equals its rated value  $F_{z0}$ . The default is **10**.

- **Constant Magic Formula coefficients** — Parameterize the Magic Formula directly with its coefficients. If you select this option, the panel changes from its default.

### **Constant Magic Formula Coefficients**

#### **Magic formula coefficients**

Magic Formula  $B$ ,  $C$ ,  $D$ , and  $E$  coefficients. The defaults are:

<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>
10	1.9	1	0.97

- **Load-dependent Magic Formula coefficients**—Parametrize the Magic Formula directly with load-dependent coefficients. If you select this option, the panel changes from its default.

### Load-Dependent Magic Formula Coefficients

#### Tire nominal vertical load

Nominal normal force  $F_{z0}$  on tire. The default is  $4e+3$ .

From the drop-down list, choose units. The default is newtons (N).

#### Magic formula coefficient parameters

Specify the parameters that define the load-dependent  $C$ ,  $D$ ,  $E$ ,  $K$ ,  $H$ , and  $V$  coefficients as vectors, one for each coefficient. The defaults are:

Coefficient	Parameters	Default Values
C	$p_{Cx1}$	1.685
D	$[ p_{Dx1} p_{Dx2} ]$	$[ 1.21 -0.037 ]$
E	$[ p_{Ex1} p_{Ex2} p_{Ex3} p_{Ex4} ]$	$[ 0.344 0.095 -0.02 0 ]$
K	$[ p_{Kx1} p_{Kx2} p_{Kx3} ]$	$[ 21.51 -0.163 0.245 ]$
H	$[ p_{Hx1} p_{Hx2} ]$	$[ -0.002 0.002 ]$
V	$[ p_{Vx1} p_{Vx2} ]$	$[ 0 0 ]$

### Dimensions

#### Rolling radius

Unloaded tire-wheel radius  $r_w$ . The default is  $0.3$ .

From the drop-down list, choose units. The default is meters (m).

### Dynamics

#### Compliance

Select how to model the dynamical compliance of the tire. The default is **No compliance – Suitable for HIL simulation**.

- **No compliance – Suitable for HIL simulation** — Tire is modeled with no dynamical compliance.



- **Specify stiffness and damping**—Tire is modeled as a stiff, dampened spring and deforms under load. If you select this option, the panel changes from its default.

### **Tire Stiffness and Damping**

#### **Longitudinal stiffness**

Tire longitudinal stiffness  $C_{Fx}$ . The default is  $1e+6$ .

From the drop-down list, choose units. The default is newtons/meter (N/m).

#### **Longitudinal damping**

Tire longitudinal damping  $b_{Fx}$ . The default is 1000.

From the drop-down list, choose units. The default is newtons/(meters/second) (N/ (m/s)).

### **Inertia**

Select how to model the rotational inertia of the tire. The default is **No inertia**.

- **No inertia**—Tire is modeled with no inertia.
- **Specify inertia and initial velocity**—Tire is modeled with rotational inertia. If you select this option, the panel changes from its default.

### **Tire Rotational Inertia and Initial Velocity**

#### **Tire Inertia**

Rotational inertia  $I_w$  of the wheel-tire assembly. The default is 1.

From the drop-down list, choose units. The default is kilograms-meters-squared ( $kg \cdot m^2$ ).

#### **Initial velocity**

Initial angular velocity  $\Omega(0)$  of the tire. The default is 0.

From the drop-down list, choose units. The default is radians/second (rad/s).

## **Rolling Resistance**

### **Rolling resistance**

Method used to specify the rolling resistance acting on a rotating wheel hub. The default value is `No rolling resistance`. Options include:

- `No rolling resistance`

Select this option to ignore the effect of rolling resistance on a model.

- `Specify rolling resistance`

Select between two rolling resistance models: `Constant coefficient` and `Pressure and velocity dependent`.

The default value is `Constant coefficient`.

### **Constant coefficient**

#### **Constant Coefficient**

Coefficient that sets the proportionality between the normal force and the rolling resistance force. The parameter must be greater than zero. The default value is 255.

#### **Velocity Threshold**

Velocity at which the full rolling resistance force is transmitted to the rolling hub. The parameter ensures the force remains continuous during velocity direction changes, which increases the numerical stability of the simulation. The parameter must be greater than zero. The default value is 0.001 m/s.

### **Pressure and velocity dependent**

#### **Tire pressure**

Inflation pressure of the tire. The parameter must be greater than zero. The default value is 250e+3 Pa.

#### **Alpha**

Exponent of the tire pressure in the model equation. See “Pressure and Velocity Dependent Model” on page 1-226. The default value is -0.003.

#### **Beta**

Exponent of the normal force model equation. The default value is 0.97.

#### **Coefficient A**

Velocity independent force component in the model equation. The parameter must be greater than zero. The default value is 84e-4.

**Coefficient B**

Velocity dependent force component in the model equation. The parameter must be greater than zero. The default value is  $6.2e-4$  s/m.

**Coefficient C**

Force component that depends on the square of the velocity term in the model equation. The parameter must be greater than zero. The default value is  $1.6e-4$  s<sup>2</sup>/m<sup>2</sup>.

**Velocity Threshold**

Velocity at which the full rolling resistance force is transmitted to the rolling hub. The parameter ensures the force remains continuous during velocity direction changes, which increases the numerical stability of the simulation. The parameter must be greater than zero. The default value is  $1e-3$  m/s.

**Slip Calculation****Velocity threshold**

Wheel hub velocity  $V_{th}$  below which the slip calculation is modified to avoid singular evolution at zero velocity. Must be positive. The default is  $0.1$ .

From the drop-down list, choose units. The default is meters per second (m/s).

**Tire Model**

The Tire block models the tire as a rigid wheel-tire combination in contact with the road and subject to slip. When torque is applied to the wheel axle, the tire pushes on the ground (while subject to contact friction) and transfers the resulting reaction as a force back on the wheel. This action pushes the wheel forward or backward. If you include the optional tire compliance, the tire also flexibly deforms under load.

The figure shows the forces acting on the tire. The table defines the tire model variables.



### Tire Model Variables

Symbol	Description and Unit
$r_w$	Wheel radius
$V_x$	Wheel hub longitudinal velocity
$u$	Tire longitudinal deformation
$\Omega$	Wheel angular velocity
$\Omega'$	Contact point angular velocity = $\Omega$ if $u = 0$
$r_w\Omega'$	Tire tread longitudinal velocity
$V_{sx} = r_w\Omega - V_x$	Wheel slip velocity
$V'_{sx} = r_w\Omega' - V_x$	Contact slip velocity = $V_{sx}$ if $u = 0$
$\kappa = V_{sx} /  V_x $	Wheel slip
$\kappa' = V'_{sx} /  V_x $	Contact slip = $\kappa$ if $u = 0$
$V_{th}$	Wheel hub threshold velocity
$F_z$	Vertical load on tire

Symbol	Description and Unit
$F_x$	Longitudinal force exerted on the tire at the contact point.
$C_{F_x} = (\partial F_x / \partial u)_0$	Tire longitudinal stiffness under deformation
$b_{F_x} = (\partial F_x / \partial \dot{u})_0$	Tire longitudinal damping under deformation
$I_w$	Wheel-tire inertia; effective mass = $I_w / r_w^2$
$\tau_{\text{drive}}$	Torque applied by the axle to the wheel

## Tire Kinematics and Response

### Roll and Slip

If the tire did not slip, it would roll and translate as  $V_x = r_w \Omega$ . But the tire actually does slip and develops a longitudinal force  $F_x$  only in response to slip.

The wheel slip velocity is  $V_{sx} = r_w \Omega - V_x$ . The *wheel slip* is  $\kappa = V_{sx} / |V_x|$ . For a locked, sliding wheel,  $\kappa = -1$ . For perfect rolling,  $\kappa = 0$ .

### Slip at Low Speed

For low speeds,  $|V_x| \leq |V_{th}|$ , the wheel slip is modified to:

$$\kappa = 2V_{sx} / (V_{th} + V_x^2 / V_{th}) .$$

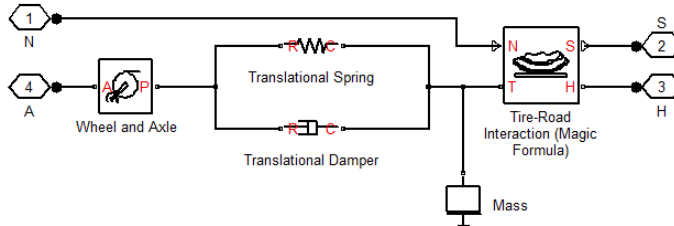
This modification allows for a nonsingular, nonzero slip at zero wheel velocity. For example, for perfect slipping (nontranslating spinning tire),  $V_x = 0$  while  $\kappa = 2r_w \Omega / V_{th}$  is finite.

### Deformation

If the tire is modeled with compliance, it is also flexible. Because in this case, the tire deforms, the tire-road contact point turns at a slightly different angular velocity  $\Omega'$  from the wheel  $\Omega$  and requires, instead of the wheel slip, the *contact point* or *contact patch slip*  $\kappa'$ . The block models the deforming tire as a translational spring-damper of stiffness  $C_{F_x}$  and damping  $b_{F_x}$ .

If the tire is not modeled with compliance, then  $\Omega' = \Omega$ ,  $V'_{sx} = V_{sx}$ , and  $\kappa' = \kappa$ . In this case, the tire starts simulation undeformed and remains undeformed.

## Tire and Wheel Dynamics



The full tire model is equivalent to this Simscape-Simscape Driveline component diagram. It simulates both transient and steady-state behavior and correctly represents starting from, and coming to, a stop. The Translational Spring and Translational Damper are equivalent to the tire stiffness  $C_{F_x}$  and damping  $b_{F_x}$ . Tire-Road Interaction (Magic Formula) models the longitudinal force  $F_x$  on the tire as a function of  $F_z$  and  $\kappa'$  using the Magic Formula, with  $\kappa'$  as the independent slip variable [1].

The Wheel and Axle radius is the wheel radius  $r_w$ . The Mass value is the effective mass,  $I_w/r_w^2$ . The tire characteristic function  $f(\kappa', F_z)$  determines the longitudinal force  $F_x$ . Together with the driveshaft torque applied to the wheel axis,  $F_x$  determines the wheel angular motion and longitudinal motion.

Without tire compliance, the Translational Spring and Translational Damper are omitted, and contact variables revert to wheel variables. In this case, the tire effectively has infinite stiffness, and port P of Wheel and Axle connects directly to port T of Tire-Road Interaction (Magic Formula).

Without tire inertia, the Mass is omitted.

## Limitations

The Tire (Magic Formula) block assumes longitudinal motion only and includes no camber, turning, or lateral motion.

## Tire Compliance

Tire compliance implies a time lag in the tire response to the forces on it. Time lag simulation increases model fidelity but reduces simulation performance. See “Adjust Model Fidelity”.

## Ports

Port	Description
A	Conserving mechanical rotational port associated with the axle of the tire
H	Conserving mechanical translational port associated with the hub of the tire
N	Physical signal input port associated with the normal force on the tire
M	Physical signal input associated with the static and kinetic friction coefficients of the tire
S	Physical signal output port associated with the relative slip between the tire and road

## Examples

These Simscape Driveline example models use the Tire (Magic Formula) block to include tires and tire-road load:

- `sdl_dual_clutch`
- `sdl_limited_slip_differential`
- `sdl_torsen_differential`
- `sdl_4wd_dynamics`
- `sdl_vehicle`

## References

[1] Pacejka, H. B. *Tire and Vehicle Dynamics*, Society of Automotive Engineers and Butterworth-Heinemann, Oxford, 2002, chapters 1,4,7, and 8

## See Also

Tire-Road Interaction (Magic Formula) | Translational Damper | Differential | Translational Spring | Vehicle Body

## **Related Examples**

- “Complete Vehicle Model”

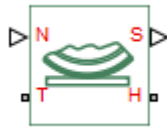


# Tire-Road Interaction (Magic Formula)

Tire-road dynamics given by magic formula coefficients

## Library

Tires & Vehicles/Tire Subcomponents



## Description

This block models the interaction between the tire tread and road pavement. The longitudinal force arising from this interaction is given by the magic formula, an empirical equation based on four fitting coefficients. Tire properties such as compliance and inertia are ignored.

Port T represents the tire tread. Port H represents the wheel hub that transmits the thrust generated by the tire to the remainder of the vehicle. Port N accepts a physical signal input of the normal force acting on the tire. The normal force is positive if it acts downward on the tire, pressing it against the pavement. Port S outputs a physical signal with the tire slip measured during simulation.

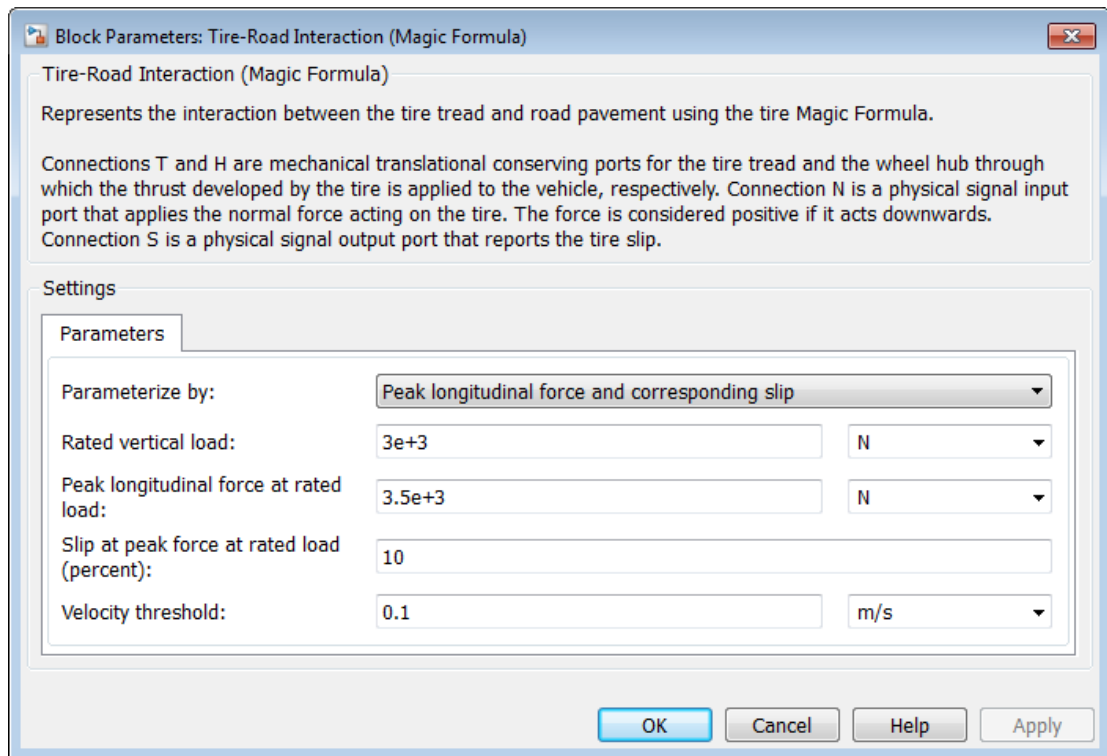
The block provides two friction variants. The default variant, **Fixed friction coefficients**, accepts the magic formula coefficients as block parameters. This variant treats the coefficients as constants or load-dependent parameters. Use this variant to model tire dynamics under constant pavement conditions.

The alternative variant, **Variable friction coefficients**, accepts the magic formula coefficients as a physical signal input. Use this variant to model tire dynamics under variable pavement conditions. Selecting this variant exposes physical signal port M. Use this port to provide the magic formula coefficients as a four-element vector, specified in the order  $[b, c, d, e]$ .

To change block variants:

- 1 Right-click the tire block.
- 2 In the context-sensitive menu, select **Simscape > Block choice**.
- 3 Select the desired block variant.

## Dialog Box and Parameters



### Parameterize by

Select how to use the Magic Formula to model the tire-road interaction. The default setting is **Peak longitudinal force and corresponding slip**. This and all dependent parameters are visible only when the block variant is set to **Fixed friction coefficients**. For more information about the block variants, see the block description.

- **Peak longitudinal force and corresponding slip** — Parametrize the Magic Formula with physical characteristics of the tire.

### Peak Force and Corresponding Slip

#### Rated vertical load

Rated vertical load force  $F_{z0}$ . The default is 3000.

From the drop-down list, choose units. The default is newtons (N).

#### Peak longitudinal force at rated load

Maximum longitudinal force  $F_{x0}$  that the tire exerts on the wheel when the vertical load equals its rated value  $F_{z0}$ . The default is 3500.

From the drop-down list, choose units. The default is newtons (N).

#### Slip at peak force at rated load (percent)

The value of the contact slip  $\kappa_0$ , in percent (%), when the longitudinal force equals its maximum value  $F_{x0}$  and the vertical load equals its rated value  $F_{z0}$ . The default is 10.

- **Constant Magic Formula coefficients** — Parametrize the Magic Formula directly with constant coefficients. If you select this option, the panel changes from its default.

### Constant Magic Formula Coefficients

#### Magic formula coefficients

Dimensionless Magic Formula  $B$ ,  $C$ ,  $D$ , and  $E$  coefficients. The defaults are:

B	C	D	E
10	1.9	1	0.97

- **Load-dependent Magic Formula coefficients** — Parametrize the Magic Formula directly with load-dependent coefficients. If you select this option, the panel changes from its default.

### Load-Dependent Magic Formula Coefficients

#### Tire nominal vertical load

Nominal normal force  $F_{z0}$  on tire. The default is  $4e+3$ .

From the drop-down list, choose units. The default is newtons (N).

### Magic formula coefficient parameters

Specify the parameters that define the load-dependent  $C$ ,  $D$ ,  $E$ ,  $K$ ,  $H$ , and  $V$  coefficients as vectors, one for each coefficient. The defaults are:

Coefficient	Parameters	Default Values
K	[ $p_{Kx1}$ $p_{Kx2}$ $p_{Kx3}$ ]	[ 21.51 -0.163 0.245 ]
H	[ $p_{Hx1}$ $p_{Hx2}$ ]	[ -0.002 0.002 ]
V	[ $p_{Vx1}$ $p_{Vx2}$ ]	[ 0 0 ]
C	$p_{Cx1}$	1.685
D	[ $p_{Dx1}$ $p_{Dx2}$ ]	[ 1.21 -0.037 ]
E	[ $p_{Ex1}$ $p_{Ex2}$ $p_{Ex3}$ $p_{Ex4}$ ]	[ 0.344 0.095 -0.02 0 ]

### Velocity threshold

The wheel hub velocity  $V_{th}$  below which the slip calculation is modified to avoid singular evolution at zero velocity. Must be positive. The default is 0.1.

From the drop-down list, choose units. The default is meters per second (m/s).

## Tire-Road Interaction Model

The Tire-Road Interaction (Magic Formula) block models the longitudinal forces at the tire-road contact patch using the Magic Formula of Pacejka [7].

The figure displays the forces on the tire. The table defines the tire model variables.



### Tire-Road Contact Variables

Symbol	Description and Unit
$\Omega$	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 = tread velocity T – hub velocity H
$\kappa = V_{sx} /  V_x $	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.

## Tire Response

### Forces and Characteristic Function

A tire 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  $\kappa$

### Magic Formula with Constant Coefficients

The Magic Formula is a specific form for the tire characteristic function, characterized by four dimensionless coefficients ( $B, C, D, E$ ), or stiffness, shape, peak, and curvature:

$$F_x = f(\kappa, F_z) = F_z \cdot D \cdot \sin( C \cdot \arctan[ \{ B\kappa - E \cdot [ B\kappa - \arctan(B\kappa) ] \} ] ) .$$

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

### Magic Formula with Load-Dependent Coefficients

A more general Magic Formula uses dimensionless coefficients that are functions of the tire load. A more complex set of parameters  $p_i$ , entered in the dialog box, specifies these functions:

$$F_{x0} = D_x \cdot \sin( C_x \cdot \arctan[ \{ B_x \kappa_x - E_x \cdot [ B_x \kappa_x - \arctan(B_x \kappa_x) ] \} ] ) + S_{Vx} ,$$

where

$$df_z = (F_z - F_{z0})/F_z ,$$

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

$$C_x = p_{Cx1} ,$$

$$D_x = \mu_x \cdot F_z ,$$

$$\mu_x = p_{Dx1} + p_{Dx2} \cdot df_z ,$$

$$E_x = (p_{Ex1} + p_{Ex2} \cdot df_z + p_{Ex3} \cdot df_z^2)[1 - p_{Ex4} \cdot \text{sgn}(\kappa_x)] ,$$

$$K_{xx} = F_z \cdot (p_{Kx1} + p_{Kx2} \cdot df_z) \cdot \exp(p_{Kx3} \cdot df_z) ,$$

$$B_x = K_{xx}/(C_x D_x + \varepsilon_x) ,$$

$$S_{Hx} = p_{Hx1} + p_{Hx2} \cdot df_z ,$$

$$S_{Vx} = F_z \cdot (p_{Vx1} + p_{Vx2} \cdot df_z) .$$

$S_{Hx}$  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.  $\mu_x$  is the

longitudinal load-dependent friction coefficient.  $\varepsilon_x$  is a small number inserted to prevent division by zero as  $F_z$  approaches zero.

### Peak Longitudinal Force and Corresponding Slip

The block uses a representative set of Magic Formula coefficients. The block scales the coefficients to yield the peak longitudinal force  $F_{x0}$  at the corresponding slip  $\kappa_0$  that you specify, for rated vertical load  $F_{z0}$ .

### Magic Formula Coefficients for Typical Road Conditions

Numerical values 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

## Limitations

The Tire-Road Interaction (Magic Formula) block assumes longitudinal motion only and includes no camber, turning, or lateral motion.

## Ports

Port	Description
A	Conserving mechanical rotational port associated with the axle of the tire
H	Conserving mechanical translational port associated with the hub of the tire
N	Physical signal input port associated with the normal force on the tire
M	Physical signal input associated with the static and kinetic friction coefficients of the tire

Port	Description
S	Physical signal output port associated with the relative slip between the tire and road

## See Also

Tire (Magic Formula) |

## Related Examples

- “Complete Vehicle Model”



# Tire (Simple)

No-slip tire model with minimal parameters

## Library

Tires & Vehicles



## Description

The block represents a simple, no-slip model of a tire parameterized by its radius. The model assumes an infinite torque transfer capability.

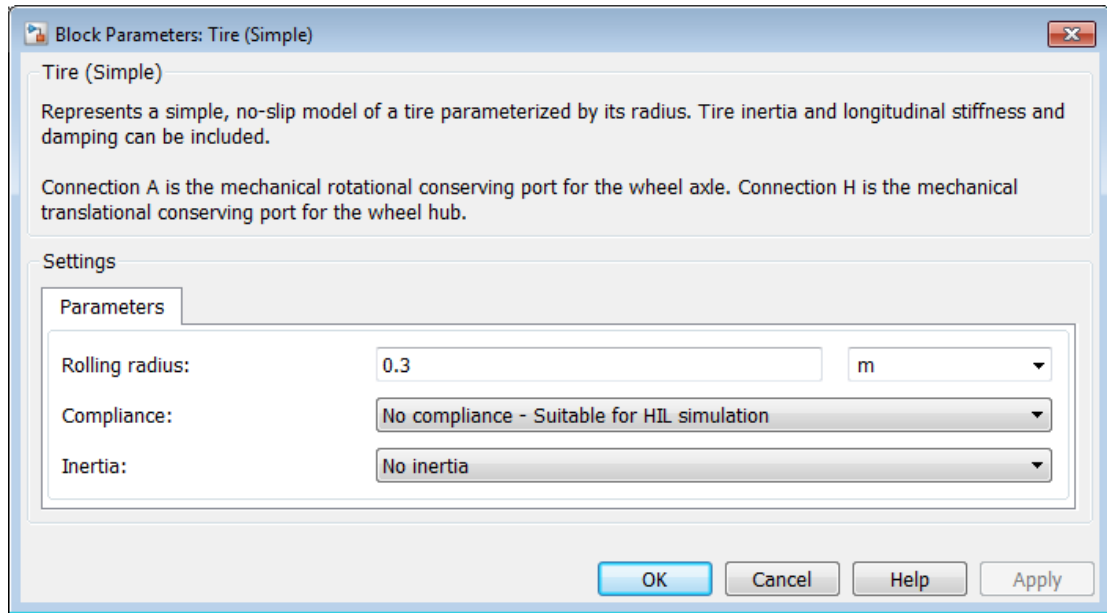
Connection A is a mechanical rotational conserving port associated with the axle of the tire. Connection H is a mechanical translational conserving port associated with the hub of the tire.

You can optionally add inertia, stiffness, or damping. These dynamics require additional computation and might make the model less suitable for real-time simulation.

## Assumptions and Limitations

- The tire does not slip.
- There is an infinite torque transfer capability.

## Dialog Box and Parameters



### Rolling radius

The rolling radius of the tire. The rolling radius must be greater than zero. Default is 0.3 m.

### Compliance

Specifies whether the model includes longitudinal stiffness and damping.

- **No compliance - suitable for HIL simulation** — (Default) Does not include longitudinal stiffness and damping.
- **Specify stiffness and damping** — Includes longitudinal stiffness and damping. Exposes the **Longitudinal stiffness** and **Longitudinal damping** parameters.

### Longitudinal stiffness

The longitudinal stiffness of the tire. The parameter must be greater than zero. Default is 1e6 N/m.

The **Longitudinal stiffness** parameter appears if the **Compliance** parameter is Specify stiffness and damping.

### Longitudinal damping

The longitudinal damping of the tire. The parameter must be greater than zero. Default is 100 N/(m/s).

The **Longitudinal damping** parameter appears if the **Compliance** parameter is Specify stiffness and damping.

### Inertia

Specifies whether the model includes tire inertia.

- **No inertia** — (Default) Does not include tire inertia.
- **Specify inertia and initial velocity** — Includes tire inertia and initial velocity. Exposes the **Tire inertia** and **Initial velocity** parameters.

### Tire inertia

The rotational inertia of the tire. The parameter must be greater than zero. Default is 1 kg\*/m<sup>2</sup>.

The **Tire inertia** parameter appears if the **Inertia** parameter is Specify inertia and initial velocity.

### Initial velocity

The initial rotational velocity of the tire. Default is 0 rad/s.

The **Initial velocity** parameter appears if the **Inertia** parameter is Specify inertia and initial velocity.

## Ports

Port	Description
A	Conserving mechanical rotational port associated with the axle of the tire
H	Conserving mechanical translational port associated with the hub of the tire

## Example

The `sdl_4wd_dynamics` example model shows the use of the Tire (Simple) block.

### **See Also**

Tire (Friction Parameterized) | Tire (Magic Formula) | Tire-Road Interaction (Magic Formula)

### **Related Examples**

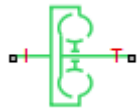
- “Complete Vehicle Model”

# Torque Converter

Viscous fluid coupling between rotating driveline shafts

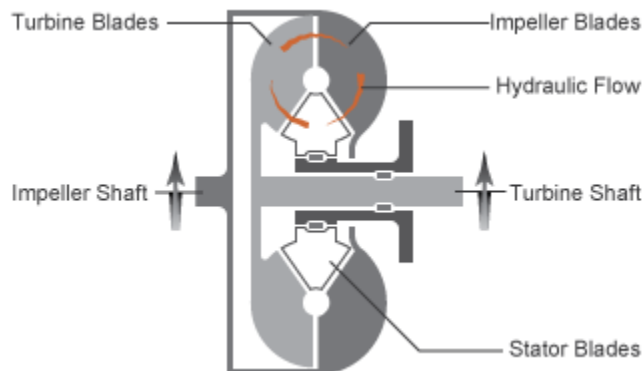
## Library

Couplings & Drives



## Description

A torque converter couples two driveline axes, transferring torque and angular motion by the hydrodynamic action of a viscous fluid. Unlike a friction clutch, a torque converter cannot lock the axes together. The Torque Converter block acts between the two ports I and T. The block acts as a lookup function of the relative angular velocity of the two connected driveline axes. This function is defined at discrete angular velocities. For model details, see “Torque Converter Model” on page 1-331.



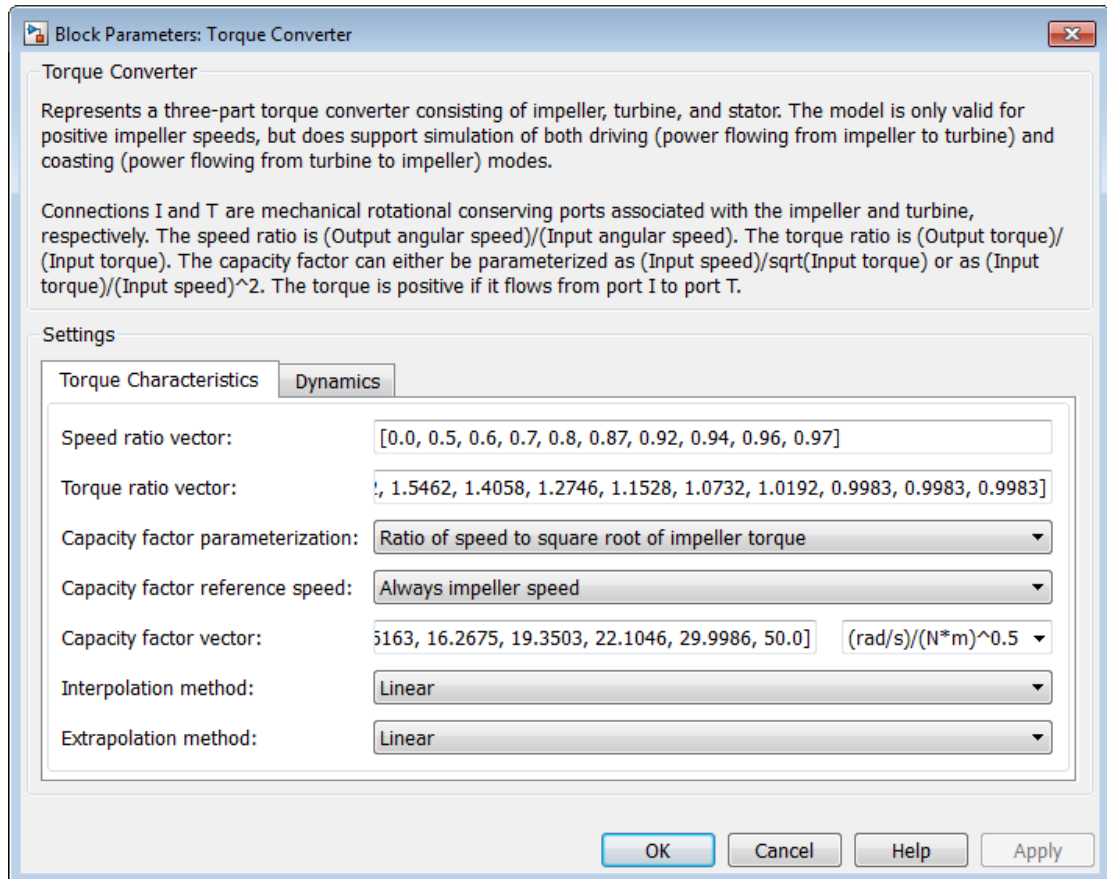
## Ports and Conventions

The impeller or pump port I and turbine port T are rotational conserving ports.

The Torque Converter block follows these conventions:

- The impeller port I is the port that connects to the engine, and the turbine port T is the port that connects to the load. In normal operation, power thus flows from the impeller to the turbine.
- Forward power flow implies power flowing from I to T. Reverse power flow implies power flowing from T to I.
- The power input is through the shaft with the larger speed. The power output is through the shaft with the smaller speed.

## Dialog Box and Parameters



### Torque Characteristics

#### Speed ratio vector

Vector of values of the independent variable, the dimensionless speed ratio  $R_\omega$ . You must order these values in ascending order.

#### Torque ratio vector

Vector of values of the block function's first dependent variable, the dimensionless torque ratio  $R_\tau$ . Each torque ratio value corresponds to a speed ratio value.

### Capacity factor parameterization

Definition of the capacity factor, either  $K$  (ratio of impeller speed  $\omega_I$  to square root of impeller torque  $\tau_I$ ) or  $K^*$  (ratio of  $\tau_I$  to  $\omega_I^2$ ). The default is  $K$ .

### Capacity factor reference speed

Choice of speed in the capacity factor definition, depending on speed ratio  $R_\omega$ . Select either:

- Impeller speed  $\omega_I$  for all values of  $R_\omega$ .
- Impeller speed  $\omega_I$  for  $R_\omega < 1$ , and turbine speed  $\omega_T$  for  $R_\omega > 1$ .

### Capacity factor vector

Vector of values of the block function's second dependent variable, the torque conversion capacity factor  $K$ . Each capacity factor value corresponds to a speed ratio value.

From the drop-down list, choose units.

- If you choose the default capacity factor definition  $K$ , the default units are radians/second/ $\sqrt{\text{newton-meters}}$  ( $\text{rad/s} / (\text{N}\cdot\text{m})^{0.5}$ ).
- If you choose the alternative capacity factor definition  $K^*$ , the default units are newton-meters/(radians/second)<sup>2</sup> ( $\text{N}\cdot\text{m} / (\text{rad/s})^2$ ).

### Interpolation method

Interpolates torque ratio and capacity factor functions between discrete relative velocity values within the range of definition. The default is **Linear**.

### Extrapolation method

Extrapolates torque ratio and capacity factor functions outside the range of definition. The default is **Linear**.

## Dynamics

### Model transmission lag

Select how to model transmission lag from input to output driveshaft. The default is **Specify time constant and initial torque**.

- **No lag** — Suitable for HIL simulation — Torque transfer is instantaneous.



- Specify time constant and initial torque ratio — Torque is transferred with a time lag. If you select this option, the panel changes from its default.

### Time Constant and Initial Torque Ratio

#### Torque transmission time constant

Dynamic torque transfer time constant  $t_c$ . The default is 0.02.

From the drop-down list, choose units. The default is seconds (s).

#### Initial turbine-to-impeller torque ratio

Ratio of turbine torque  $\tau_T$  to impeller torque  $\tau_I$  at the start of the simulation.

## Torque Converter Model

The torque converter is a mechanism for transferring torque between impeller and turbine shafts. Because the coupling of I and T occurs by viscous action, the torque transfer depends on the difference  $\omega = \omega_T - \omega_I \neq 0$ , or the speed ratio  $R_\omega \neq 1$ . In normal operation, the two axes have different speeds, and the output axis speed never exactly reaches the input axis speed. The torque transfer is largest when  $R_\omega \rightarrow 0$  or  $\infty$ , and shrinks as  $R_\omega \rightarrow 1$ . Because  $R_\omega$  can never reach exactly one, a torque converter always transfers some torque.

## Speed Ratio, Torque Ratio, and Capacity Factor

You specify the torque ratio and the capacity factor of the torque converter as discrete functions of the speed ratio with tabular vector entries. The three vectors of the variable values must have the same length.

- The speed ratio  $R_\omega$  is the turbine angular speed divided by the impeller angular speed:  
 $R_\omega = \omega_T / \omega_I$ .
- The torque ratio  $R_\tau$  is the output (turbine) torque divided by the input (impeller) torque:  
 $R_\tau = \tau_T / \tau_I$ .
- The capacity factor  $K$  or  $K^*$  is defined in two ways for  $R_\omega < 1$ , with either the default or the alternative definition:

- Default, the input speed divided by the square root of the input torque:  

$$K = \omega_I / \sqrt{\tau_I}$$
- Alternative, the input torque divided by the square of the input speed:  

$$K^* = \tau_I / \omega_I^2$$
- The capacity factor reference speed for  $R_\omega > 1$  is  $\omega_I$  by default. That is, the input speed  $\omega_I$  is used in the ratio that defines either  $K$  or  $K^*$ .

For  $R_\omega > 1$ , the alternative choice for reference speed is to replace  $\omega_I$  by the output speed  $\omega_T$  in this defining ratio.

The two dependent variables,  $R_\tau$  and  $K$ , are functions of the independent variable  $R_\omega$ . They specify the characteristics of the torque converter:  
 $R_\tau = R_\tau(R_\omega)$ ,  $K = K(R_\omega)$ .

### Continuation Near Speed Ratio of Unity

If you do not specify capacity factor data for a speed ratio of 1, the block uses a capacity factor value of  $10 \cdot K_{\text{Max}}$ , where  $K_{\text{Max}}$  is the maximum value in the specified capacity factor vector. The corresponding torque ratio is assumed to be 0. For all other speed ratio values not explicitly specified in the lookup table data, the block uses the interpolation or extrapolation method selected in the block dialog box.

### Instantaneous Torque Transfer

When there is no time lag, the input impeller (I) and output turbine (T) torques are:

$$\tau_I = \text{sgn}(1 - \omega_T/\omega_I) [\omega_I / K]^2, \tau_T = \tau_I \cdot R_\tau,$$

in normal operation (forward power flow).

### Lagged Torque Transfer

You can optionally include the effect of torque transmission time lag, caused by internal fluid flow and compressibility. Instead of  $\tau_T$  and  $\tau_I$  being instantaneously constrained to one another, a first-order time lag introduces a delayed response in the impeller torque:  
 $t_c \cdot (d\tau_I/dt) + \tau_I = \tau_I(\text{steady state})$ .

The preceding instantaneous function of the capacity factor  $K$  determines the steady-state value of  $\tau_I$ .

## Limitations

The impeller shaft must always rotate in a positive direction. Simulation is not valid for  $\omega_I < 0$ .

If you drive the Torque Converter from a torque source, such as the Generic Engine, you must include an inertia in the source, to represent the engine, shaft inertia, or other source components. You must set the initial speed for this inertia to a positive value to ensure that the impeller starts by rotating in a positive direction.

## Torque Transmission Time Lag

Torque converters lag in their response to changing input torque. By default, Torque Converter includes no time lag in its response. You can include a response lag by specifying a time constant. Time lag simulation increases model fidelity but reduces simulation performance. See “Adjust Model Fidelity”.

## Examples

These Simscape Driveline example models include torque converters as part of complete drivetrains:

- `sdl_4wd_dynamics`
- `sdl_vehicle`

## Reference

Society of Automotive Engineers, *Hydrodynamic Drive Test Code (Surface Vehicle Recommended Practice)*, SAE J643, May 2000.

## See Also

Disk Friction Clutch | Fundamental Friction Clutch | Generic Engine

## Related Examples

- “Complete Vehicle Model”

# Torsional Spring-Damper

Rotational spring and damper coupling, with Coulomb friction, locking, and hard stops

## Library

Couplings & Drives

## Description



The Torsional Spring-Damper block represents a dynamic element that imposes a combination of internally generated torques between the two connected driveshaft axes, the rod and the case. The complete torque includes these components:

- Linear damped spring
- Coulomb friction (including locking static friction)
- Hard stop compliance

The second and third components are optional. For model details, see “Torsional Spring-Damper Model” on page 1-337.

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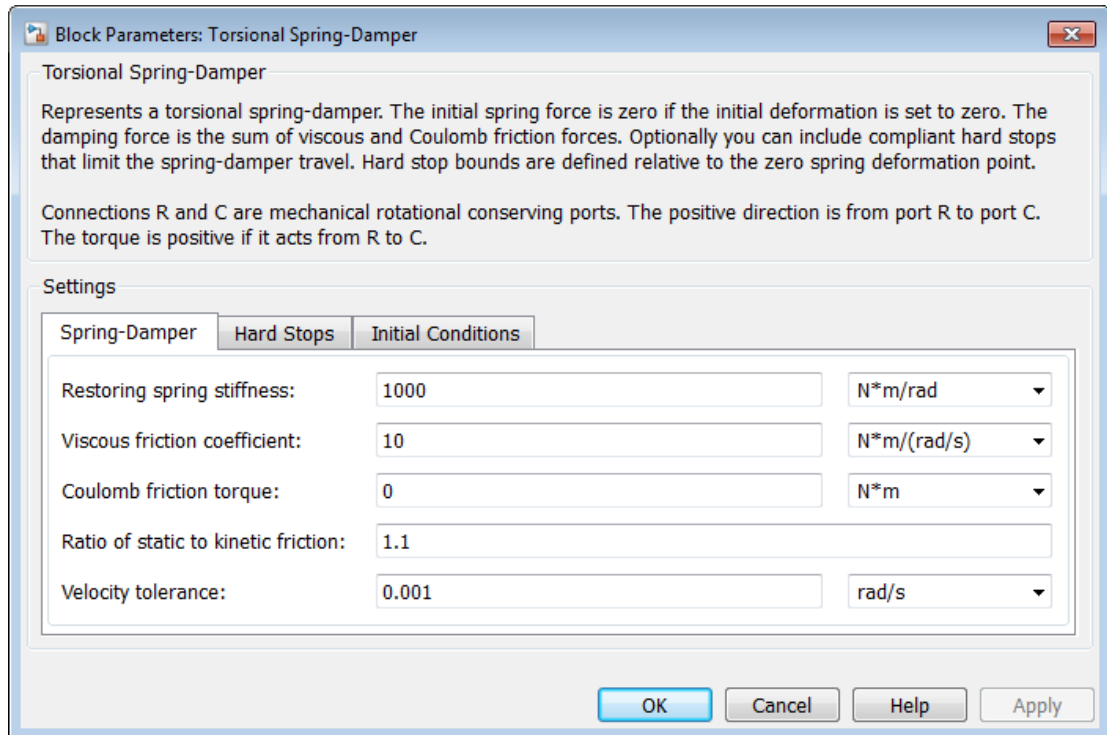
**Note:** Torsional Spring-Damper is based on the Loaded-Contact Rotational Friction block and the Simscape Rotational Spring, Rotational Damper, and Rotational Hard Stop blocks. (The first and fourth blocks are required for Coulomb friction and hard stops, respectively.) For more information, see these block reference pages.

---

## Ports

R and C are rotational conserving ports representing, respectively, the rod and case driveshafts. The relative motion is measured as  $\omega = \omega_R - \omega_C$ , the angular velocity of rod relative to case.

## Dialog Box and Parameters



### Spring-Damper

#### Restoring spring stiffness

Torsional spring stiffness  $k$  acting between connected driveshafts. Must be greater than zero. The default is 1000.

From the drop-down list, choose units. The default is newton-meters/radian ( $\text{N}\cdot\text{m}/\text{rad}$ ).

#### Viscous friction coefficient

Torsional damping  $\mu$  acting between the connected driveshafts. Must be greater than or equal to zero. The default is 10.

From the drop-down list, choose units. The default is newton-meters/(radian/second) ( $\text{N}\cdot\text{m}/(\text{rad}/\text{s})$ ).

### **Coulomb friction torque**

Constant kinetic friction torque  $\tau_K$  acting between connected driveshafts. Must be greater than or equal to zero. The default is 0.

From the drop-down list, choose units. The default is newton-meters ( $\text{N}\cdot\text{m}$ ).

### **Ratio of static to kinetic friction**

Constant ratio  $R$  of static Coulomb friction torque  $\tau_S$  to kinetic Coulomb friction torque  $\tau_K$  acting between connected driveshafts. Must be greater than one. The default is 1.1.

### **Velocity tolerance**

Minimum relative angular speed  $\omega_{\text{Tol}}$  below which the two connected driveshafts can lock and rotate together. Must be greater than zero. The default is 0.001.

From the drop-down list, choose units. The default is radians/second ( $\text{rad}/\text{s}$ ).

## **Hard Stops**

### **Hard stop model**

Select how to model the hard stops. The default is **No hard stops – Suitable for HIL simulation**.

- **No hard stops** — Do not include hard stops in relative motion of connected driveshafts.
- **Compliant hard stops** — Model friction geometry in terms of annulus dimensions. If you select this option, the panel changes from its default.

### **Compliant hard stops**

#### **Upper bound**

Upper hard stop angular displacement  $\delta_+$  from the zero-torque reference angle  $\phi = 0$ . Must be greater than  $\delta_-$ . The default is 10.

From the drop-down list, choose units. The default is degrees (**deg**).

#### **Lower bound**

Lower hard stop angular displacement  $\delta_-$  from the zero spring force reference angle  $\phi = 0$ . Must be less than  $\delta_+$ . The default is  $-10$ .

From the drop-down list, choose units. The default is degrees (**deg**).

### Contact stiffness

Hard stop stiffness  $k_{HS}$  applied if the relative angle  $\phi$  moves into the hard stop region. Must be greater than zero. The default is  $1e+6$ .

From the drop-down list, choose units. The default is newton-meters/radian ( $N \cdot m / rad$ ).

### Contact damping

Hard stop damping  $\mu_{HS}$  applied if the relative angle  $\phi$  moves into the hard stop region. Must be greater than zero. The default is  $10$ .

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (rad / s)$ ).

## Initial Conditions

### Initial deformation

Initial deformation of the torsional spring relative to the zero-torque reference angle  $\phi = 0$ . The default is  $0$ .

From the drop-down list, choose units. The default is degrees (**deg**).

## Torsional Spring-Damper Model

The complete torque  $\tau$  imposed by Torsional Spring-Damper between the connected driveshafts is the sum of three terms: stiff-damping, hard stop compliance, and Coulomb.  
 $\tau = \tau_{SD} + \tau_{HS} + \tau_C$ .

The table summarizes the torsional spring-damper variables.

### Torsional Spring-Damper Variables

Symbol	Definition	Significance
$\phi$	Relative angle between ring and hub	Relative angular position of ring and hub

Symbol	Definition	Significance
$\omega$	Relative angular velocity	$\omega = \omega_R - \omega_C$
$k$	Torsional stiffness	<i>See the following model</i>
$\mu$	Torsional damping	<i>See the following model</i>
$\delta_+, \delta_-$	Upper and lower hard stop angular displacements	<i>See the following model</i>
$k_{HS}$	Contact stiffness applied in hard stop regions	<i>See the following model</i>
$\mu_{HS}$	Contact damping applied in hard stop regions	<i>See the following model</i>
$\tau_K$	Kinetic friction	Constant sliding Coulomb friction
$\tau_S$	Static friction	Constant locking Coulomb friction
$R$	$\tau_S/\tau_K$	Ratio of static to kinetic Coulomb friction
$\omega_{Tol}$	Maximum relative speed for clutch locking	<i>See the following model</i>

## Stiffness and Damping

The stiff-damping torque is a simple linear spring-damping:

$$\tau_{SD} = -k\phi - \mu\omega .$$

## Hard Stops

The hard stop torque is applied if  $\phi$  moves outside the angular gap between the upper and lower hard stop bounds.

$T_{HS}$	Range
$-k_{HS}(\phi - \delta_+) - \mu_{HS}\omega$	$\phi > \delta_+$
0	$\delta_- < \phi < \delta_+$
$-k_{HS}(\phi - \delta_-) - \mu_{HS}\omega$	$\phi < \delta_-$



## Coulomb Friction — Locking

The Coulomb friction torque is a constant  $\tau_K$  if  $\omega$  is nonzero (unlocked), and a constant  $\tau_S$  if  $\omega$  is zero (locked).

$$\tau_S = R\tau_K.$$

### Locking Conditions

The Torsional Spring-Damper locks the connected driveshafts together if both:

- $|\omega| < \omega_{Tol}$
- The torque across the torsional spring-damper is less than  $\tau_S$ .

If the clutch locks,  $\omega$  is reset to zero. If the torque across the torsional spring-damper exceeds  $\tau_S$ , the driveshafts unlock from one another, and  $\omega$  becomes nonzero.

### See Also

[Dog Clutch](#) | [Loaded-Contact Rotational Friction](#) | [Rotational Damper](#) | [Rotational Hard Stop](#) | [Rotational Spring](#)

### Related Examples

- “Gear Coupling Control with Clutches”

# Translational Detent

Double-sided, spring-loaded translational detent

## Library

Brakes & Detents/Translational



## Description

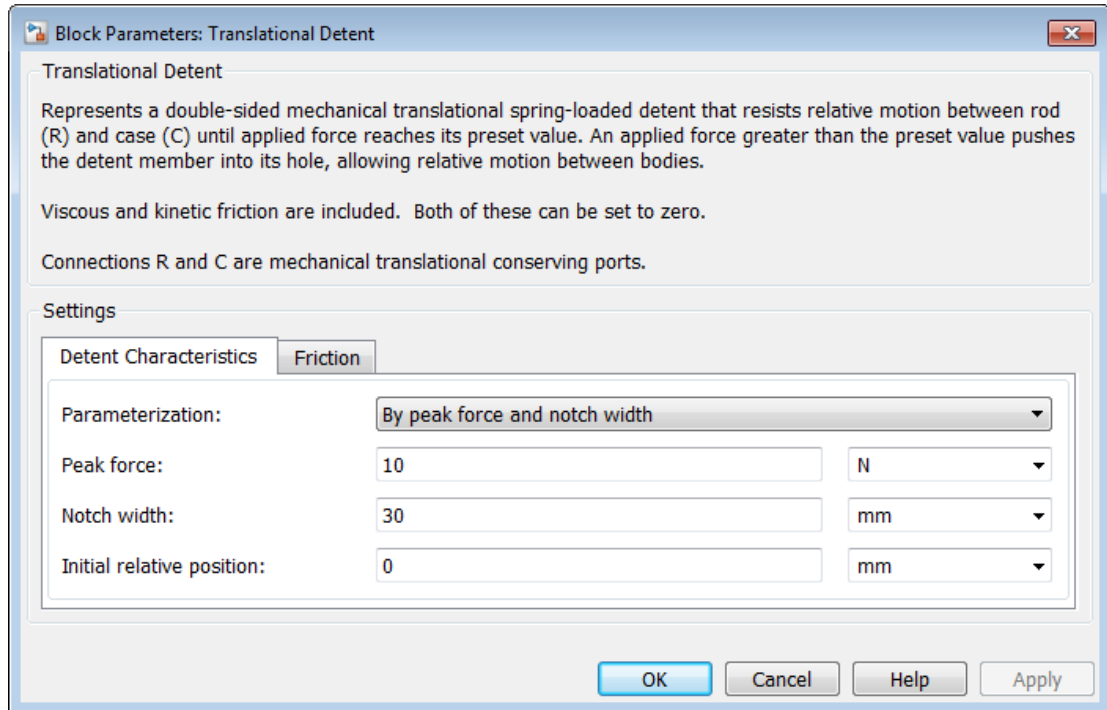
The Translational Detent block represents a double-sided, spring-loaded translational detent with a ball and conical notch.

The detent slider slides horizontally over the detent case. These two parts develop a horizontal shear force between them. The inside of the slider is the conical notch. The detent case contains a vertical spring. The detent ball lies between the spring and the conical notch. With the block, you can model ball and angled notch detents with geometric and spring characteristics, peak force and notch width, or a lookup table. The model also includes viscous damping and kinetic friction between the slider and case. You can set the friction to zero.

## Ports

R and C are translational conserving ports associated with the slider and case, respectively.

## Dialog Box and Parameters



## Detent Characteristics

### Parameterization

Select how to specify the detent characteristics. The default is **By peak force and notch width**.

- **By peak force and notch width** — Specify detent characteristics by the peak shear force and the notch width.

### Peak Force and Notch Width

#### Peak force

The peak shear force developed inside the detent. The default is 10.

From the drop-down list, choose units. The default is newtons (N).

### **Notch width**

The width of the region where the shear force develops. The default is 30.

From the drop-down list, choose units. The default is millimeters (mm).

- **By lookup table** — Define the detent characteristics by one-dimensional table lookup based on the relative displacement between the slider and case. If you select this option, the panel changes from its default option.

### **Lookup Table**

#### **Relative displacement vector**

Specify the vector of input relative displacements that correspond to the values in **Force vector**. These two vectors must be of the same size. The displacements must be specified in strictly increasing order. The default values are [-15 -12.3 -7.6 -1.1 1.1 7.6 12.3 15].

From the drop-down list, choose units. The default is millimeters (mm).

#### **Force vector**

Specify the vector of input values for the shear force that correspond to the values in **Relative displacement vector**. The default values are [0 0 -8.365 -5.87 5.87 8.365 0 0].

From the drop-down list, choose units. The default is newtons (N).

#### **Interpolation method**

Select one of the following interpolation methods for approximating the output value when the input value is between two consecutive grid points:

- **Linear** — Select this option to get the best performance.
- **Smooth** — Select this option to produce a continuous curve with continuous first-order derivatives.

For more information on interpolation algorithms, see the **PS Lookup Table (1D)** block reference page.

#### **Extrapolation method**

Select one of the following extrapolation methods for determining the output value when the input value is outside the range specified in the argument list:

- **Linear** — Select this option to produce a curve with continuous first-order derivatives in the extrapolation region and at the boundary with the interpolation region.
- **Nearest** — Select this option to produce an extrapolation that does not go above the highest point in the data or below the lowest point in the data.

For more information on extrapolation algorithms, see the **PS Lookup Table (1D)** block reference page.

- **By geometry** — Define the detent characteristics by ball-notch geometry and dynamics. If you select this option, the panel changes from its default option.

### **Geometric and Spring Parameters**

#### **Ball diameter**

Specify the diameter of the ball. The default is 12.

From the drop-down list, choose units. The default is millimeters (mm).

#### **Notch angle**

Specify the full angle of the notch. Must be greater than 0 and less than or equal to 179 degrees. The default is 120.

From the drop-down list, choose units. The default is degrees (deg).

#### **Notch depth**

Specify the depth of the notch in the slider. Must be greater than zero. The default is 4.5.

From the drop-down list, choose units. The default is millimeters (mm).

#### **Preload force**

Specify the force to which the detent spring is preloaded. Must be greater than or equal to 0. The default is 15.

From the drop-down list, choose units. The default is newtons (N).

#### **Spring stiffness**

Specify the stiffness of the detent spring. Must be greater than 0. The default is 3000.

From the drop-down list, choose units. The default is newtons/meter (N/m).

### **Shear reversal region**

Specify the width of the region where the ball moves from one notch face to the other. Must be greater than 0. The default is 0.1.

From the drop-down list, choose units. The default is millimeters (mm).

### **Initial relative position**

The relative displacement of the slider and case when simulation starts. The default is 0.

From the drop-down list, choose units. The default is millimeters (mm).

## **Friction**

### **Viscous friction coefficient**

Specify the viscous friction coefficient for the ball-notch contact. Must be greater than or equal to 0. The default is 0.1.

From the drop-down list, choose units. The default is newtons/(meters/second) (N/(m/s)).

### **Friction to peak force ratio**

Specify the kinetic friction coefficient for the ball-notch contact. Must be greater than or equal to 0. The default is 0.01.

The kinetic friction is this ratio multiplied by the peak shear force.

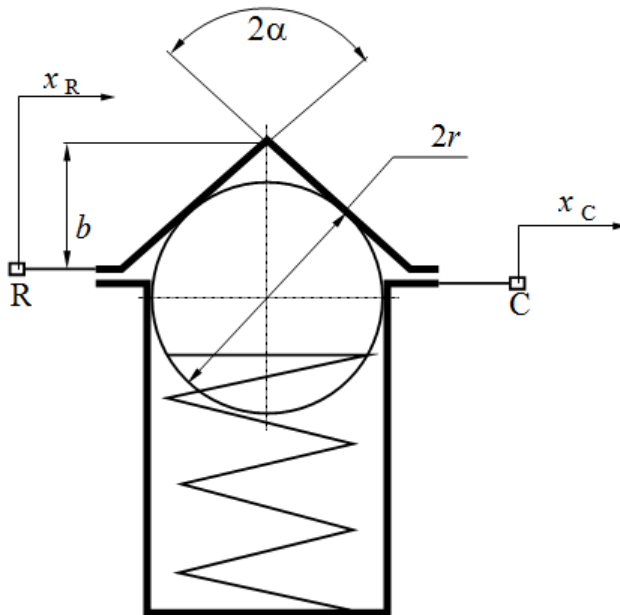
### **Friction velocity threshold**

Specify the relative velocity required for peak kinetic friction in the detent. Must be greater than 0. The default is 0.05.

From the drop-down list, choose units. The default is meters/second (m/s).

## Translational Detent Model

The geometry of the ball-notch detent is shown in the following figure. As the conical slider slides horizontally over the case, the relative displacement  $x = x_R - x_C$  causes a horizontal shear force  $F$  to develop.

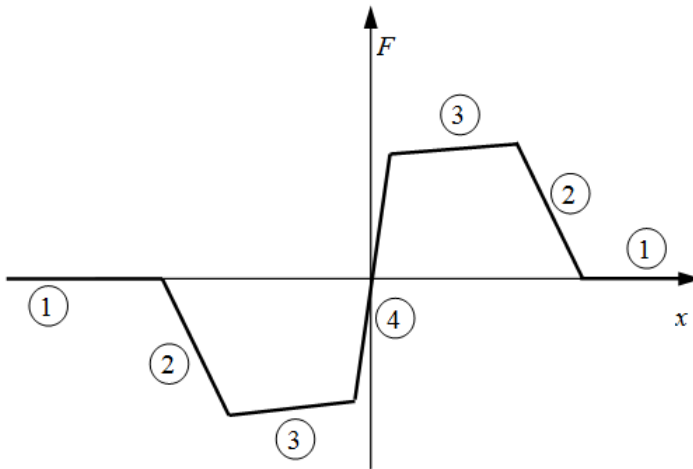


$b$	Notch depth
$r$	Ball radius
$a$	Notch half angle

Depending on your choice of parameterization, the shear force model is defined by geometric and spring parameters, by the peak force and notch width, or by a lookup table specifying relative displacement versus force.

### Geometric and Spring Parameters

The geometric and spring parameterization uses four regions to define the shear force. The following figure displays these regions.



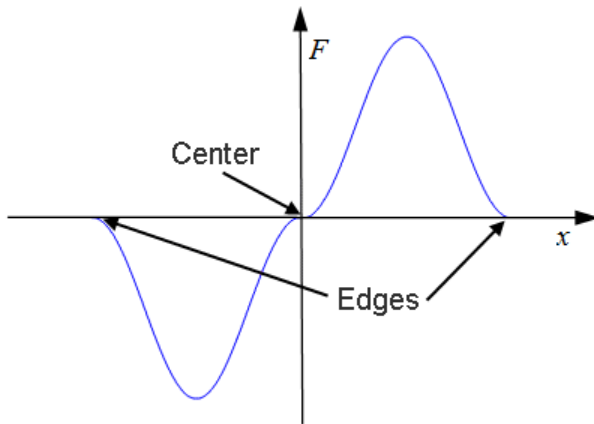
Because the ball is spherical and the notch is symmetric, the horizontal force versus displacement function is symmetric about the origin. (See “Peak Force and Notch Width” on page 1-346.)

Reg	Ball Position and Contact Angle	Shear Force
1	Ball is outside conical notch. Contact angle is vertical.	Viscous damping and kinetic friction only. No spring contribution.
2	Ball is entering notch, in contact with notch corner. Contact angle rotates from vertical.	Spring, viscous damping, and kinetic friction contributions. Peaks at transition from region 2 to region 3.
3	Ball slides along face of notch. Contact angle is constant.	Force decreases as spring extends, but does not go to zero (spring preload force).
4	Ball moves from one face to the other. Contact angle switches direction.	Force switches direction. Shear reversal region width controls how smooth this switch is.

## Peak Force and Notch Width

If you choose the peak force and notch width parameterization, the block ensures that the force-relative displacement curve provides a continuous force and force derivative over the detent region. The peak forces are halfway between the detent center and detent edge, as shown in the following figure.





## Lookup Table

With the lookup table parameterization, you can create an arbitrary function relating shear force to relative displacement. If you create such a function, consider the following best practices.

### Energy Conservation

If you want to ensure that the detent conserves energy, the total integral of the force-relative displacement curve (area under the curve) must be zero.

### Simulation Performance

To stabilize simulation of the detent, avoid discontinuities in the force-relative displacement function. The most important requirement is to have a shear reversal region of nonzero width, analogous to region 4 in the geometric parameterization.

## Limitations

The model does not account for inertia. Add mass terms externally to the R and C ports as required.

If you use the peak force-notch width or the lookup table parameterization, the kinetic friction is independent of the detent normal force.

## Example

The `sdl_stepping_mechanism_with_detents` example model shows the use of the Translational Detent block.

## See Also

Loaded-Contact Translational Friction | Rotational Detent

## Related Examples

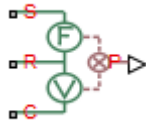
- “Clutches, Clutch-Like Elements, and Coulomb Friction”

# Translational Power Sensor

Mechanical sensor used to measure average or instantaneous translational power

## Library

Sensors



## Description

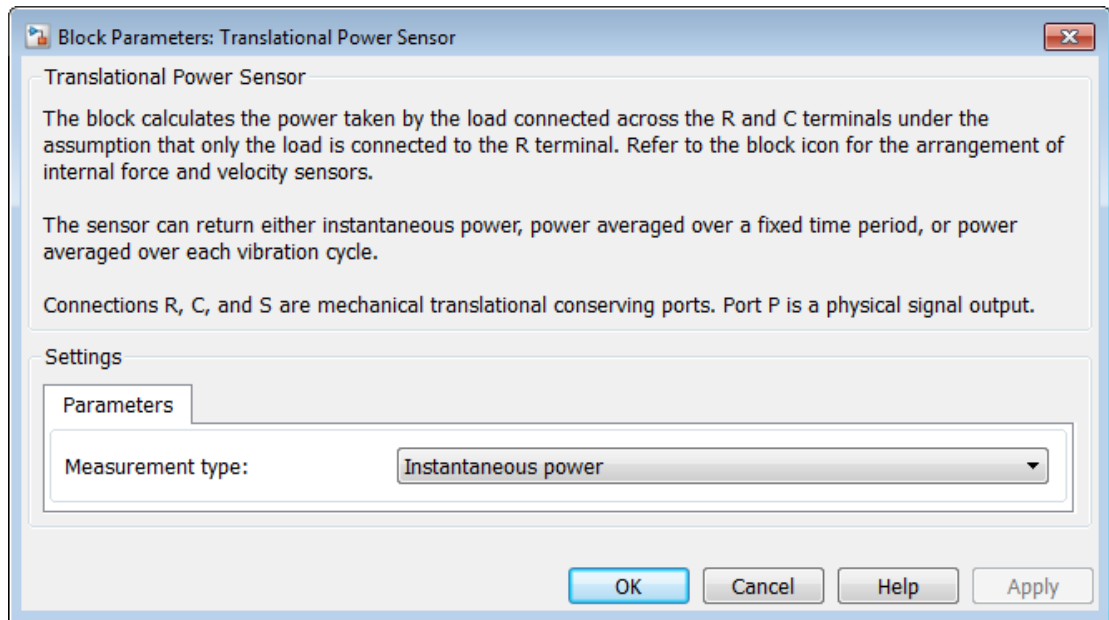
The block represents a sensor that you can use to measure the translational power change due to one or more driveline components connected between ports R and C. The power output can be an instantaneous or average value. Two averaging options are available: period and vibration averaging.

The instantaneous power is the product of the current velocity and force. Use the instantaneous power to analyze peak power transmission and identify heavily-loaded components.

The time-averaged power is the integral of the instantaneous power over one sample period, divided by that period. For simulation times smaller than the sample period, the average power is zero. The power is constant for each sample period.

The vibration-averaged power is the integral of the power over one vibration period, divided by that period. The vibration period is the time between two consecutive crossings from negative to positive velocity values. Use this averaging method only for oscillations with velocity passing through zero. The averaging period can change if the vibration has a variable frequency. For simulation times smaller than the vibration period, the average power is zero. The power output is constant for each vibration period.

## Dialog Box and Parameters



### Measurement Type

Select either instantaneous or average power measurement. The default type is Instantaneous Power.

- **Instantaneous power** — Output the power measured for the current time step.
- **Average power over a specified period**— Output the power averaged over a fixed time period.

### Averaging period

Enter the time period used to compute the average power. Typical values include the cycle length of a reciprocating device or the actuation force.

The default value is 1. The default unit is s.

- **Average power over a vibration**— Output the power averaged over one vibration period.

### Maximum vibration frequency

Enter the maximum vibration frequency over which the power should be averaged. Very high values can reduce simulation speed. Very low values can result in lower power measurements.

The default value is 1000. The default unit is Hz.

## Ports

Port	Description
P	Physical signal output port for translational power
S	Rotational conserving port associated with driving source
C	Rotational conserving port associated with loaded driveline component(s)
R	Rotational conserving port associated with case holding loaded driveline component(s)

## See Also

Rotational Power Sensor

# Unbalanced Load

Load with angle-dependent rotational inertia

## Library

Inertias & Loads



## Description

This block models the effects of a load whose rotational inertia varies instantaneously with the rotation angle. Examples include the wobbling of a spinning axle and shaking of an off-center rotating machine. You can specify the load inertia in terms of its rotation path or as an angle-inertia lookup table.

The block provides two rotation path parameterizations. One assumes circular motion of the unbalanced load. The other assumes elliptical motion. In each case, the distance between the unbalanced load and the main rotation axis varies with the rotation angle. The varying distance causes the moment of inertia, given by the parallel-axis theorem, to vary during rotation:

$$I(\theta) = I_0 + Mr^2(\theta),$$

where:

- $I$  is the moment of inertia about the main rotation axis.
- $I_0$  is the moment of inertia about the intrinsic rotation axis of the unbalanced load.
- $M$  is the total mass of the unbalanced load.
- $r$  is the distance between the unbalanced load and the main rotation axis.

The angle dependence of the moment of inertia leads to an angle dependence of the inertial torque acting on the unbalanced load:

$$T_I(\theta) = I(\theta)\dot{\omega},$$

where:

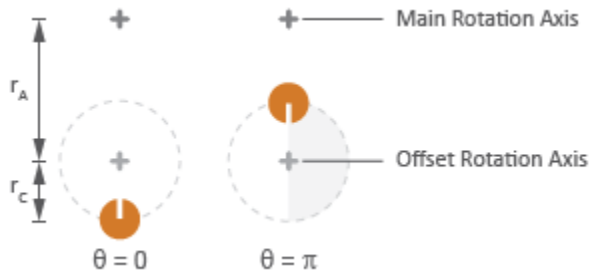
- $T_I$  is the inertial torque.
- $\omega$  is the angular velocity of the load.

If the load moves in a circular path, its distance to the main rotation axis is given by

$$r(\theta) = \sqrt{(r_C \cos(\theta) + r_A)^2 + (r_C \sin(\theta))^2},$$

where:

- $r_A$  is the distance between the main rotation axis and the offset rotation axis.
- $r_C$  is the radius of the circular path.



### Circular Rotation Path

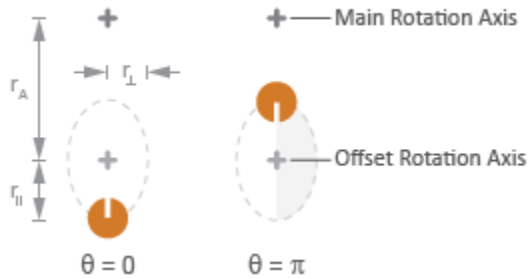
If the load moves in an elliptical path, its distance to the main rotation axis is given by

$$r(\theta) = \sqrt{(r_{\parallel} \cos(\theta) + r_A)^2 + (r_{\perp} \sin(\theta))^2},$$

where:

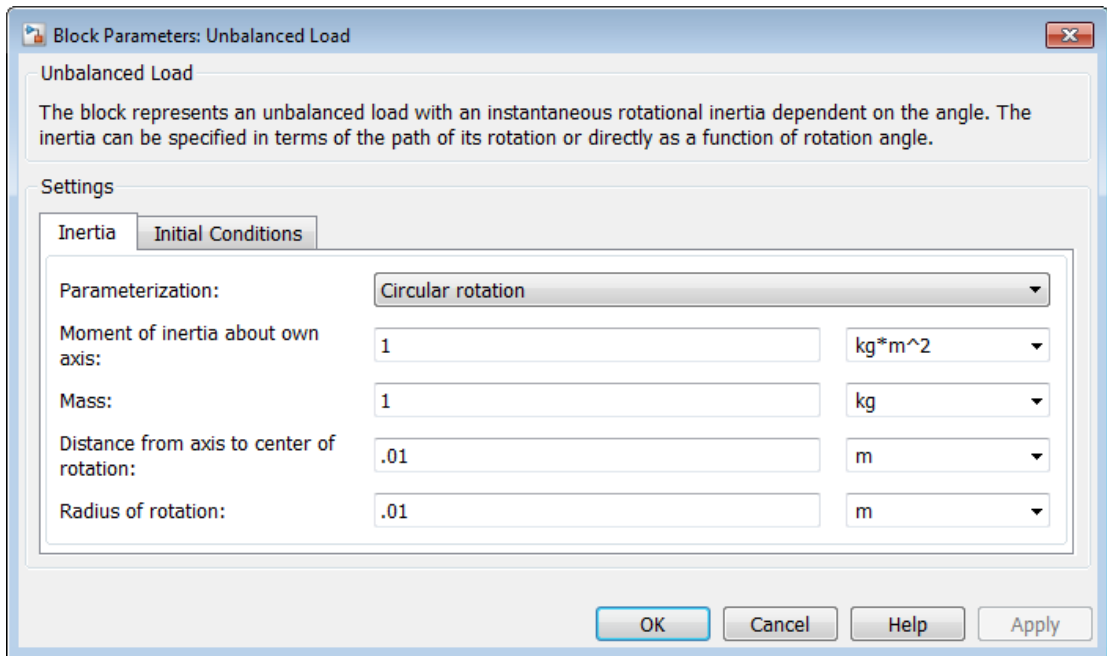
- $r_{\parallel}$  is the radius of the elliptical path in line with the distance from the main rotation axis.

- $r_{\perp}$  is radius of the elliptical path perpendicular to the distance from the main rotation axis.



### Elliptical Rotation Path

## Dialog Box and Parameters





## Inertia

### Parameterization

Choice of parameterization for modeling the moment of inertia of the unbalanced load. Options include **Circular rotation**, **Elliptical rotation**, and **Specify table lookup**. The default setting is **Circular rotation**.

Select **Circular rotation** or **Elliptical rotation** to parameterize the load inertia in terms of the load's rotation path. Select **Specify table lookup** to provide the load inertia directly across its rotation path.

### Moment of inertia about own axis

Moment of inertia about the intrinsic rotation axis of the unbalanced load. This moment of inertia is assumed constant throughout simulation. This parameter appears only when **Parameterization** is set to **Circular rotation**. The default value is 1 kg\*m<sup>2</sup>.

### Mass

Mass of the unbalanced load. This parameter appears only when **Parameterization** is set to **Circular rotation**. The default value is 1 kg.

### Distance from axis to center of rotation

Distance between the main rotation axis and the center of the rotation path. This parameter appears only when **Parameterization** is set to **Circular rotation**. The default value is 0.01 m.

### Radius of rotation

Radius of the circular rotation path traversed by the unbalanced load. This parameter appears only when **Parameterization** is set to **Circular rotation**. The default value is 0.01 m.

### Radius of rotation inline with distance from axis

Length of the semimajor axis of the elliptical rotation path traversed by the unbalanced load. The semimajor axis is in line with the line segment joining the main rotation axis and the elliptical rotation center. This parameter appears only when **Parameterization** is set to **Elliptical rotation**. The default value is 0.01 m.

### Radius of rotation perpendicular to distance from axis

Length of the semiminor axis of the elliptical rotation path traversed by the unbalanced load. The semiminor axis is perpendicular to the line segment joining the main rotation axis and the elliptical rotation center. This parameter appears

only when **Parameterization** is set to **Elliptical rotation**. The default value is 0.005 m.

### **Angle vector**

Array of angular positions at which to specify the load inertia. The block calculates the load inertia between the angles specified using linear interpolation. This parameter appears only when **Parameterization** is set to **Specify table lookup**. The default vector is [0, pi, 3\*pi/2] rad.

### **Inertia vector**

Array of load inertias about the intrinsic rotation axis of the load. Each inertia corresponds to an angle specified in the **Angle vector** parameter. This parameter appears only when **Parameterization** is set to **Specify table lookup**. The default vector is [1, 10, 1] kg\*m<sup>2</sup>.

## **Initial Conditions**

### **Initialization**

Choice of parameter through which to specify the initial state of the unbalanced load. Options include **Specify angular momentum** and **Specify angular velocity**.

### **Initial angular momentum**

Angular momentum of the unbalanced load at the start of simulation. This parameter appears only when the **Initialization** parameter is set to **Specify angular momentum**. The default value is 0 m<sup>2</sup>\*kg/s.

### **Initial angular velocity**

Angular velocity of the unbalanced load at the start of simulation. This parameter appears only when the **Initialization** parameter is set to **Specify angular velocity**. The default value is 0 rad/s.

### **Initial angle**

Angular position of the unbalanced load at the start of simulation. The initial angle determines the initial inertia of the unbalanced load. The default value is 0 rad.

## **Ports**

The block has one conserving rotational port. This port identifies the location of the unbalanced load in a driveline model.

**See Also**

Variable Inertia | Variable Mass

# Unidirectional Clutch

Clutch that transmits power in a single direction

## Library

Clutches

## Description

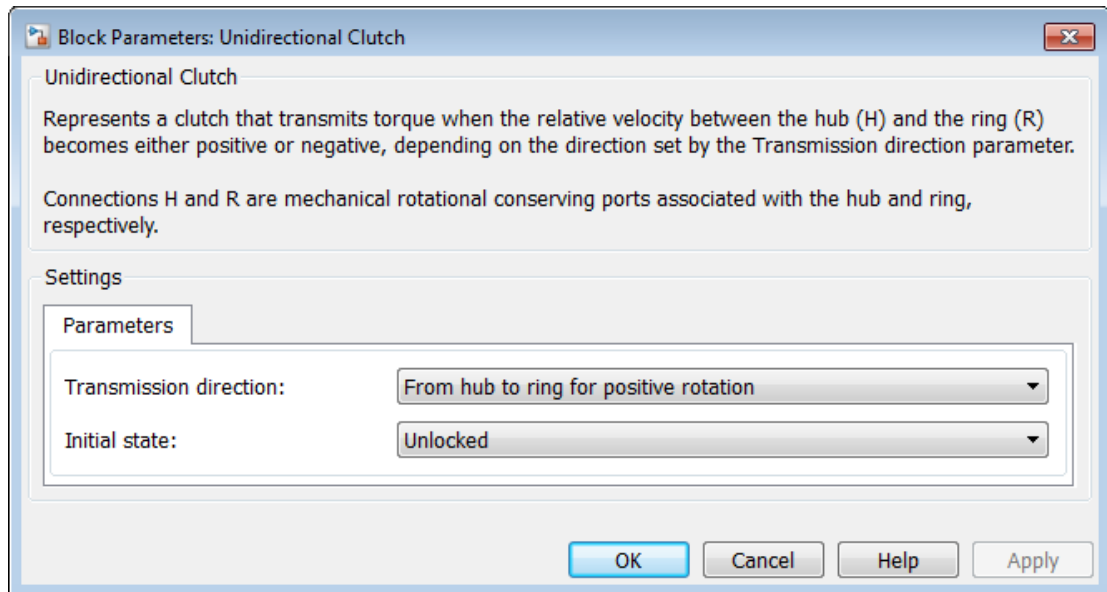


The Unidirectional Clutch block models an ideal one-way clutch based on a coupled ring-hub. It transmits torque when the relative velocity of hub and ring becomes positive or negative, depending on how you set the transmission direction. For model details, see “Unidirectional Clutch Model” on page 1-359.

## Ports

H and R are rotational conserving ports representing, respectively, the hub and ring driveshaft axes. The clutch motion is measured as the *slip*  $\omega = \omega_H - \omega_R$ , the angular velocity of hub relative to ring.

## Dialog Box and Parameters



### Transmission direction

From the drop-down list, select the relative rotation direction (sign of  $\omega$ ) for which the clutch locks and transfers torque. The default is From hub to ring for positive rotation.

### Initial state

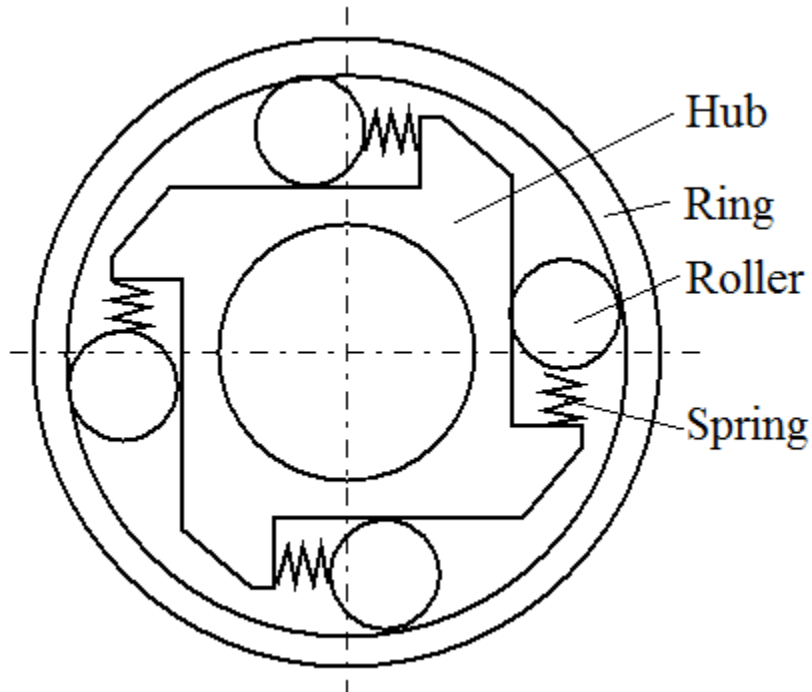
Clutch state at the start of simulation. The clutch can be in one of two states, locked and unlocked. A locked clutch constrains the base and follower shafts to spin at the same velocity, i.e., as a single unit. An unlocked clutch allows the two shafts to spin at different velocities, resulting in slip between the clutch plates. The default setting is Unlocked.

## Unidirectional Clutch Model

The Unidirectional Clutch, if locked, transmits torque from hub to ring. If it is unlocked, it transmits no torque. The clutch does not have a state of being unlocked but still engaged (transmitting torque).

## Clutch Geometry, Variable, and State Summary

The figure displays the geometry of the unidirectional clutch. The table summarizes the unidirectional clutch variables.



### Clutch Variable

Symbol	Definition	Significance
$\omega$	Relative angular velocity (slip)	$\omega_H - \omega_R$

The Unidirectional Clutch block implements an ideal model of a one-way clutch and does not include any internal dynamics, such as the rollers and springs.

### Locking Condition

The transmission direction determines the condition for locking.

- If you choose transmission for the positive direction, the clutch locks if  $\omega = \omega_H - \omega_R \geq 0$  and becomes zero from positive values. The slip  $\omega$  then remains zero, and the clutch transfers torque.

If the driveline dynamics then causes  $\omega < 0$  at a later time, the clutch abruptly unlocks and stops transferring torque.

- If you choose transmission for the negative direction, the clutch locks if  $\omega = \omega_H - \omega_R \leq 0$  and becomes zero from negative values. The slip  $\omega$  then remains zero, and the clutch transfers torque.

If the driveline dynamics then causes  $\omega > 0$  at a later time, the clutch abruptly unlocks and stops transferring torque.

For example, locking and torque transfer in the positive direction as follows.

- When the hub rotates faster than the ring ( $\omega > 0$ ), the small gap prearranged between the hub and the ring is cleared. The spring-loaded rollers wedge between the hub and the ring, causing the two to contact, lock, and rotate together;  $\omega$  resets to zero. (The rotation convention in the figure is clockwise.)
- If the ring rotates faster than the hub ( $\omega < 0$ ), the rollers are pushed out of contact and the clutch unlocks.

For a clutch schematic, see “Clutch Geometry, Variable, and State Summary” on page 1-360.

### Power Dissipated by the Clutch

The unidirectional clutch is ideal and does not dissipate power. Either the clutch is unlocked and applies no kinetic friction, or it is locked (no slip) and applies only static friction.

## Example

The `sdl_stepping_mechanism` example model uses the Unidirectional Clutch to translate a mass in one direction only (ratcheting).

### See Also

Dog Clutch | Fundamental Friction Clutch

## **Related Examples**

- “Gear Coupling Control with Clutches”

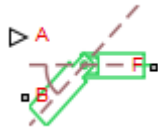


# Universal Joint

Rotational coupling between two driveline shafts

## Library

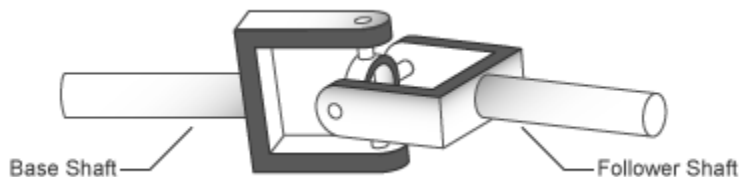
Couplings & Drives



## Description

This block represents a rotational coupling between two driveline shafts. The coupling transfers torque between the shafts so they spin as a unit under an applied load. Two rotational degrees of freedom, internal to the coupling, allow the shafts to connect at an angle. This intersection angle varies according to the physical signal input from port A. Compliance, modeled as a parallel spring-damper set, allows the coupling to deform under load.

You can use the Universal Joint block as a connection between two rotational driveline components—for example, between the driving and driven shafts in an automobile drive train.



The ratio of the shaft angular velocities depends on two parameters: the intersection angle between the two shafts and the rotation angle of the base shaft. A physical signal input provides the intersection angle while a dialog box parameter provides the initial

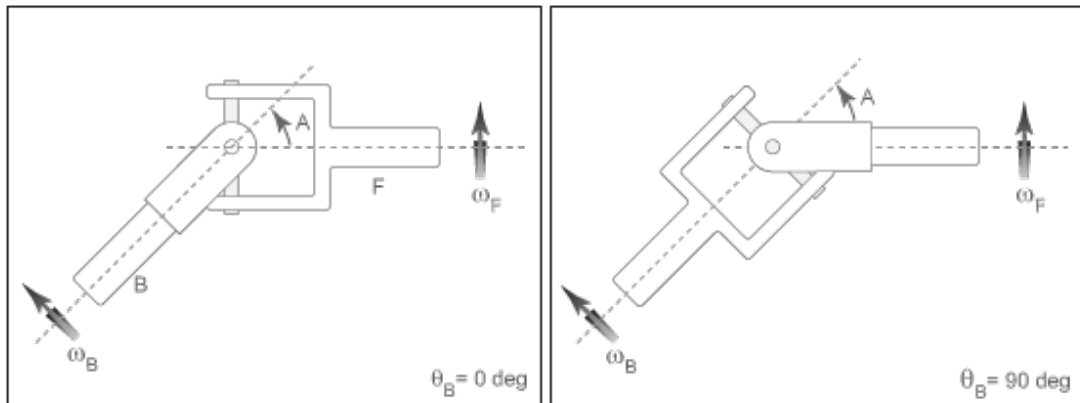
base shaft angle. These two angles fix the ratio of the two shaft angular velocities according to the nonlinear equation:

$$\omega_F = \frac{\cos(A)}{1 - \sin^2(A) \cdot \cos^2(\theta_B)} \omega_B,$$

where:

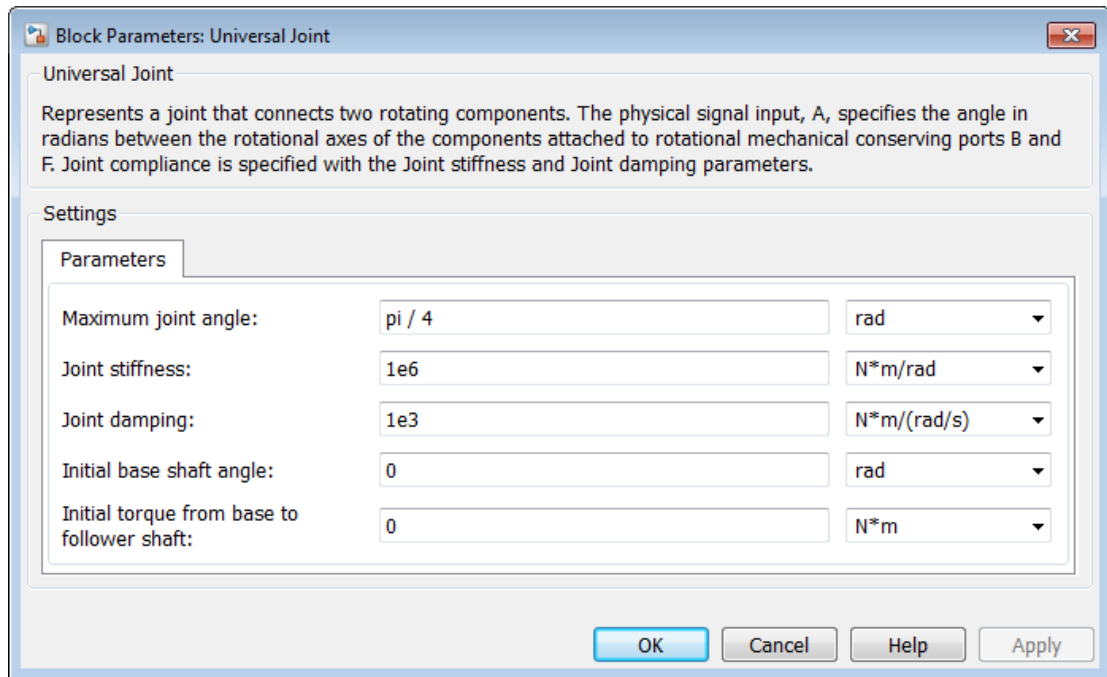
- $\omega_F$  is the angular velocity of the follower shaft about its length axis.
- $\omega_B$  is the angular velocity of the base shaft about its length axis.
- $\theta_B$  is the rotation angle of the base shaft about its length axis.
- $A$  is the intersection angle between base and follower shafts about the base shaft pin.

The two schematics in the figure illustrate the equation parameters. In each schematic, the left shaft represents the base shaft, while the right shaft represents the follower shaft. The right schematic shows the coupling seen in the left schematic after the shafts spin  $90^\circ$  about their length axes (dashed line segments).



In the figure, the intersection angle is the angle between the two shafts about the base shaft's pin. The absolute value of this angle must fall in the range  $0 \leq A < \text{Maximum intersection angle}$ . The base shaft angle is the angle of the base shaft about its length axis. The base shaft angle is also the time-integral of the base shaft angular velocity,  $\omega_B$ .

## Dialog Box and Parameters



### Maximum joint angle

Maximum intersection angle the joint allows. This angle measures the rotation between base and follower shafts about the base shaft pin. The value of this angle must fall in the range  $0 \leq A < \pi/2$ . From the drop-down list, select a physical unit. The default value is  $\pi/4$  rad.

### Joint stiffness

Linear spring stiffness of the joint. The spring stiffness accounts for elastic energy storage in the joint due to material compliance. In the drop-down list, select a physical unit. The default value is  $1e6$  N\*m/rad.

### Joint damping

Linear damping coefficient of the joint. The damping coefficient accounts for energy dissipation in the joint due to material compliance. In the drop-down list, select a physical unit. The default value is  $1e3$  N\*m/(rad/s).

### **Initial base shaft angle**

Rotation angle of the base shaft about its length axis at time zero. From the drop-down list, select a physical unit. The default value is 0 rad.

### **Initial torque from base to follower shaft**

Torque that the base shaft transfers to the follower shaft at time zero. This torque determines the initial state of material compliance at the joint. Set this value to greater than zero to preload the shafts with torque. Changing this value alters the initial transient response due to material compliance. Select a physical unit. The default value is 0 N\*m.

## **Ports**

<b>Port</b>	<b>Description</b>
B	Conserving rotational port associated with the base shaft
F	Conserving rotational port associated with the follower shaft
A	Physical signal input port for the intersection angle

### **See Also**

Belt Drive | Belt Pulley | Chain Drive | Flexible Shaft | Rope Drum

# Variable Inertia

Time-varying inertia specified as physical signal input

## Library

Inertias & Loads



## Description

This block models the effects of a time-varying inertia. Components with variable inertia include satellites unfolding arrays of solar panels. A physical signal input port provides the instantaneous inertia at each time step throughout simulation. To minimize solver errors, avoid discontinuities and abrupt changes in the input signal.

As the component inertia changes, so does the inertial torque acting on that component:

$$T_I = I\dot{\omega},$$

where:

- $T_I$  is the inertial torque.
- $I$  is the variable inertia.
- $\omega$  is the angular velocity of the inertia.

The physical signal input saturates at the minimum inertia specified in the block dialog box. Whenever the input falls below the minimum inertia, the block performs its calculations on the minimum inertia instead. The inertial torque becomes:

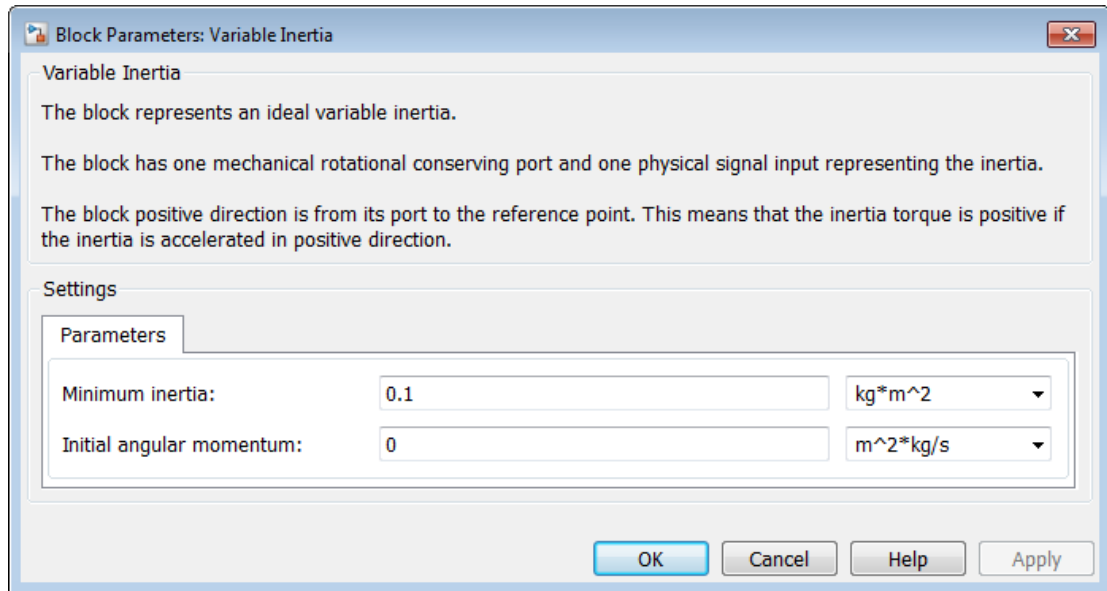
$$T_I = I_{Min}\dot{\omega},$$

where:

- $I_{\text{Min}}$  is the minimum inertia allowed.

The angular momentum of the variable inertia is conserved. In the absence of external torques, a decrease in the moment of inertia leads to a proportional increase in angular velocity. The angular momentum remains constant until a net external torque causes it to change.

## Dialog Box and Parameters



### Minimum inertia

Lowest value that the variable inertia can take on during simulation. The physical signal input saturates at this value. If the input falls below the minimum inertia, it is set equal to the minimum inertia itself. The default value is  $0.1 \text{ kg}\cdot\text{m}^2$ .

### Initial angular momentum

Angular momentum of the variable inertia at the start of simulation. The default value is  $0 \text{ m}^2\cdot\text{kg/s}$ .

## Ports

The block has one conserving rotational port and one physical signal input port. The conserving rotational port identifies the driveline component whose inertia varies with time. The physical signal input port provides the means to specify the inertia as a function of time.

## See Also

Variable Mass | Unbalanced Load

## Variable Mass

Time-varying mass specified as physical signal input

### Library

Inertias & Loads



### Description

This block models the effects of a time-varying mass. Components with variable mass include fuel tanks with progressively lower fuel contents. A physical signal input port provides the instantaneous mass at each time step throughout simulation. To minimize solver errors, avoid discontinuities and abrupt changes in the input signal.

As the component mass changes, so does the inertial force acting on that component:

$$F_I = m\dot{v},$$

where:

- $F_I$  is the inertial force.
- $m$  is the variable mass.
- $v$  is the velocity of the mass.

The physical signal input saturates at the minimum mass specified in the block dialog box. Whenever the input falls below the minimum mass, the block performs its calculations on the minimum mass instead. The inertial force becomes:

$$F_I = m_{Min}\dot{v},$$

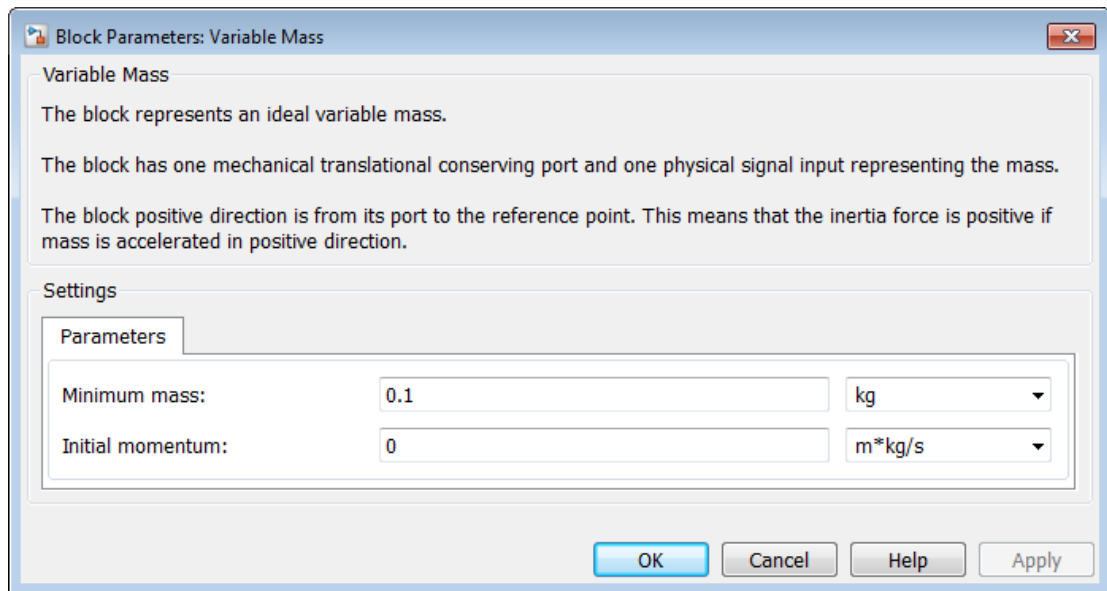
where:

- $m_{Min}$  is the minimum mass allowed.



The linear momentum of the variable mass is conserved. In the absence of external forces, a decrease in mass leads to a proportional increase in linear velocity. The linear momentum remains constant until a net external force causes it to change.

## Dialog Box and Parameters



### Minimum mass

Lowest value that the variable mass can take on during simulation. The physical signal input saturates at this value. If the input falls below the minimum mass, it is set equal to the minimum mass itself. The default value is 0.1 kg.

### Initial momentum

Linear momentum of the variable mass at the start of simulation. The default value is 0 m\*kg/s.

## Ports

The block has one conserving translational port and one physical signal input port. The conserving translational port identifies the driveline component whose mass varies with

time. The physical signal input port provides the means to specify the mass as a function of time.

**See Also**

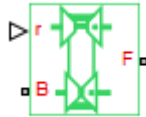
Variable Inertia | Unbalanced Load

# Variable Ratio Transmission

Dynamic gearbox with variable and controllable gear ratio, transmission compliance, and friction losses

## Library

Couplings & Drives



## Description

The Variable Ratio Transmission block represents a gearbox that dynamically transfers motion and torque between the two connected driveshaft axes, base and follower.

Ignoring the dynamics of transmission compliance, the driveshafts are constrained to corotate with a variable gear ratio that you control. You can choose whether the follower axis rotates in the same or opposite direction as the base axis. If they rotate in the same direction,  $\omega_F$  and  $\omega_B$  have the same sign. If they rotate in opposite directions,  $\omega_F$  and  $\omega_B$  have opposite signs.

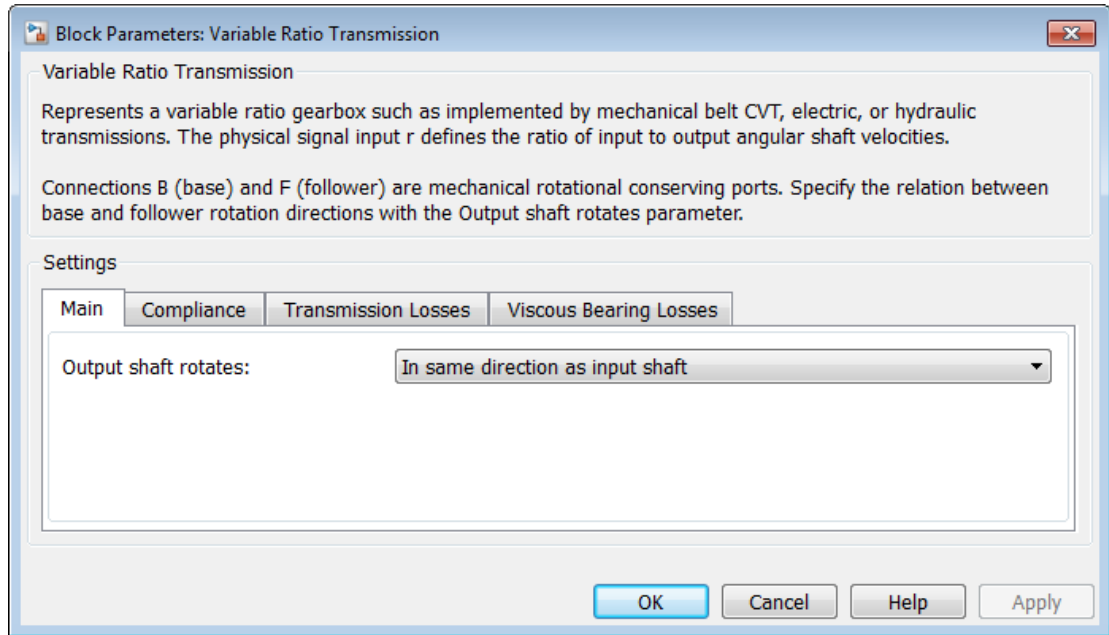
Transmission compliance introduces internal time delay between the axis motions. Unlike a gear, a variable ratio transmission therefore does not act as a kinematic constraint. You can also control torque loss caused by transmission and viscous bearing losses. For model details, see “Variable Ratio Transmission Model” on page 1-376.

## Ports

B and F are rotational conserving ports representing, respectively, the base and follower driveshafts.

You specify the unitless variable gear ratio  $g_{FB}(t)$  as a function of time at the physical signal input at port r. If the signal value becomes zero or negative, the simulation stops with an error.

## Dialog Box and Parameters



### Main

#### Output shaft rotates

From the drop-down list, choose how the output driveshaft rotates relative to the input driveshaft. The default is **In same direction as input shaft**.

### Compliance

#### Transmission stiffness at base (B)

Reciprocal of transmission angular compliance  $k_p$ , angular displacement per unit torque, measured at the base. The default is 30000.

From the drop-down list, choose units. The default is newton-meters/radian (N\*m/rad).

#### Transmission damping at base (B)

Reciprocal of transmission angular compliance damping  $k_v$ , angular speed per unit torque, measured at the base. The default is 0.05.

From the drop-down list, choose units. The default is newton-meters/(radian/second) ( $\text{N}\cdot\text{m}/(\text{rad}/\text{s})$ ).

### Initial input torque at base (B)

Torque applied at the base driveshaft at the start of simulation ( $t = 0$ ). The default is 0.

From the drop-down list, choose units. The default is newton-meters ( $\text{N}\cdot\text{m}$ ).

## Transmission Losses

### Losses model

Select how to implement friction losses from nonideal torque transfer. The default is No losses.

- **No losses** – Suitable for HIL simulation — Torque transfer is ideal.
- **Constant efficiency** — Transfer of torque across gearbox is reduced by a constant efficiency  $\eta$  satisfying  $0 < \eta \leq 1$ . If you select this option, the panel changes from its default.

### Constant Efficiency

#### Efficiency

Effective torque transfer efficiency  $\eta$  between the base and follower driveshafts.

#### Follower angular velocity threshold

Absolute angular velocity threshold  $\omega_{\text{th}}$  above which full efficiency loss is applied, for follower velocity  $\omega_{\text{F}}$ .

From the drop-down list, choose units. The default is radians/second ( $\text{rad}/\text{s}$ ).

## Viscous Bearing Losses

### Viscous friction coefficients at base (B) and follower (F)

Vector of viscous damping coefficients  $[\mu_{\text{B}} \mu_{\text{F}}]$  applied at the base and follower driveshafts, respectively. The default is  $[ 0 \ 0 ]$ .

From the drop-down list, choose units. The default is newton-meters/(radian/second) (N\*m/ (rad/s)).

## Variable Ratio Transmission Model

### Ideal Motion and Torque Transfer

Variable Ratio Transmission is a dynamical mechanism for transferring motion and torque between base and follower.

If the relative compliance  $\phi$  between the axes is absent, the block is equivalent to a gear with a variable ratio  $g_{FB}(t)$ . Such a gear imposes a time-dependent kinematic constraint on the motions of the two driveshafts:

$$\omega_B = \pm g_{FB}(t) \omega_F, \tau_F = \pm g_{FB}(t) \tau_B.$$

However, Variable Ratio Transmission does include compliance between the axes. Dynamical motion and torque transfer replace the kinematic constraint, with a nonzero  $\phi$  that dynamically responds through base compliance parameters  $k_p$  and  $k_v$ :

$$d\phi/dt = \pm g_{FB}(t) \omega_F - \omega_B,$$

$$\tau_B = -k_p \phi - k_v d\phi/dt,$$

$$\pm g_{FB}(t) \tau_B + \tau_F - \tau_{\text{loss}} = 0.$$

$\tau_{\text{loss}} = 0$  in the ideal case.

### Estimating Compliance Parameters

- You can estimate the base angular compliance  $k_p$  from the transmission time constant  $t_c$  and inertia  $J$ :  $k_p = J(2\pi/t_c)^2$ .
- You can estimate the base angular velocity compliance  $k_v$  from the transmission time constant  $t_c$ , inertia  $J$ , and damping coefficient  $C$ :  $k_v = (2Ct_c)/2\pi = 2C\sqrt{J/k_p}$ .

### Nonideal Torque Transfer and Losses

With nonideal torque transfer,  $\tau_{\text{loss}} \neq 0$ . Losses in the Variable Ratio Transmission are modeled similarly to how losses are modeled in nonideal gears. For general information on nonideal gear modeling, see “Model Gears with Losses”.

In a nonideal gearbox, the angular velocity and compliance dynamics are unchanged. The transferred torque and power are reduced by:

- Coulomb friction (for example, between belt and wheel, or internal belt losses due to stretching) characterized by an efficiency  $\eta$ .
- Viscous coupling of driveshafts with bearings, parametrized by viscous friction coefficients  $\mu$ .

$$\tau_{\text{loss}} = \tau_{\text{Coul}} \tanh(4\omega_{\text{out}}/\omega_{\text{th}}) + \mu_{\text{B}}\omega_{\text{B}} + \mu_{\text{F}}\omega_{\text{F}}, \tau_{\text{Coul}} = |\tau_{\text{F}}| \cdot (1 - \eta).$$

When the angular velocity changes sign, the hyperbolic tangent regularizes the sign change in the Coulomb friction torque.

Power Flow	Power Loss Condition	Output Driveshaft $\omega_{\text{out}}$
Forward	$\omega_{\text{B}}\tau_{\text{B}} > \omega_{\text{F}}\tau_{\text{F}}$	Follower, $\omega_{\text{F}}$
Reverse	$\omega_{\text{B}}\tau_{\text{B}} < \omega_{\text{F}}\tau_{\text{F}}$	Base, $\omega_{\text{B}}$

## Meshing Efficiency

The friction loss represented by efficiency  $\eta$  is fully applied only if the absolute value of the follower angular velocity  $\omega_{\text{F}}$  is greater than a velocity threshold  $\omega_{\text{th}}$ .

If this absolute velocity is less than  $\omega_{\text{th}}$ , the actual efficiency is automatically regularized to one at zero velocity.

## Example

The `sdl_variable_gear` example model provides a basic example of a simple gear.

## See Also

Simple Gear | Torque Converter

## Related Examples

- “Gear Coupling Control with Clutches”

# Variable Rotational Damper

Rotational damper with variable damping coefficient

## Library

Couplings & Drives/Springs & Dampers



## Description

The block represents a rotational viscous damper with a variable damping coefficient. A physical signal input port provides the magnitude of the damping coefficient. The magnitude of the damping torque is equal to the product of the physical signal input and the relative angular velocity between the two rotational conserving ports, R and C. A minimum damping coefficient prevents non-physical negative damping values.

The damping torque satisfies the following expression:

$$T = \begin{cases} B \cdot \omega & B \geq B_{\min} \\ B_{\min} \cdot \omega & B < B_{\min} \end{cases},$$

The parameters are:

- $T$  — Torque transmitted through damper
- $B$  — Viscous damping coefficient
- $\omega$  — Relative angular velocity measured between the two rotational conserving ports according to  $\omega = \omega_R - \omega_C$
- $\omega_R$  — Angular velocity of rotational conserving port R
- $\omega_C$  — Angular velocity of rotational conserving port C

The block applies equal and opposite damping torques on the rotational conserving ports. The sign of the damping torque acting on port R is equal to the sign of the relative

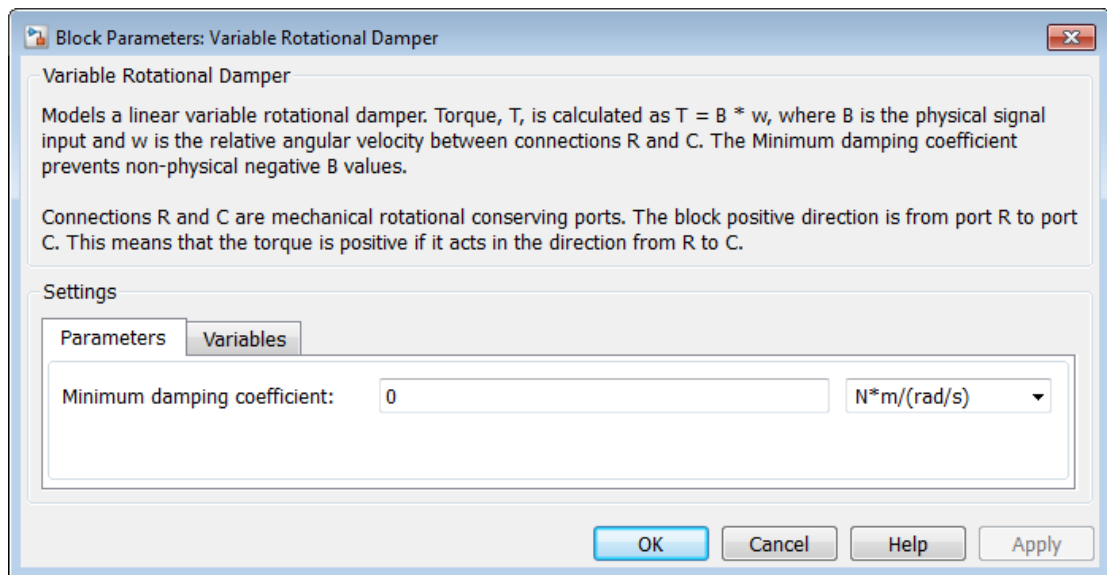


angular velocity. A positive relative angular velocity corresponds to a positive damping torque acting on port R, and a negative damping torque of equal magnitude acting on port C.

## Assumptions and Limitations

- The block represents only viscous damping
- The value of the damping coefficient must be equal to or greater than zero.

## Dialog Box and Parameters



## Parameters

### Minimum damping coefficient

Minimum value allowed for the damping coefficient. The physical signal input saturates below this level. The parameter must be greater than or equal to zero. The default value is 0. The default unit is  $\text{N}\cdot\text{m}/(\text{rad}/\text{s})$ .

## Variables

Specify the desired initial values of the block dynamical variables. These variables guide model assembly at simulation time zero. When two or more variables conflict with each other, the priority setting determines which of the variables to satisfy. For more information, see “Set Priority and Initial Target for Block Variables”.

Variables that you can specify include:

- $t$  — Spring torque
- $w$  — Relative rotational velocity

## Ports

Port	Description
B	Physical signal input port representing the variable damping coefficient
C	Rotational conserving port
R	Rotational conserving port

## See Also

Nonlinear Rotational Damper | Variable Translational Damper |  
Nonlinear Translational Damper

# Variable Rotational Spring

Rotational spring with variable spring stiffness

## Library

Couplings & Drives/Springs & Dampers



## Description

The block represents a torsional spring with variable spring stiffness. A physical signal input port provides the value of the variable spring stiffness. The magnitude of the spring torque is equal to the product of the physical signal input and the relative angular displacement between the two rotational conserving ports. A minimum spring rate value prevents non-physical values.

The rotational spring torque satisfies the following expression:

$$T = \begin{cases} K \cdot \theta & K \geq K_{\min} \\ K_{\min} \cdot \theta & K < K_{\min} \end{cases},$$

The parameters are:

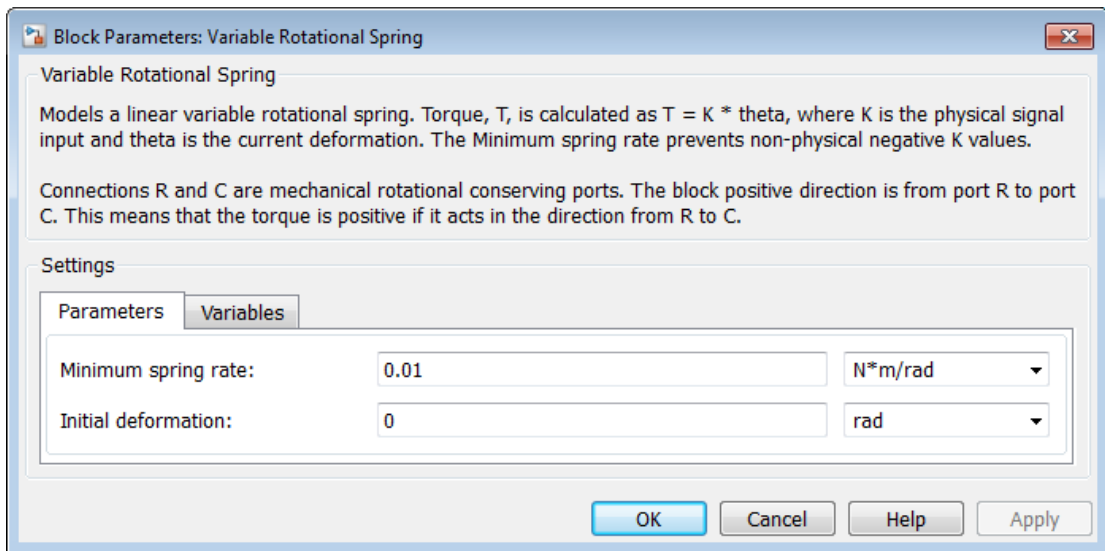
- $T$  — Torque transmitted through the spring
- $K$  — Spring rate (stiffness)
- $K_{\min}$  — Minimum allowable spring rate (stiffness)
- $\theta$  — Relative angular displacement measured between the two rotational conserving ports according to  $\theta = \theta_{init} + \theta_R - \theta_C$
- $\theta_{init}$  — Initial angular deformation between the two rotational conserving ports
- $\theta_R$  — Absolute angular displacement of rotational conserving port R
- $\theta_C$  — Absolute angular displacement of rotational conserving port C

The block applies equal and opposite spring torques on the two rotational conserving ports. The sign of the spring torque acting on port R is equal to the sign of the relative angular velocity. A positive relative angular velocity corresponds to a positive damping torque acting on port R, and a negative damping torque of equal magnitude acting on port C.

## Assumptions and Limitations

- The value of the spring rate must be greater than zero.

## Dialog Box and Parameters



## Parameters

### Minimum spring rate

Minimum value allowed for the spring rate (stiffness). The physical signal input saturates below the specified value. The parameter must be greater than zero. The default value is 0.01. The default unit is (N\*m/rad).

### Initial Deformation

Initial angular displacement between rotational conserving ports R and C. The initial value is 0. The initial unit is rad.

### Variables

Specify the desired initial values of the block dynamical variables. These variables guide model assembly at simulation time zero. When two or more variables conflict with each other, the priority setting determines which of the variables to satisfy. For more information, see “Set Priority and Initial Target for Block Variables”.

Variables that you can specify include:

- $t$  — Spring torque
- $w$  — Deformation rate
- $\theta$  — Rotational deformation

### Ports

Port	Description
K	Physical signal input port representing the variable spring stiffness
C	Rotational conserving port
R	Rotational conserving port

### See Also

Nonlinear Rotational Spring | Variable Translational Spring |  
Nonlinear Translational Spring

# Variable Translational Damper

Translational viscous damper with variable damping coefficient

## Library

Couplings & Drives/Springs & Dampers



## Description

The block represents a translational viscous damper with variable damping coefficient. A physical signal input port provides the magnitude of the translational damping coefficient. The magnitude of the damping force is equal to the product of the physical signal input and the magnitude of the relative linear velocity between the two translational conserving ports. A minimum damping coefficient prevents non-physical negative damping values.

The translational damping force satisfies the following expression:

$$F = \begin{cases} B \cdot v, & B \geq B_{\min} \\ B_{\min} \cdot v, & B < B_{\min} \end{cases},$$

The parameters are:

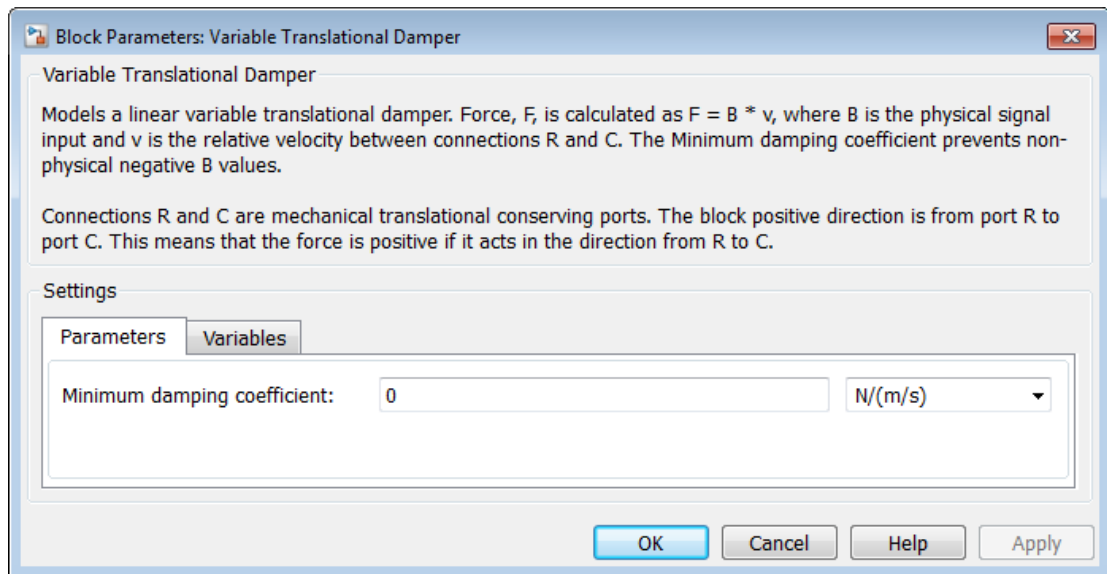
- $F$  — Force transmitted through the translational damper between the two translational conserving ports
- $B$  — Viscous damping coefficient
- $B_{\min}$  — Minimum allowed damping coefficient
- $v$  — Relative linear velocity measured between the two translational conserving ports
- $v_R$  — Linear velocity of port R
- $v_C$  — Linear velocity of port C

The block applies equal and opposite damping forces on the two translational conserving ports. The sign of the damping force acting on port R is equal to the sign of the relative linear velocity. A positive linear velocity corresponds to a positive damping force acting on port R, and a negative damping force of equal magnitude acting on port C.

## Assumptions and Limitations

- The block represents strictly viscous damping.
- The value of the damping coefficient must be greater than or equal to zero.

## Dialog Box and Parameters



## Parameters

### Minimum damping coefficient

Minimum value allowed for the variable damping coefficient. The physical signal input saturates below the specified value. The parameter must be greater than or equal to zero. The default value is 0. The default unit is N/(m/s).

## Variables

Specify the desired initial values of the block dynamical variables. These variables guide model assembly at simulation time zero. When two or more variables conflict with each other, the priority setting determines which of the variables to satisfy. For more information, see “Set Priority and Initial Target for Block Variables”.

Variables that you can specify include:

- $f$  — Damper force
- $v$  — Relative translational velocity

## Ports

Port	Description
B	Physical signal input port representing the variable translational damping coefficient
C	Translational conserving port
R	Translational conserving port

## See Also

Nonlinear Translational Damper, Variable Rotational Damper, Nonlinear Rotational Damper

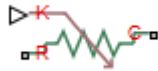


# Variable Translational Spring

Translational spring with variable spring stiffness

## Library

Couplings & Drives/Springs & Dampers



## Description

The block represents a translational spring with variable spring stiffness. A physical signal input port provides the variable spring stiffness. The magnitude of the spring force is equal to the product of the physical signal input and the relative linear displacement between the two translational conserving ports. A minimum spring rate prevents non-physical values.

The translational spring force satisfies the following expression:

$$F = \begin{cases} K \cdot x, & K \geq K_{\min} \\ K_{\min} \cdot x & K < K_{\min} \end{cases},$$

The parameters are:

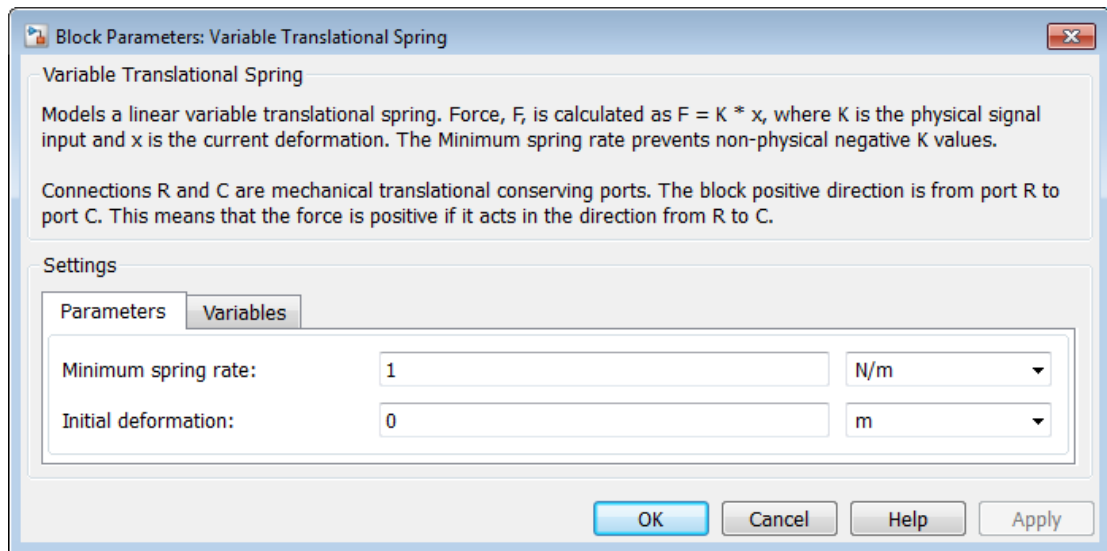
- $F$  — Force transmitted through the spring between the two translational conserving ports
- $K$  — Spring rate (stiffness)
- $K_{\min}$  — Minimum allowed spring rate (stiffness)
- $x$  — Relative displacement between the two translational conserving ports according to  $x = x_{init} + x_R - x_C$
- $x_{init}$  — initial spring deformation
- $x_R$  — Absolute displacement of translational conserving port R
- $x_C$  — Absolute displacement of translational conserving port C

The block applies equal and opposite spring forces on the two translational conserving ports. The sign of the spring force acting on port R is equal to the sign of the relative linear displacement between the two ports. A positive linear velocity corresponds to a positive spring force acting on port R, and a negative spring force of equal magnitude acting on port C.

## Assumptions and Limitations

- The value of the variable spring stiffness must be greater than zero.

## Dialog Box and Parameters



## Parameters

### Minimum spring rate

Minimum value allowed for the spring rate. The physical signal input saturates below the specified value. The parameter must be greater than zero. The default value is 1. The default unit is N/m

### Initial deformation

Initial displacement between the two translational conserving ports. The default value is 0. The default unit is m.

## Variables

Specify the desired initial values of the block dynamical variables. These variables guide model assembly at simulation time zero. When two or more variables conflict with each other, the priority setting determines which of the variables to satisfy. For more information, see “Set Priority and Initial Target for Block Variables”.

Variables that you can specify include:

- $f$  — Spring force
- $v$  — Deformation rate
- $x$  — Translational deformation

## Ports

Port	Description
K	Physical signal input port representing the variable spring stiffness
C	Translational conserving port
R	Translational Conserving port

## See Also

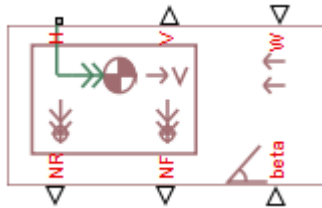
Nonlinear Translational Spring | Variable Rotational Spring |  
Nonlinear Rotational Spring

## Vehicle Body

Two-axle vehicle with longitudinal dynamics and motion and adjustable mass, geometry, and drag properties

### Library

Tires & Vehicles

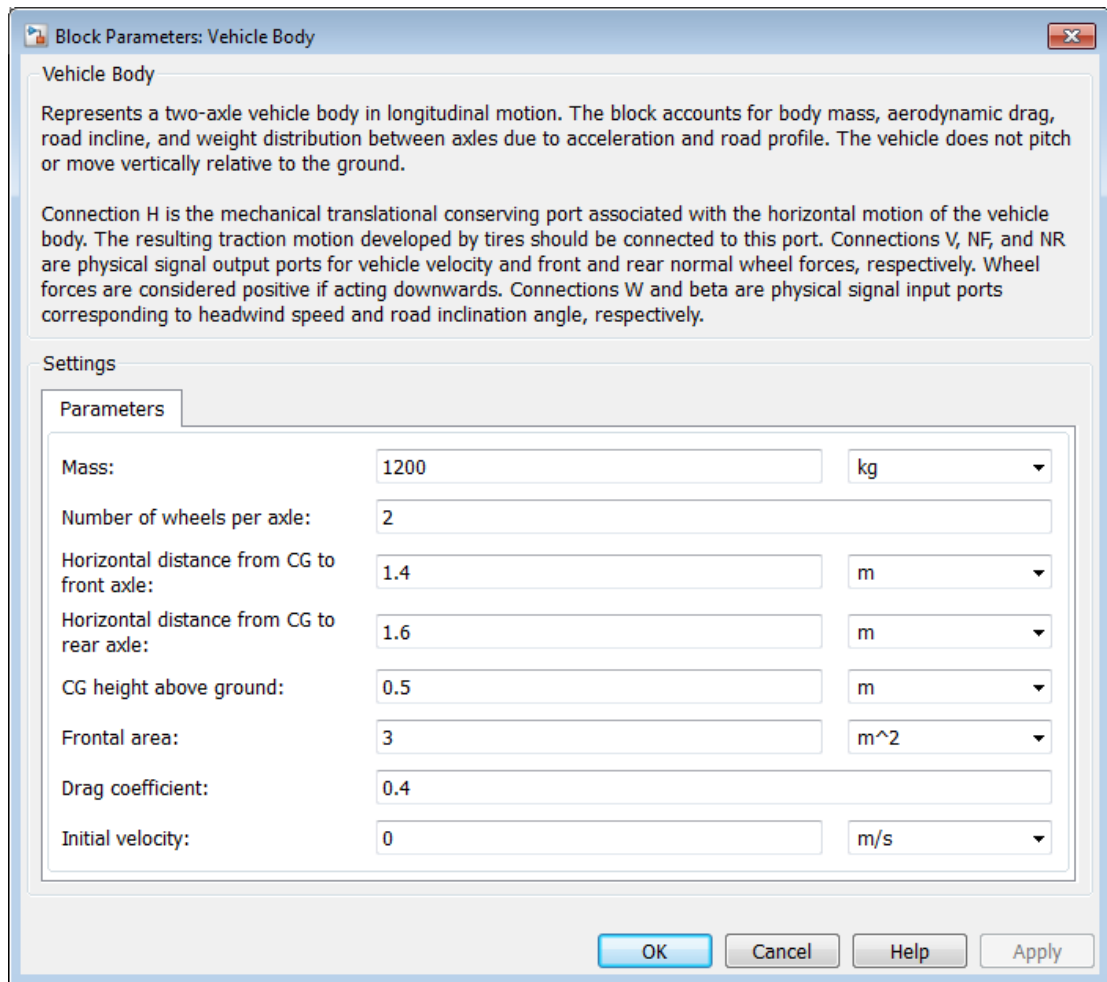


### Description

This block models a vehicle with two axles in longitudinal motion. The axles can have different wheel counts—for example, two wheels on the front axle and one wheel on the rear axle. The vehicle wheels are assumed identical in size. Vehicle properties and effects that you specify include mass, geometry, and drag.

Port H represents the vehicle body. Physical signal input ports W and theta provide the means to specify the headwind speed and road incline angle. Physical signal output ports V, NF, and NR provide the measurements of the vehicle longitudinal velocity, front-axle normal force, and rear-axle normal force. The signal units are the Simscape defaults—m/s for velocities, rad for angles, and N for forces.

## Dialog Box and Parameters



### Mass

Mass  $m$  of the vehicle. The default is 1200.

From the drop-down list, choose units. The default is kilograms (kg).

**Number of wheels per axle**

Wheel counts on the front and rear axles, specified as a scalar number or a two-element array. If the input is a scalar number, the wheel counts of the front and rear axles are assumed the same. For example, if the input is 2, then the front and rear axles are each assumed to have two wheels.

If the input is a two-element array, the first number is the front-axle wheel count and the second number the rear-axle wheel count. For example, if the input is the array [ 2, 1 ], then the front axle is assumed to have two wheels and the rear axle one wheel.

The default is 2, corresponding to two wheels on each axle.

**Horizontal distance from CG to front axle**

Horizontal distance  $a$  from the vehicle's center of gravity to the vehicle's front wheel axle. The default is 1.4.

From the drop-down list, choose units. The default is meters (m).

**Horizontal distance from CG to rear axle**

Horizontal distance  $b$  from the vehicle's center of gravity to the vehicle's rear wheel axle. The default is 1.6.

From the drop-down list, choose units. The default is meters (m).

**CG height above ground**

Height  $h$  of the vehicle's center of gravity from the ground. The default is 0.5.

From the drop-down list, choose units. The default is meters (m).

**Frontal area**

Effective cross-sectional area  $A$  presented by the vehicle in longitudinal motion, to compute the aerodynamic drag force on the vehicle. The default is 3.

From the drop-down list, choose units. The default is meters-squared ( $m^2$ ).

**Drag coefficient**

The dimensionless aerodynamic drag coefficient  $C_d$ , for the purpose of computing the aerodynamic drag force on the vehicle. The default is 0.4.

**Initial velocity**

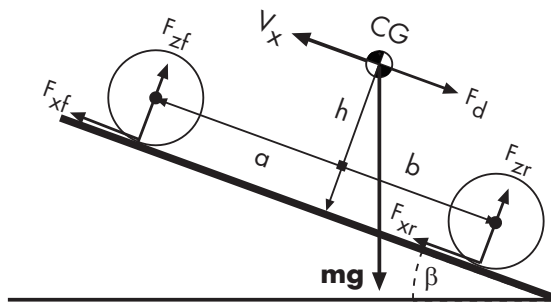
The initial value  $V_x(0)$  of the vehicle's horizontal velocity. The default is 0.

From the drop-down list, choose units. The default is meters/second (m/s).

## Vehicle Body Model

The vehicle axles are parallel and form a plane. The longitudinal  $x$  direction lies in this plane and perpendicular to the axles. If the vehicle is traveling on an incline slope  $\beta$ , the normal  $z$  direction is not parallel to gravity but is always perpendicular to the axle-longitudinal plane.

This figure and table define the vehicle motion model variables.



### Vehicle Dynamics and Motion

#### Vehicle Model Variables

Symbol	Description and Unit
$g$	Gravitational acceleration = $9.81 \text{ m/s}^2$
$\beta$	Incline angle
$m$	Vehicle mass
$h$	Height of vehicle CG above the ground
$a, b$	Distance of front and rear axles, respectively, from the normal projection point of vehicle CG onto the common axle plane
$V_x$	Longitudinal vehicle velocity
$V_w$	Headwind speed
$n$	Number of wheels on each axle

Symbol	Description and Unit
$F_{xf}, F_{xr}$	Longitudinal forces on each wheel at the front and rear ground contact points, respectively
$F_{zf}, F_{zr}$	Normal load forces on the each wheel at the front and rear ground contact points, respectively
$A$	Effective frontal vehicle cross-sectional area
$C_d$	Aerodynamic drag coefficient
$\rho$	Mass density of air = 1.18 kg/m <sup>3</sup>
$F_d$	Aerodynamic drag force

## Vehicle Dynamics and Motion

The vehicle motion is determined by the net effect of all the forces and torques acting on it. The longitudinal tire forces push the vehicle forward or backward. The weight  $mg$  of the vehicle acts through its center of gravity (CG). Depending on the incline angle, the weight pulls the vehicle to the ground and pulls it either backward or forward. Whether the vehicle travels forward or backward, aerodynamic drag slows it down. For simplicity, the drag is assumed to act through the CG.

$$\begin{aligned}
 m\dot{V}_x &= F_x - F_d - mg \cdot \sin \beta, \\
 F_x &= n(F_{xf} + F_{xr}), \\
 F_d &= \frac{1}{2} C_d \rho A (V_x - V_W)^2 \cdot \text{sgn}(V_x - V_W)
 \end{aligned}$$

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

$$\begin{aligned}
 F_{zf} &= \frac{-h(F_d + mg \sin \beta + m\dot{V}_x) + b \cdot mg \cos \beta}{n(a + b)}, \\
 F_{zr} &= \frac{+h(F_d + mg \sin \beta + m\dot{V}_x) + a \cdot mg \cos \beta}{n(a + b)}
 \end{aligned}$$

The wheel normal forces satisfy  $F_{zf} + F_{zr} = mg \cos \beta / n$ .



## Limitations

The Vehicle Body 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.

## Ports

Port	Description
H	Translational conserving port associated with the horizontal motion of the vehicle body
W	Physical signal input port for specifying the headwind speed
theta	Physical signal input port for specifying the road incline angle
V	Physical signal output port for measuring the vehicle longitudinal velocity
NF	Physical signal output port for measuring the normal force on the front axle
NR	Physical signal output port for measuring the normal force on the rear axle

## Examples

These Simscape Driveline example models contain working examples of vehicle bodies:

- `sdl_dual_clutch`
- `sdl_manual_transmission`
- `sdl_4wd_dynamics`
- `sdl_vehicle`

## See Also

Tire (Magic Formula)

## Related Examples

- “Complete Vehicle Model”

## Worm Gear

Worm gear with adjustable gear ratio and friction losses

### Library

Gears

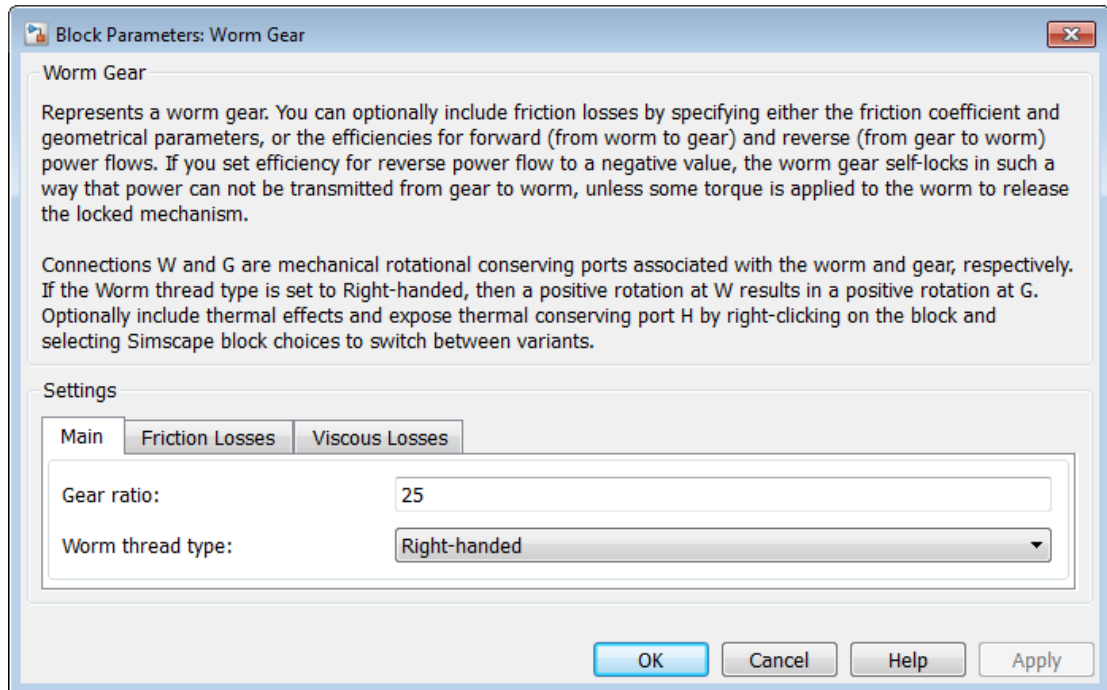


### Description

The block represents a rotational gear that constrains the two connected driveline axes, worm (W) and gear (G), to rotate together in a fixed ratio that you specify. You can choose whether the gear rotates in a positive or negative direction. Right-handed rotation is the positive direction. If the worm thread is right-handed,  $\omega_W$  and  $\omega_G$  have the same sign. If the worm thread is left-handed,  $\omega_W$  and  $\omega_G$  have opposite signs.

You can model the effects of heat flow and temperature change through an optional thermal conserving port. To expose the thermal port, right-click the block and select **Simscape > Block choices > Show thermal port**. Exposing the thermal port causes new parameters specific to thermal modeling to appear in the block dialog box.

## Dialog Box and Parameters



### Main

#### Gear ratio

Gear or transmission ratio  $R_{WG}$  determined as the ratio of the worm angular velocity to the gear angular velocity. The default is 25.

#### Worm thread type

Choose the directional sense of gear rotation corresponding to positive worm rotation. The default is **Right-handed**. If you select **Left-handed**, rotation of the worm in the generally-assigned positive direction results in the gear rotation in negative direction.

## Friction Losses

Parameters for friction losses vary with the block variant chosen—that with a thermal port for thermal modeling or that without a thermal port.

### Without Thermal Port

#### Friction model

Select how to implement friction losses from nonideal meshing of gear threads. The default is `No friction losses`.

- `No friction losses` — Suitable for HIL simulation — Gear meshing is ideal.
- `Constant efficiency` — Transfer of torque between worm and gear is reduced by friction. If you select this option, the panel expands.

#### Constant Efficiency

#### Friction parametrization

Select how to characterize the friction between gear threads. The default is `Friction coefficient and geometrical parameters`.

- `Friction coefficient and geometrical parameters` — Friction is determined by contact friction between surfaces.

#### Normal pressure angle

The thread pressure angle  $a$  in the normal plane. Must be greater than zero and less than 90 degrees. The default is `17.5`.

From the drop-down list, choose units. The default is degrees (`deg`).

#### Lead angle

Thread helix angle  $\lambda = \arctan[L/(\pi d)]$ .  $L$  is the worm lead,  $d$  is the worm pitch diameter. Must be greater than zero. The default is `20`.

From the drop-down list, choose units. The default is degrees (`deg`).

#### Friction coefficient

Dimensionless coefficient of normal friction in the thread. Must be greater than zero. The default is `0.08`.

- **Efficiencies** — Friction is determined by constant efficiencies  $0 < \eta < 1$ . If you select this option, the panel changes from its default.

### **Efficiencies**

#### **Worm-gear efficiency**

Efficiency  $\eta_{WG}$  of the power transfer from worm to gear.

#### **Gear-worm efficiency**

Efficiency  $\eta_{GW}$  of the power transfer from gear to worm.

### **Power threshold**

Power threshold above which full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

### **With Thermal Port**

#### **Temperature**

Array of temperatures used to construct a 1-D temperature-efficiency lookup table. The array values must increase left to right. The temperature array must be the same size as the **Efficiency** array. The default array is [280 300 320] K.

#### **Worm-gear efficiency**

Array of component efficiencies with the worm as the driver—that is, with power flowing from the worm to the gear. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.75 0.7 0.65].

#### **Gear-worm efficiency**

Array of component efficiencies with the gear as the driver—that is, with power flowing from the gear to the worm. The array values are the efficiencies at the temperatures in the **Temperature** array. The two arrays must be the same size. The default array is [0.5 0.45 0.4].

### **Power threshold**

Power threshold above which the full efficiency factor is in effect. A hyperbolic tangent function smooths the efficiency factor between zero at rest and the value provided by the temperature-efficiency lookup table at the power threshold. The default value is 0.001 W.

## Viscous Losses

### Viscous friction coefficients at worm (W) and gear (G)

Vector of viscous friction coefficients [ $\mu_W \mu_G$ ], for the worm and gear, respectively. The default is [0 0].

From the drop-down list, choose units. The default is newton-meters/(radians/second) ( $N \cdot m / (rad/s)$ ).

## Thermal Port

### Thermal mass

Thermal energy required to change the component temperature by a single degree. The greater the thermal mass, the more resistant the component is to temperature change. The default value is 50 J/K.

### Initial temperature

Component temperature at the start of simulation. The initial temperature influences the starting meshing or friction losses by altering the component efficiency according to an efficiency vector that you specify. The default value is 300 K.

## Worm Gear Model

### Model Variables

$R_{WG}$	Gear ratio
$\omega_W$	Worm angular velocity
$\omega_G$	Gear angular velocity
$a$	Normal pressure angle
$\lambda$	Worm lead angle
$L$	Worm lead
$d$	Worm pitch diameter
$\tau_G$	Gear torque
$\tau_W$	Torque on the worm

$\tau_{\text{loss}}$	Torque loss due to meshing friction. The loss depends on the device efficiency and the power flow direction. To avoid abrupt change of the friction torque at $\omega_G = 0$ , the friction torque is introduced via the hyperbolic function.
$\tau_{\text{fr}}$	Steady-state value of the friction torque at $\omega_G \rightarrow \infty$ .
$k$	Friction coefficient
$\eta_{WG}$	Torque transfer efficiency from worm to gear
$\eta_{GW}$	Torque transfer efficiency from gear to worm
$p_{\text{th}}$	Power threshold
$[\mu_W \mu_G]$	Vector of viscous friction coefficients for the worm and gear

## Ideal Gear Constraint and Gear Ratio

Worm gear imposes one kinematic constraint on the two connected axes:

$$\omega_W = R_{WG}\omega_G .$$

The two degrees of freedom are reduced to one independent degree of freedom. The forward-transfer gear pair convention is  $(1,2) = (W,G)$ .

The torque transfer is:

$$R_{WG}\tau_W - \tau_G - \tau_{\text{loss}} = 0 ,$$

with  $\tau_{\text{loss}} = 0$  in the ideal case.

## Nonideal Gear Constraint

In the nonideal case,  $\tau_{\text{loss}} \neq 0$ . For general considerations on nonideal gear modeling, see “Model Gears with Losses”.

### Geometric Surface Contact Friction

In the contact friction case,  $\eta_{WG}$  and  $\eta_{GW}$  are determined by:

- The worm-gear threading geometry, specified by lead angle  $\lambda$  and normal pressure angle  $\alpha$ .
- The surface contact friction coefficient  $k$ .

$$\eta_{WG} = (\cos\alpha - k \tan\lambda)/(\cos\alpha + k/\tan\lambda) ,$$

$$\eta_{GW} = (\cos\alpha - k/\tan\lambda)/(\cos\alpha + k \tan\lambda) .$$

## Constant Efficiencies

In the constant friction case, you specify  $\eta_{WG}$  and  $\eta_{GW}$ , independently of geometric details.

## Self-Locking and Negative Efficiency

$\eta_{GW}$  has two distinct regimes, depending on lead angle  $\lambda$ , separated by the *self-locking point* at which  $\eta_{GW} = 0$  and  $\cos\alpha = k/\tan\lambda$ .

- In the *overhauling regime*,  $\eta_{GW} > 0$ , and the force acting on the nut can rotate the screw.
- In the *self-locking regime*,  $\eta_{GW} < 0$ , and an external torque must be applied to the screw to release an otherwise locked mechanism. The more negative is  $\eta_{GW}$ , the larger the torque must be to release the mechanism.

$\eta_{WG}$  is conventionally positive.

## Meshing Efficiency

The efficiencies  $\eta$  of meshing between worm and gear are fully active only if the transmitted power is greater than the power threshold.

If the power is less than the threshold, the actual efficiency is automatically regularized to unity at zero velocity.

## Viscous Friction Force

The viscous friction coefficient  $\mu_W$  controls the viscous friction torque experienced by the worm from lubricated, nonideal gear threads and viscous bearing losses. The viscous friction torque on a worm driveline axis is  $-\mu_W\omega_W$ .  $\omega_W$  is the angular velocity of the worm with respect to its mounting.

The viscous friction coefficient  $\mu_G$  controls the viscous friction torque experienced by the gear, mainly from viscous bearing losses. The viscous friction torque on a gear driveline axis is  $-\mu_G\omega_G$ .  $\omega_G$  is the angular velocity of the gear with respect to its mounting.

## Limitations

- Gear inertia is assumed negligible.



- Gears are treated as rigid components.
- Coulomb friction slows down simulation. See “Adjust Model Fidelity”.

## Ports

Port	Description
W	Rotational conserving port representing the worm component
G	Rotational conserving port representing the gear component
H	Thermal conserving port for thermal modeling

## See Also

Leadscrew | Sun-Planet Worm Gear

## Related Examples

- “Represent and Transfer Driveline Motion and Torque”



# Function Reference

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## **sd1\_update**

Convert Simscape Driveline first-generation model or library to second-generation format

### **Syntax**

```
newsysname = sd1_update('sys')  
newsysname = sd1_update('sys','oldlib1','newlib1','oldlib2', ...)
```

### **Description**

`newsysname = sd1_update('sys')` converts Simscape Driveline First Generation components in the Simulink<sup>®</sup> system `sys`.

`newsysname = sd1_update('sys','oldlib1','newlib1','oldlib2', ...)` converts the Simscape Driveline First Generation components in the Simulink system `sys` that contains references to the Simscape Driveline First Generation libraries `oldlib1`, `oldlib2`, ... which are already converted to `newlib1`, `newlib2`, ..., respectively.

In both forms, `sd1_update` creates a new system based on the Simscape Driveline transitional library (`sd1_classic`) and returns the name of the new system. The new system is saved in your current directory and remains loaded.

### **Output Arguments**

#### **newsysname**

String variable containing name of new, converted Simulink system

### **Examples**

#### **Converting a Model**

Update the model `drive_ex1`:

```
sdl_ex1 = sdl_update('drive_ex1');
```

## Converting a Model and a Linked Library

If a model `drive_model` references blocks from library `drive_userlib`, update `drive_userlib` into a new library and `drive_md1` into a new model:

```
sdl_userlib = sdl_update('drive_userlib'); % Update library first  
sdl_model = sdl_update('drive_model','drive_userlib',sdl_userlib);  
% Then update model linked to library
```

`sdl_userlib` and `sdl_model` are string variables containing system names, not the system names themselves.

## More About

- “Model and Library Automatic Conversion Examples” on page 3-22



# Relationship of First and Second Generation Technologies

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- “First-Generation Models and Libraries” on page 3-2
- “First and Second Generation Libraries” on page 3-4
- “Manual Reconstruction of First Generation Models” on page 3-11
- “Automatic Conversion of First Generation Models and Libraries” on page 3-15
- “Modification and Troubleshooting of Automatically Converted Models” on page 3-17
- “Model and Library Automatic Conversion Examples” on page 3-22

drivelib

## First-Generation Models and Libraries

### In this section...

“Current First-Generation Functionality” on page 3-2

“Manual Conversion of First-Generation Models” on page 3-3

“Modification of Automatically Converted Models” on page 3-3

### Current First-Generation Functionality

Simscape Driveline contains two technologies: first- and second-generation. First-generation technology includes the legacy blocks of Simscape Driveline version 1, which are based on the Simulink language. Second-generation technology introduces a new block library that is based on the Simscape physical modeling language.

### First-Generation Models

The following list outlines the tasks you can perform with Simscape Driveline first-generation technology:

- Add first-generation blocks to a model.
- Modify and simulate first-generation models.
- Manually convert first-generation models to second-generation format.
- Automatically convert first-generation models to second-generation format with a conversion utility.
- Create and simulate hybrid models that contain first- and second-generation blocks.

### First-Generation User-Defined Libraries

First-generation user-defined libraries remain functional in Simscape Driveline software. The following list outlines the tasks you can perform with the user-defined libraries:

- Build, modify, and employ user-defined libraries that contain first-generation blocks.
- Manually convert first-generation user-defined libraries to second-generation format.
- Automatically convert first-generation models and libraries to second-generation format with a conversion utility.
- Create and change hybrid user-defined libraries that contain first- and second-generation blocks.



## Conversion of Models with User-Defined Blocks

If a model contains first-generation user-defined blocks, you can convert the user-defined blocks to second-generation format. Once you have converted the blocks, you can convert the model that employs the blocks. After conversion, the converted model automatically uses the converted blocks.

## Limitations with Conversion and Multi-Generation Models

Most first-generation blocks and block parameters have a second-generation equivalent, but exceptions exist. See “Correspondence of First and Second Generation Blocks” on page 3-7

First- and second-generation blocks connect only *indirectly*. The blocks use Simulink and Simscape signals, respectively, and you must use a converter block to convert between the two signal types. Two converter blocks exist in the Simscape Utilities library: PS-Simulink Converter and Simulink-PS Converter.

## Manual Conversion of First-Generation Models

Most first-generation blocks have a matching second-generation block. You can manually reconstruct a first-generation model by switching first-generation blocks with their second-generation equivalents. Manual conversion of first-generation models is more time-consuming and requires greater attention to detail. See “Manual Reconstruction of First Generation Models” on page 3-11.

## Modification of Automatically Converted Models

Simscape Driveline provides a conversion utility that you can use to automatically convert a first-generation model or library to second-generation format. The utility carries out the conversion task with minimal input on your side. When conversion is complete, you can manually modify the model or library with additional second-generation blocks. See “Modification and Troubleshooting of Automatically Converted Models” on page 3-17.

## First and Second Generation Libraries

### In this section...

“First and Second Generation Block Compatibility” on page 3-4

“First Generation Library” on page 3-5

“Second Generation Library” on page 3-5

“Transitional Library” on page 3-6

“Correspondence of First and Second Generation Blocks” on page 3-7

Second-generation technologies introduces blocks that rely on the Simscape physical modeling language. The second-generation libraries contain a matching block for nearly every first-generation block, with few exceptions. To facilitate the transition from first- to second-generation technology, Simscape Driveline provides a transitional block library.

### First and Second Generation Block Compatibility

The following considerations distinguish first- and second-generation blocks:

- First-generation blocks rely on Simscape software, but not on the Simscape library. Instead, the blocks exist in an independent library that relies on the Simulink language.
- Second-generation blocks rely on *both* Simscape software and library. The blocks exist in a library that reuses Simscape blocks.
- Second-generation blocks integrate fully with transitional library blocks. You can connect the blocks directly without restriction.
- First- and second-generation blocks can connect in a model or user-defined library through a Simscape converter block. Two converter blocks exist in the Simscape Utilities library:
  - **PS-Simulink Converter**—Convert a Simscape signal with physical units to a dimensionless Simulink signal.
  - **Simulink-PS Converter**—Convert a dimensionless Simulink signal to a Simscape signal with physical units.
- First- and second-generation blocks can also connect through the first-generation **Rotational Coupling** block. Use the block to connect a first-generation connection line to a mechanical rotational connection line.

- You cannot automatically convert second-generation models or user-defined libraries to the first-generation format.

## First Generation Library

The first-generation block library provides the basis for first-generation models and user-defined libraries. You can continue to access the first-generation library:

- At the MATLAB command line, enter `drivelib` or `driveline`.

For more information on first-generation blocks, see “First Generation Block Libraries”.



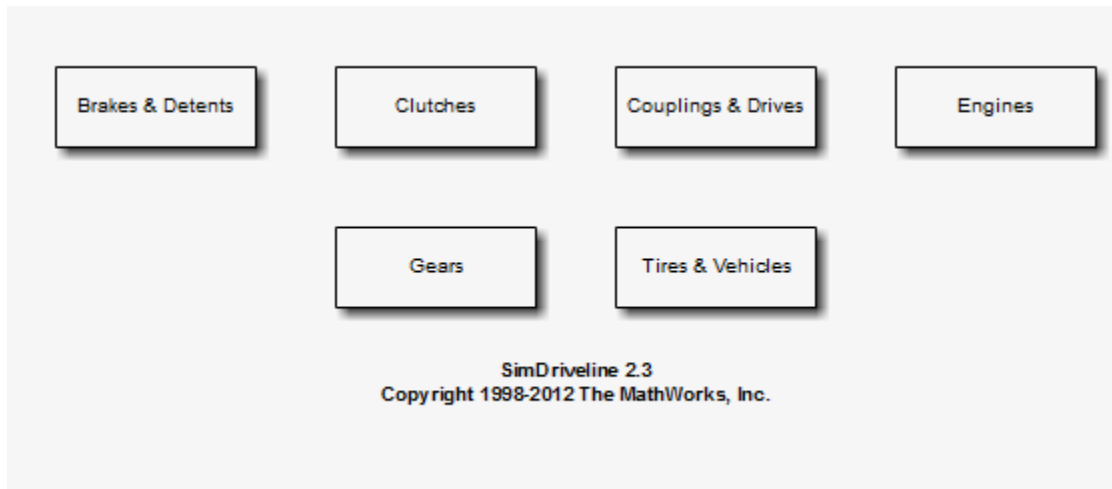
### First Generation Block Library

## Second Generation Library

The second-generation block library provides the basis for second-generation models and user-defined libraries. The library contains blocks that replicate the functionality of first-generation blocks. New blocks add functionality not present in the first-generation library.

You can access the second-generation product library:

- At the MATLAB command line, enter `sdl_lib`.



#### Second Generation Block Library

#### Transitional Library

Simscape Driveline provides a transitional block library. The library provides blocks that are functionally equivalent to first-generation blocks but compatible with second-generation blocks. Transitional library blocks are built on the blocks from the Simscape Foundation and Simscape Driveline Second Generation libraries.

You can access the transitional library:

- At the MATLAB command line, enter `sdl_classic`



#### Transitional Library

The blocks of the transitional library are built with the Simscape language and their ports are mechanical conserving ports. This library is the bridge between the first- and second-generation products. The conversion function uses the transitional library to generate the second-generation equivalent of a first-generation model. See “How the Simscape Driveline Update Function Works” on page 3-15 and “About Automatically Converted Models” on page 3-16.

## Correspondence of First and Second Generation Blocks

- “Equivalent Blocks” on page 3-7
- “Replacement Blocks” on page 3-7
- “Missing Block Parameters” on page 3-9
- “Special Transitional Library Blocks” on page 3-9
- “Transmission Templates Blocks” on page 3-10

### Equivalent Blocks

The transitional library provides second-generation blocks that are functionally equivalent to first-generation blocks.

Blocks in the first-generation Gears library have exact equivalents in the second-generation Gears library. The **Variable Ratio Gear** is an exception. This block has no second-generation equivalent or replacement. Second-generation block **Variable Ratio Transmission** provides similar functionality to

The **Rotational Coupling** block in the first-generation Interface Elements library behaves as a Simscape physical connection line between two second-generation driveline ports.

### Replacement Blocks

---

**Tip** All transitional blocks can be replaced with functional equivalents using Simscape Driveline Second Generation and Simscape blocks. For natural and consistent Simscape implementation, MathWorks recommends manual block replacement and model reconstruction where appropriate, after automatic conversion. See “Modification and Troubleshooting of Automatically Converted Models” on page 3-17.

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The following tables provide the relationship between first- and second-generation blocks.

<b>First-Generation Block</b>	<b>Second-Generation Replacement</b>
Controllable Friction Clutch	Disk Friction Clutch
Fundamental Friction Clutch	Fundamental Friction Clutch
Torque Converter	Torque Converter
Torsional Spring-Damper	Torsional Spring-Damper
Diesel Engine	Generic Engine configured to diesel ignition
Gasoline Engine	Generic Engine configured to spark ignition
Tire	Tire (Magic Formula) + related Simscape foundation components

<b>First-Generation Block</b>	<b>Simscape Foundation Replacement</b>
Driveline Environment	Solver Configuration
Housing	Mechanical Rotational Reference
Hard Stop	Rotational Hard Stop
Inertia	Inertia
Torque Sensor	Ideal Torque Sensor
Torque Actuator	Ideal Torque Source + Mechanical Rotational Reference
Motion Actuator	Ideal Angular Velocity Source + Mechanical Rotational Reference
Motion Sensor	Ideal Rotational Motion Sensor + Mechanical Rotational Reference

<b>First Generation Block</b>	<b>Simulink Replacement</b>
Longitudinal Vehicle Dynamics	Pure Simulink masked subsystem

## Missing Block Parameters

First-generation blocks accept input parameters that have no counterpart in transitional or second-generation blocks. Parameters without counterpart are lost during the conversion. The following table outlines the block parameters that do not carry over from first-generation blocks.

Missing block dialog field or check box	Missing block parameter
Fundamental Friction Clutch Block	
Use automatic clutch velocity tolerance for variable-step solvers	UseAutomaticVelocityTolerance
Use default clutch velocity tolerance from the Driveline Environment block	UseDefaultVelocityTolerance
Driveline Environment Block	
Default clutch velocity tolerance	DefaultClutchVelocityTolerance
Use automatic clutch velocity tolerance for variable-step solvers	DefaultUseAutoClutchVelocityTolerance
Fundamental Friction Clutch Block	
Use automatic clutch velocity tolerance for variable-step solvers	UseAutomaticVelocityTolerance
Use default clutch velocity tolerance from the Driveline Environment block	UseDefaultVelocityTolerance
Tire Block	
Relaxation length at rated load	sigma_k
Variable Ratio Gear Block	
Include Coriolis acceleration	Coriolis

## Special Transitional Library Blocks

Some first-generation blocks have no functional equivalent in Simscape Driveline Second Generation or Simscape Foundation libraries. Blocks without the functional equivalents appear in the transitional library as special blocks. Two special blocks exist in the transitional library: **Shared Environment** and **Initial Condition**. The two blocks integrate fully with Simscape Driveline Second Generation and Simscape Foundation blocks. However, unlike the remainder of the transitional library, the blocks but are built

directly from *neither* library. The following table outlines the special blocks present in the transitional library.

First Generation Block	Transitional Library Block	Comments
Shared Environment	Shared Environment	—
Initial Condition	Initial Condition	The block parameter is equivalent to the <b>Initial Velocity</b> parameters of the <b>Inertia</b> block in the Simscape Foundation library

#### Transmission Templates Blocks

The first-generation Transmission Templates library has no functional equivalent in the transitional or second-generation libraries. The library contains masked subsystems built from first-generation blocks that include inertia, gear and clutch elements. If you have a first-generation model with a Transmission Templates block, you can convert the model to a second-generation model. Conversion reproduces the model with the second-generation counterparts of first-generation blocks.



# Manual Reconstruction of First Generation Models

**In this section...**

“Automatic Conversion Versus Manual Reconstruction” on page 3-11

“Recreating Equivalent Blocks and Connections” on page 3-11

“Recreating Equivalent Parameters and Signals” on page 3-12

“Reconstruct Clutch Parameters and Signals” on page 3-12

“Recreate Specialized Model Functionality” on page 3-14

## Automatic Conversion Versus Manual Reconstruction

Simscape Driveline provides a conversion utility that you can use to automatically translate first-generation models and libraries to the second-generation format. The conversion utility replaces first-generation blocks with their second-generation functional equivalents. You can manually modify any automatically converted model or library. See “Automatic Conversion of First Generation Models and Libraries” on page 3-15 and “Modification and Troubleshooting of Automatically Converted Models” on page 3-17.

Manual reconstruction of a model or library is an option. During manual reconstruction of a model, you directly replace each first-generation block with a second-generation equivalent block. You must provide the appropriate input parameters to the blocks. You must also connect the blocks with the appropriate physical connection lines.

---

**Tip** Manual reconstruction of a first-generation model requires more time and attention to detail. Streamline the conversion process by using the conversion utility first. Then, after the utility automatically converts your model or library, review for accuracy. You can manually change any blocks and parameters

---

## Recreating Equivalent Blocks and Connections

Almost all first-generation blocks have equivalent second-generation blocks. With second-generation blocks, you can recreate all first-generation functionality. For information about the mapping of first- to second-generation blocks, see “Correspondence of First and Second Generation Blocks” on page 3-7.

In a first-generation model, every driveline requires a **Driveline Environment** block. The second-generation equivalent is a **Simscape Solver Configuration** block for each physical network. In this case, a second-generation driveline is a physical network.

You recreate the first-generation driveline connection lines between first-generation blocks by connecting the equivalent second-generation blocks (based on the Simscape library) with mechanical rotational connection lines.

## Recreating Equivalent Parameters and Signals

Most of the equivalent second-generation blocks have parameters identical or similar to the parameters of the corresponding first-generation blocks. The primary difference is how first- and second-generation blocks implement signals.

- First-generation blocks accept and generate unitless Simulink signals. Some input signals are normalized by dividing by physical reference values with units. Output signals are converted to physical values and units by multiplying by physical reference values. These values and units are set in the blocks.
- Second-generation blocks accept and generate Simscape physical signals that carry units. The blocks accept these units, but do not implement them.

To achieve equivalent functionality in the second-generation model, you therefore might have to redefine your signals and to change how parameters are entered in a block. You can convert between Simulink signals and Simscape physical signals with **Simulink-PS Converter** and **PS-Simulink Converter** blocks. If you need to, use the **Simulink Gain** block to rescale signal values.

With certain blocks, there are also minor technical differences in how parameters are entered. You can determine these differences by comparing the old block and new block reference pages.

## Reconstruct Clutch Parameters and Signals

The first-generation **Controlled Friction Clutch** is functionally equivalent to the second-generation **Disk Friction Clutch**. If you reconstruct the **Controlled Friction Clutch** with a **Disk Friction Clutch**, the key parameters and signals that you need rearrange include:

- Input signal P (pressure).

The first-generation input is a normalized, unitless Simulink signal that modulates the physical value that the block parameters determine. When this signal value is 1, the kinetic friction across the clutch discs is the full kinetic friction torque implied by the block's parameters. The normalized pressure signal can have a threshold between 0 and 1.

The second-generation input is a Simscape physical signal carrying units of pressure. This signal is used directly in the calculation of the torque applied across the clutch. The physical pressure can have a threshold that you must enter as a physical value with correct units.

- Peak normal force  $F_{\max}$  in the first-generation block, which is replaced by engagement piston area  $A$  in the second-generation block. In second-generation, you multiply  $A$  by input pressure to determine peak force.
- Coefficient of friction table  $\mu$ , or mu, in the first-generation block. In the second-generation block, this option is available. But, as an alternative, you can also use a fixed friction coefficient.

To replace a Controlled Friction Clutch with a Disk Friction Clutch, using the same normalized Simulink signal for pressure:

- 1 Place a Gain block and a Simulink-PS Converter block, connected in that order, between the normalized input signal and the Disk Friction Clutch pressure port P.
- 2 Set the gain value to  $F_{\max}/A$ . In the Simulink-PS Converter block, set the **Input signal unit** to Pa (pascal). (If you use a different pressure unit in the Disk Friction Clutch, use that unit here instead.)

Map the old clutch to the new clutch parameters:

- 1 In the new block, set **Engagement threshold pressure** to  $F_{\max}/A$  times the value of **Engagement threshold for normalized pressure** in the old block.
- 2 If the old mu table parameter is a 2-by-2 matrix, and the two friction coefficient values are the same, then set the new **Kinetic friction coefficient** to the old friction coefficient value. Set the new **Static friction coefficient** to the old **Static friction peak factor** times this value.

Otherwise, in the new block, select the Table lookup kinetic friction coefficient option for **Friction model**. Set **Kinetic friction coefficient relative velocity vector** to  $\mu(:, 1)$  and **Kinetic friction coefficient vector** to  $\mu(:, 2)$ .

- 3 Copy exactly the remaining parameters, or leave them as default in the new clutch.

### **Recreate Specialized Model Functionality**

First-generation models can have specialized features. You might have to perform additional tasks to recreate these features in second-generation format. Some issues to consider are reconstructing initial conditions, modeling physics, removing algebraic loops, and taking advantage of Simscape features not available in first-generation, such as local solvers.

These specialized modeling issues are similar to manually optimizing automatically converted models after translation. For additional guidance, see “Best Practices with Automatically Converted Models” on page 3-19.

# Automatic Conversion of First Generation Models and Libraries

## In this section...

“What Automatic Conversion Does” on page 3-15

“How the Simscape Driveline Update Function Works” on page 3-15

“About Automatically Converted Models” on page 3-16

## What Automatic Conversion Does

- You can convert models based on first-generation blocks to new models based on second-generation blocks.
- You can also convert existing user-defined libraries based on first-generation blocks to new user-defined libraries based on second-generation blocks.
- In both cases, conversion generates new models and libraries built from the transitional second-generation library.
- Conversion directly involves the first-generation product block library and the second-generation transitional library, but not the second-generation product library.

## How the Simscape Driveline Update Function Works

The `sd1_update` function converts first-generation models and user-defined libraries to second-generation equivalents. To convert a model, at the command line, enter:

```
newmdlname = sd1_update('mdlname');
```

If the original model is open, the new one is open. If the original model is closed, the function loads the original model, then creates and loads the new model, without opening it. The new model is saved in your current directory, and its name is stored in the output string variable; in this case, `newmdlname`.

For additional details, see “Model and Library Automatic Conversion Examples” on page 3-22 and the `sd1_update` function reference page.

### Converting User-Defined Libraries

To convert a first generation user-defined library, use the same function form used to convert a first-generation model.

#### **Converting Models Linked to User-Defined Libraries**

To convert a first-generation model linked to one or more user-defined libraries:

- 1 Convert the linked libraries.
- 2 Enter the function form specifying not only the model to convert, but both the first- and second-generation linked libraries:

```
newmdlname = sdl_update('mdlname','oldlib1','newlib1',...);
```

#### **About Automatically Converted Models**

“Transitional Library” on page 3-6 presents the characteristics of the transitional second-generation library and its relationship to the main second-generation product library.

#### **Looking Under Converted Block Masks**

The transitional library blocks are masked subsystems. You can view the underlying blocks by looking under the masks.

- Some first-generation blocks have exact second-generation equivalents, and the masked subsystems wrap the second-generation blocks into forms that look like the first-generation blocks.
- Upon conversion, first-generation blocks without exact second-generation equivalents are recreated as replacement masked subsystems built from second-generation, Simscape Foundation, or pure Simulink components. The replacement subsystems consist of multiple blocks that function the same way the corresponding first-generation block does.

#### **First-Generation Blocks Without Second-Generation Equivalents or Replacements**

For first-generation blocks without subsystem replacements or exact equivalents, the underlying subsystems in the converted blocks are built from Simscape software, but not directly on the Simscape or Simscape Driveline Second Generation library.

#### **Transmission Subsystem Conversion**

Upon conversion, first-generation Transmission Templates are recreated as unmasked subsystems built from second-generation blocks. The conversion translates below the subsystem level, at the level of individual blocks (gears, clutches, inertias, etc.) that are linked to the first-generation library.

# Modification and Troubleshooting of Automatically Converted Models

**In this section...**

“Manually Revise and Optimize Converted Models” on page 3-17

“Unlink and Replace Transitional Library Blocks” on page 3-17

“Best Practices with Automatically Converted Models” on page 3-19

“Transitional Library Input Handling Options” on page 3-20

## Manually Revise and Optimize Converted Models

The most important differences between first- and second-generation arise from Simscape features that include:

- Simscape Driveline components with realistic loss, threshold, and compliance dynamics
- Simscape Foundation library
- Physical signals with units
- Local solvers
- Data logging

The practical impact of these Simscape-based features lies in how you optimally build more complex physical models. Once you have automatically updated a first-generation model to second-generation format, you may want or need to manually revise it to take advantage of and better conform to the Simscape environment.

---

**Note:** Manual optimization of a converted model sometimes requires detailed understanding of how equivalent second-generation blocks replace first-generation blocks. To learn in detail how this mapping works, see “Manual Reconstruction of First Generation Models” on page 3-11.

---

## Unlink and Replace Transitional Library Blocks

Because the converted model uses the transitional library `sdl_classic`, the model does not have to appear or be constructed as it would if you had built it from the start with the

Simscape Driveline 2 and Simscape product libraries. Follow some or all of these steps to make the converted model more naturally fit the second-generation, Simscape-based environment.

#### **Disabling and Breaking Transitional Library Links—Unmasking Subsystems**

You use the block context menus on the masked subsystems for these tasks.

- Because the converted blocks are masked subsystems, you can free the converted model from the transitional library by disabling and optionally breaking the converted block links to `sdl_classic`.
- You can also remove a subsystem mask entirely.
  - 1 Open the block dialog box and edit the subsystem mask to determine how the block dialog parameters are referenced in the underlying subsystem.
  - 2 Replace the block dialog parameters in the underlying subsystem with the model-level parameter values or variables.
  - 3 Unmask the subsystem.

---

**Tip** Before removing the mask, be sure to locate and copy the subsystem dialog parameter values or variables into the underlying subsystem blocks. You cannot retrieve these values or variables once you have removed the mask.

---

#### **Reconstructing Converted Blocks — Promoting Subsystem Blocks**

Depending on your model appearance and construction, decide whether or not you want to promote unmasked subsystem blocks higher up in the model hierarchy.

You can rearrange and, where possible, replace or modify these underlying Simscape and Simscape Driveline 2 blocks, using the regular product libraries only. For block equivalents and replacements, consult “Transitional Library” on page 3-6.

#### **Reconstructing Driveline Initial Conditions**

There is no equivalent to the first-generation `Initial Condition` block. In a Simscape-based model, you instead set initial conditions on some blocks individually, while other blocks have no initial conditions. You must ensure that the physical network as a whole has a consistent initial state.

For more about initial conditions, see “Simulation Setup”.



## Best Practices with Automatically Converted Models

To achieve optimal simulation performance and avoid simulation problems and failures with converted models, verify that your model conforms with these best practices. If it does not conform, modify the model.

- “Reconstructing Custom Physical Modeling” on page 3-19
- “Avoiding Algebraic Loops” on page 3-19
- “Changing Global Solvers — Adding Optional Local Solvers” on page 3-20

### Reconstructing Custom Physical Modeling

Consider rebuilding how you model physical processes in your converted model. In the Simscape environment, the order of preference for physical modeling is to use:

- 1 Product library blocks in the Simscape Driveline and Simscape Foundation libraries
- 2 Simscape language
- 3 Physical Signal blocks, if the Simscape language is not adequate
- 4 Simulink signals and blocks with sensors and actuators, making sure to break any algebraic loops (see “Avoiding Algebraic Loops” on page 3-19)

For guidance on how to customize and specialize your driveline components, see “Specialized and Customized Driveline Components”. Continue using Simulink for algorithmic control, nonphysical signals, and model-level input/output.

- In first-generation, you model custom and specialized physical components in Simulink, connecting to Simscape Driveline blocks through sensors and actuators with nonphysical Simulink signals.
- In second-generation, you accomplish the same goal with Simscape-based components and language, bringing all physical modeling into the Simscape environment.

### Avoiding Algebraic Loops

Simscape simulation treats differential and algebraic constraint equations similarly. To the extent possible in your model, represent algebraic constraints between physical variables with Simscape-based components. Avoid physical signal algebraic loops that are fed back through Simulink. That is, avoid instantaneous, noncausal relationships between physical variables.

For more about algebraic loops, see “Algebraic Loops”.

#### Changing Global Solvers — Adding Optional Local Solvers

The default Simulink global solver is ode45. Most physical models in the Simscape environment are best simulated using ode23 or ode15s. In addition, you can optionally use the fixed-step Simscape local solvers with Simulink global solvers to improve physical simulation.

For more information about selecting global and local solvers for physical simulations, see:

- “Driveline Simulation Performance”
- “Desktop Simulation”

#### Transitional Library Input Handling Options

Transitional library blocks that convert Simulink signals into Simscape signals provide input handling control. The block dialog box contains an **Input Handling** tab that you can use to select a filtering type for the input signal. You can select no filtering, first-order filtering, or second-order filtering. Alternatively, you can choose to specify up to two input derivatives. The **Input Handling** tab mirrors the **Simulink-PS Converter**. For more information, see “Input Handling”.

Only transitional library blocks that convert a Simulink signal into a physical signal provide an **Input Handling** tab. The blocks contain one or more Simulink inports and one or more Simscape physical signal outputs. If the block contains multiple Simulink input ports, the input handling options you specify apply equally to all ports. If you want to apply different input handling options to each input port, open the block subsystem and specify the input handling options for each **Simulink-PS Converter** block directly.

Model topology and solver choice determine the number of input derivatives required for a solution. You have the option to specify the first- and second-order derivatives, but if you fail to specify enough input derivatives, Simscape issues an error. Errors caused by insufficient input derivatives point to the **Simulink-PS Converter** block used under the mask of the transitional library block.

The following table lists the transitional library blocks that provide **Input Handling** options.

Library	Block
Gears	Variable Ratio Gear

<b>Library</b>	<b>Block</b>
Dynamic Elements	Controllable Friction Clutch
	Fundamental Friction Clutch
Sensors & Actuators	Torque Actuator
	Motion Actuator
Vehicle Components	Diesel Engine
	Gasoline Engine
	Tire

## Model and Library Automatic Conversion Examples

In this section...
“About the Automatic Conversion Examples” on page 3-22
“Convert Example Model” on page 3-22
“Convert Example Library” on page 3-22
“Convert Example Model Linked to Example Library” on page 3-23

### About the Automatic Conversion Examples

These conversion examples use two example models and one example library from first-generation. Models and libraries do not have to be open before you start converting them.

- `drive_sgear` — Standalone example model
- `drive_efficiency` — Examples library, similar to a user-defined library
- `drive_sgear_lossy` — Example model linked to `drive_efficiency`

---

**Tip** Proceed through the following examples in the order presented for complete coverage on how to use `sdl_update`.

---

### Convert Example Model

At the command line, enter:

```
v2mdlname1 = sdl_update('drive_sgear');
```

The second-generation model is generated in the current directory, and its name is stored in the string variable `v2mdlname1`.

### Convert Example Library

At the command line, enter:

```
v2libname = sdl_update('drive_efficiency');
```

The second-generation library is generated in the current directory, and its name is stored in the string variable `v2libname`.

## Convert Example Model Linked to Example Library

---

**Note:** Complete the preceding example before attempting this one.

---

At the command line, enter:

```
v2mdlname2 = sdl_update('drive_sgear_lossy','drive_efficiency',  
v2libname);
```

This form of the function specifies the first-generation library name as a literal string, but the new library name as a string variable. It uses the same string variable as in the preceding example.



# Technical Conventions

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## Driveline Abbreviations and Conventions

### In this section...

“Abbreviations” on page A-2

“Angular Motion” on page A-2

“Gear Ratios” on page A-2

### Abbreviations

An important abbreviation is DoF, which means *degree of freedom* and refers to one coordinate of angular motion. All driveline rotational DoFs are measured with respect to a single absolute coordinate system at rest.

### Angular Motion

Standard symbols for angular motion analysis include the following:

Symbol	Meaning (Units)
$r$	Gear radius
$N$	Number of gear teeth
$g$	Gear ratio
$\theta$	Angle
$\omega$	Angular velocity
$\tau$	Torque

### Gear Ratios

For a pair of coupled, coplanar gear wheels, the gear ratio  $g_{21}$  of gear 2 to gear 1 is defined as the ratio of the second gear wheel radius to the first. This definition is equivalent to the ratio of the number of teeth on the second gear wheel to the number of teeth on the first.

$$g_{21} \equiv r_2/r_1 = N_2/N_1$$

The gear ratio is the ratio of torques and the reciprocal of the angular velocity ratio.



$$g_{21} = \tau_2/\tau_1 = \omega_1/\omega_2$$

For gear boxes made of more than two gear wheels, the gear ratio is defined to be the ratio of torques or the reciprocal of the ratio of angular velocities, between the output and input shafts.

If the gear is reversing, the output  $\omega$  and  $\tau$  have opposite signs from the input  $\omega$  and  $\tau$ .



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