Simscape™ 3
Reference

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Simscape™ Reference

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5 Simscape Foundation Domains

6 Configuration Parameters

A Bibliography

Glossary

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Block Reference

Foundation

Electrical

Electrical Elements

Capacitor	Simulate linear capacitor in electrical systems
Diode	Simulate piecewise linear diode in electrical systems
Electrical Reference	Simulate connection to electrical ground
Gyrator	Simulate ideal gyrator in electrical systems
Ideal Transformer	Simulate ideal transformer in electrical systems
Inductor	Simulate linear inductor in electrical systems
Mutual Inductor	Simulate mutual inductor in electrical systems
Op-Amp	Simulate ideal operational amplifier
Resistor	Simulate linear resistor in electrical systems
Rotational Electromechanical Converter	Provide interface between electrical and mechanical rotational domains
Switch	Simulate switch controlled by external physical signal
Translational Electromechanical Converter	Provide interface between electrical and mechanical translational domains
Variable Resistor	Simulate linear variable resistor in electrical systems

Electrical Sensors

Current Sensor	Simulate current sensor in electrical systems
Voltage Sensor	Simulate voltage sensor in electrical systems

Electrical Sources

AC Current Source	Simulate ideal sinusoidal current source
AC Voltage Source	Simulate ideal constant voltage source
Controlled Current Source	Simulate ideal current source driven by input signal
Controlled Voltage Source	Simulate ideal voltage source driven by input signal
Current-Controlled Current Source	Simulate linear current-controlled current source
Current-Controlled Voltage Source	Simulate linear current-controlled voltage source
DC Current Source	Simulate ideal constant current source
DC Voltage Source	Simulate ideal constant voltage source
Voltage-Controlled Current Source	Simulate linear voltage-controlled current source
Voltage-Controlled Voltage Source	Simulate linear voltage-controlled voltage source

Hydraulic

Hydraulic Elements

Constant Area Hydraulic Orifice	Simulate hydraulic orifice with constant cross-sectional area
Constant Volume Hydraulic Chamber	Simulate hydraulic capacity of constant volume
Fluid Inertia	Simulate pressure differential across tube or channel due to change in fluid velocity
Hydraulic Piston Chamber	Simulate variable volume hydraulic capacity in cylinders
Hydraulic Reference	Simulate connection to atmospheric pressure
Hydraulic Resistive Tube	Simulate hydraulic pipeline which accounts for friction losses only
Linear Hydraulic Resistance	Simulate hydraulic pipeline with linear resistance losses
Rotational Hydro-Mechanical Converter	Simulate ideal hydro-mechanical transducer as building block for rotary actuators
Translational Hydro-Mechanical Converter	Simulate single chamber of hydraulic cylinder as building block for various cylinder models

Variable Area Hydraulic Orifice	Simulate hydraulic variable orifice created by cylindrical spool and sleeve
Variable Hydraulic Chamber	Simulate hydraulic capacity of variable volume with compressible fluid

Hydraulic Sensors

Hydraulic Flow Rate Sensor	Simulate ideal flow meter
Hydraulic Pressure Sensor	Simulate ideal pressure sensing device

Hydraulic Sources

Hydraulic Flow Rate Source	Simulate ideal source of hydraulic energy, characterized by flow rate
Hydraulic Pressure Source	Simulate ideal source of hydraulic energy, characterized by pressure

Hydraulic Utilities

Custom Hydraulic Fluid	Set working fluid properties by specifying parameter values

Magnetic

Magnetic Elements (p. 1-7)	Magnetic building blocks, such as reluctances, electromagnetic converters, and actuators
Magnetic Sensors (p. 1-7)	Flux and mmf sensors
Magnetic Sources (p. 1-7)	Flux and mmf sources

Magnetic Elements

Electromagnetic Converter	Simulate lossless electromagnetic energy conversion device
Magnetic Reference	Simulate reference for magnetic ports
Reluctance	Simulate magnetic reluctance
Reluctance Force Actuator	Simulate magnetomotive device based on reluctance force
Variable Reluctance	Simulate variable reluctance

Magnetic Sensors

Flux Sensor	Simulate ideal flux sensor
MMF Sensor	Simulate ideal magnetomotive force sensor

Magnetic Sources

Controlled Flux Source	Simulate ideal flux source driven by input signal
Controlled MMF Source	Simulate ideal magnetomotive force source driven by input signal
Flux Source	Simulate ideal flux source
MMF Source	Simulate ideal magnetomotive force source

Mechanical

Mechanical Sensors (p. 1-8)	Mechanical sensors and sources
Mechanical Sources (p. 1-8)	Mechanical sensors and sources
Mechanisms (p. 1-9)	Various simple mechanisms

Rotational Elements (p. 1-9)	Mechanical elements for rotational motion
Translational Elements (p. 1-9)	Mechanical elements for translational motion

Mechanical Sensors

Ideal Force Sensor	Simulate force sensor in mechanical translational systems
Ideal Rotational Motion Sensor	Simulate motion sensor in mechanical rotational systems
Ideal Torque Sensor	Simulate torque sensor in mechanical rotational systems
Ideal Translational Motion Sensor	Simulate motion sensor in mechanical translational systems

Mechanical Sources

Ideal Angular Velocity Source	Simulate ideal angular velocity source in mechanical rotational systems
Ideal Force Source	Simulate ideal source of mechanical energy that generates force proportional to the input signal
Ideal Torque Source	Simulate ideal source of mechanical energy that generates torque proportional to the input signal
Ideal Translational Velocity Source	Simulate ideal velocity source in mechanical translational systems

Mechanisms

Gear Box	Simulate gear boxes in mechanical systems
Lever	Simulate lever in mechanical systems
Wheel and Axle	Simulate wheel and axle mechanism in mechanical systems

Rotational Elements

Inertia	Simulate inertia in mechanical rotational systems
Mechanical Rotational Reference	Simulate reference for mechanical rotational ports
Rotational Damper	Simulate viscous damper in mechanical rotational systems
Rotational Friction	Simulate friction in contact between rotating bodies
Rotational Hard Stop	Simulate double-sided rotational hard stop
Rotational Spring	Simulate ideal spring in mechanical rotational systems

Translational Elements

Mass	Simulate mass in mechanical translational systems
Mechanical Translational Reference	Simulate reference for mechanical translational ports
Translational Damper	Simulate viscous damper in mechanical translational systems

Translational Friction	Simulate friction in contact between moving bodies
Translational Hard Stop	Simulate double-sided translational hard stop
Translational Spring	Simulate ideal spring in mechanical translational systems

Physical Signals

Functions

PS Add	Add two physical signal inputs
PS Divide	Compute simple division of two input physical signals
PS Gain	Multiply input physical signal by constant
PS Math Function	Apply mathematical function to input physical signal

PS Product	Multiply two physical signal inputs
PS Subtract	Compute simple subtraction of two input physical signals

Linear Operators

PS Integrator	Integrate physical signal

Lookup Tables

PS Lookup Table (1D)	Approximate one-dimensional function using specified lookup method
PS Lookup Table (2D)	Approximate two-dimensional function using specified lookup method

Nonlinear Operators

PS Abs	Output absolute value of input physical signal
PS Ceil	Output the smallest integer larger than or equal to input physical signal
PS Dead Zone	Provide region of zero output for physical signals
PS Fix	Round input physical signal toward zero
PS Floor	Output the largest integer smaller than or equal to input physical signal
PS Max	Output maximum of two input physical signals
PS Min	Output minimum of two input physical signals

PS Saturation	Limit range of physical signal
PS Sign	Output sign of input physical signal
PS Switch	Simulate single-pole double-throw switch controlled by external physical signal

Sources

PS Constant	Generate constant physical signal

Pneumatic

Pneumatic Elements

Adiabatic Cup	Simulate thermal element with no thermal mass and perfect insulation
Constant Area Pneumatic Orifice	Simulate sharp-edged orifice in pneumatic systems
Constant Area Pneumatic Orifice (ISO 6358)	Simulate fixed-area pneumatic orifice complying with ISO 6358 standard
Constant Volume Pneumatic Chamber	Simulate constant volume pneumatic chamber based on ideal gas law

Pneumatic Absolute Reference	Simulate reference to zero absolute pressure and temperature for pneumatic ports
Pneumatic Atmospheric Reference	Simulate reference to ambient pressure and temperature for pneumatic ports
Pneumatic Piston Chamber	Simulate translational pneumatic piston chamber based on ideal gas law
Pneumatic Resistive Tube	Simulate pressure loss and added heat due to flow resistance in pneumatic pipe
Rotary Pneumatic Piston Chamber	Simulate rotational pneumatic piston chamber based on ideal gas law
Rotational Pneumatic-Mechanical Converter	Provide interface between pneumatic and mechanical rotational domains
Variable Area Pneumatic Orifice	Simulate variable orifice in pneumatic systems

Pneumatic Sensors

Pneumatic Mass & Heat Flow Sensor	Simulate ideal mass flow and heat flow sensor
Pneumatic Pressure & Temperature Sensor	Simulate ideal pressure and temperature sensor

Pneumatic Sources

Controlled Pneumatic Flow Rate Source	Simulate ideal compressor with signal-controlled mass flow rate
Controlled Pneumatic Pressure Source	Simulate ideal compressor with signal-controlled pressure difference

Pneumatic Flow Rate Source	Simulate ideal compressor with constant mass flow rate
Pneumatic Pressure Source	Simulate ideal compressor with constant pressure difference

Pneumatic Utilities

Gas Properties	Specify pneumatic domain properties for attached circuit

Thermal

Thermal Elements

Conductive Heat Transfer	Simulate heat transfer by conduction
Convective Heat Transfer	Simulate heat transfer by convection
Radiative Heat Transfer	Simulate heat transfer by radiation
Thermal Mass	Simulate mass in thermal systems
Thermal Reference	Simulate reference for thermal ports

Thermal Sensors

Ideal Heat Flow Sensor	Simulate ideal heat flow meter
Ideal Temperature Sensor	Simulate ideal temperature sensor

Thermal Sources

Ideal Heat Flow Source	Simulate ideal source of thermal energy, characterized by heat flow
Ideal Temperature Source	Simulate ideal source of thermal energy, characterized by temperature

Utilities

Connection Port	Create Physical Modeling connector port for subsystem
PS-Simulink Converter	Convert physical signal into Simulink® output signal
Simulink-PS Converter	Convert Simulink input signal into physical signal
Solver Configuration	Represent Physical Networks environment and solver configuration
Two-Way Connection	Create two-way connector port for subsystem

2

Blocks — Alphabetical List

AC Current Source

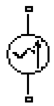
Purpose

Simulate ideal sinusoidal current source

Library

Electrical Sources

Description



The AC Current Source block represents an ideal current source that maintains sinusoidal current through it, independent of the voltage across its terminals.

The output current is defined by the following equation:

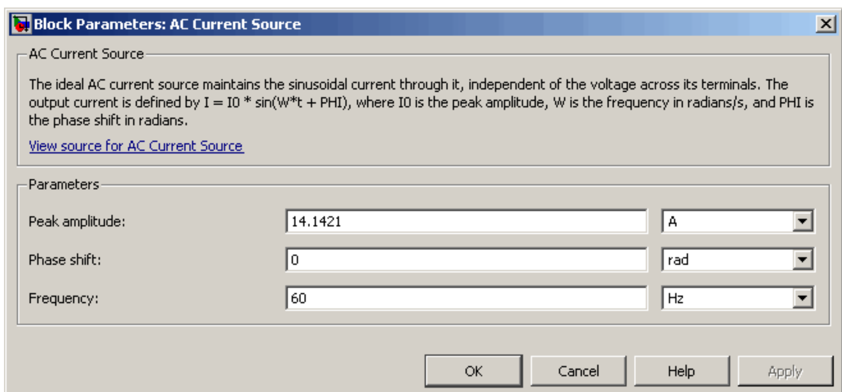
$$I = I_0 \cdot \sin(\omega \cdot t + \varphi)$$

where

I	Current
I_0	Peak amplitude
ω	Frequency
φ	Phase shift
t	Time

The positive direction of the current flow is indicated by the arrow.

Dialog Box and Parameters



Peak amplitude
Peak current amplitude. The default value is 10*sqrt(2), or `14.1421` A.

Phase shift
Phase shift in angular units. The default value is `0`.

Frequency
Current frequency. The default value is `60` Hz.

Ports

The block has two electrical conserving ports associated with its terminals.

See Also

AC Voltage Source

AC Voltage Source

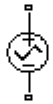
Purpose

Simulate ideal constant voltage source

Library

Electrical Sources

Description



The AC Voltage Source block represents an ideal voltage source that maintains sinusoidal voltage across its output terminals, independent of the current flowing through the source.

The output voltage is defined by the following equation:

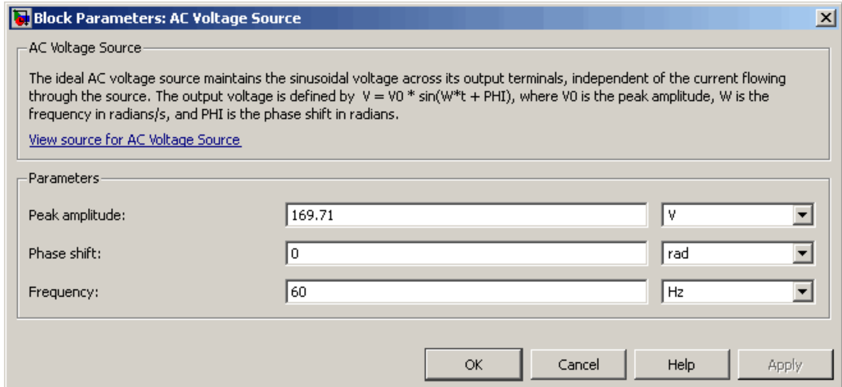
$$V = V_0 \bullet \sin(\omega \bullet t + \varphi)$$

where

V	Voltage
V_0	Peak amplitude
ω	Frequency
φ	Phase shift
t	Time

Connections + and – are conserving electrical ports corresponding to the positive and negative terminals of the voltage source, respectively. The current is positive if it flows from positive to negative, and the voltage across the source is equal to the difference between the voltage at the positive and the negative terminal, $V(+) - V(-)$.

Dialog Box and Parameters



Peak amplitude
: Peak voltage amplitude. The default value is 120*sqrt(2), or `169.71` V.

Phase shift
: Phase shift in angular units. The default value is `0`.

Frequency
: Voltage frequency. The default value is `60` Hz.

Ports

The block has the following ports:

+
: Electrical conserving port associated with the source positive terminal.

: Electrical conserving port associated with the source negative terminal.

See Also

AC Current Source

Adiabatic Cup

Purpose

Simulate thermal element with no thermal mass and perfect insulation

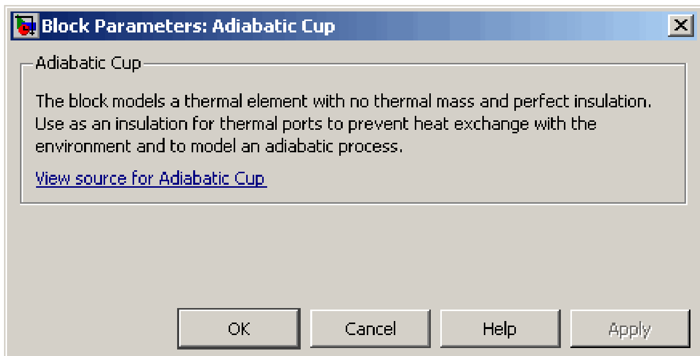
Library

Pneumatic Elements

Description

The Adiabatic Cup block models a thermal element with no thermal mass and perfect insulation. Use this block as an insulation for thermal ports to prevent heat exchange with the environment and to model an adiabatic process.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has one pneumatic conserving port.

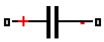
Purpose

Simulate linear capacitor in electrical systems

Library

Electrical Elements

Description



The Capacitor block models a linear capacitor, described with the following equation:

$$I = C\frac{dV}{dt}$$

where

I	Current
V	Voltage
C	Capacitance
t	Time

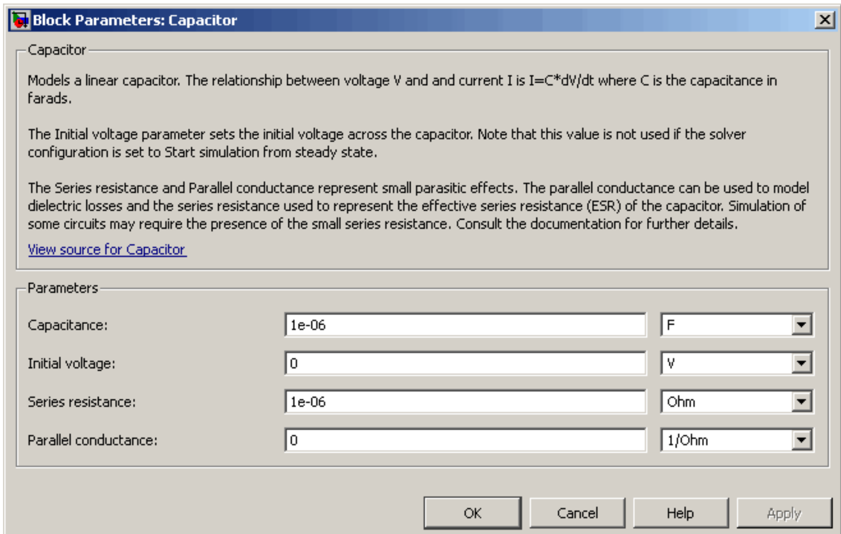
The **Initial voltage** parameter sets the initial voltage across the capacitor.

Note This value is not used if the solver configuration is set to **Start simulation from steady state**.

The **Series resistance** and **Parallel conductance** parameters represent small parasitic effects. The parallel conductance directly across the capacitor can be used to model dielectric losses, or equivalently leakage current per volt. The series resistance can be used to represent component effective series resistance (ESR) or connection resistance. Simulation of some circuits may require the presence of the small series resistance. For more information, see “Modeling Best Practices” in the Simscape™ User’s Guide.

Connections + and – are conserving electrical ports corresponding to the positive and negative terminals of the capacitor, respectively. The current is positive if it flows from positive to negative, and the voltage across the capacitor is equal to the difference between the voltage at the positive and the negative terminal, $V(+) - V(-)$.

Dialog Box and Parameters



Capacitance

Capacitance, in farads. The default value is 1 µF.

Initial voltage

Initial voltage across the capacitor. This parameter is not used if the solver configuration is set to **Start simulation from steady state**. The default value is 0.

Series resistance

Represents small parasitic effects. The series resistance can be used to represent component internal resistance. Simulation of some circuits may require the presence of the small series resistance. The default value is 1 µΩ.

Parallel conductance
Represents small parasitic effects. The parallel conductance directly across the capacitor can be used to model leakage current per volt. The default value is `0`.

Ports

The block has the following ports:

+
: Electrical conserving port associated with the capacitor positive terminal.

-
: Electrical conserving port associated with the capacitor negative terminal.

Conductive Heat Transfer

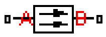
Purpose

Simulate heat transfer by conduction

Library

Thermal Elements

Description



The Conductive Heat Transfer block represents a heat transfer by conduction between two layers of the same material. The transfer is governed by the Fourier law and is described with the following equation:

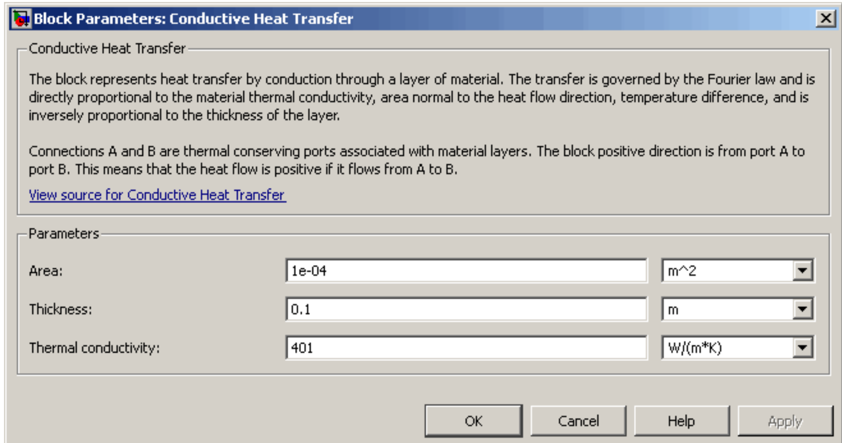
$$Q = k \bullet \frac{A}{D}(T_A - T_B)$$

where

Q	Heat flow
k	Material thermal conductivity
A	Area normal to the heat flow direction
D	Distance between layers
T_A, T_B	Temperatures of the layers

Connections A and B are thermal conserving ports associated with material layers. The block positive direction is from port A to port B. This means that the heat flow is positive if it flows from A to B.

Dialog Box and Parameters



Area

Area of heat transfer, normal to the heat flow direction. The default value is `0.0001` m^2.

Thickness

Thickness between layers. The default value is `0.1` m.

Thermal conductivity

Thermal conductivity of the material. The default value is `401` W/m/K.

Ports

The block has the following ports:

A

Thermal conserving port associated with layer A.

B

Thermal conserving port associated with layer B.

See Also

Convective Heat Transfer

Radiative Heat Transfer

Connection Port

Purpose

Create Physical Modeling connector port for subsystem

Library

Utilities

Description

The Connection Port block transfers both the conserving and the physical signal connections to the outside boundary of a subsystem block. This transfer is similar to the Inport and Outport blocks in Simulink models. A subsystem needs a Connection Port block for each physical connection line that crosses its boundary. You can manually place a Connection Port block inside a subsystem, or Simulink can automatically insert a Connection Port block when you create a subsystem within an existing network.

Port Appearance on Subsystem Boundary

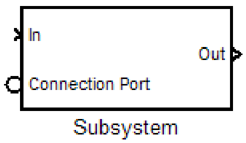
The ports on the subsystem boundary change their appearance depending on the type of port to which the Connection Port block is connected inside the subsystem.

Connection Port Block Inside a Subsystem Connects to ...		... and Appears on the Outside Boundary of the Subsystem as ...	
A Conserving port		A square Conserving port	
A Physical Signal inport or outport		A triangular Physical Signal inport or outport	
A two-way connector port of the Two-Way Connection block		A two-way connector port	
A SimMechanics™ connector port, either:		A SimMechanics connector port, either:	
	Round connector port		Round connector port
	Body coordinate system port		Body coordinate system port

Port Location and Orientation on Subsystem Boundary

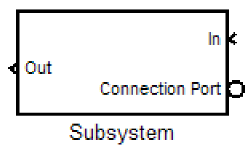
The orientation of the parent subsystem block and your choice of port location determine the Connection Port block port location on the parent subsystem boundary.

- A subsystem is in its fundamental orientation when its Simulink signal inports occur on its left side and its Simulink signal outports occur on its right side.



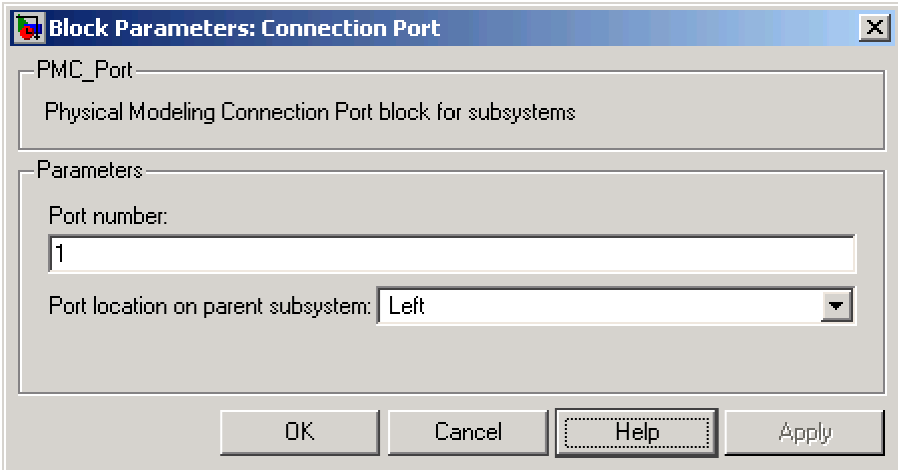
  When a subsystem is oriented in this way, the actual port location on the subsystem boundary respects your choice of port location (left or right) for the connector port.

- A subsystem orientation is reversed, with left and right interchanged, when its Simulink signal inports occur on its right side and its Simulink signal outports occur on its left side.



  When a subsystem is oriented in this way, the actual port location on the subsystem boundary reverses your choice of port location. If you choose left, the port appears on the right side. If you choose right, the port appears on the left side.

Dialog Box and Parameters



Port number

Labels the subsystem connector port that this block creates. Each connector port on the boundary of a single subsystem requires a unique number as a label. The default value for the first port is `1`.

Port location on parent subsystem

Choose here which side of the parent subsystem boundary the port is located. The choices are `Left` or `Right`. The default choice is `Left`.

See "Port Location and Orientation on Subsystem Boundary" on page 2-13.

See Also

In the *Simulink User's Guide*, see "Working with Block Masks".

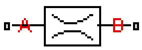
Purpose

Simulate hydraulic orifice with constant cross-sectional area

Library

Hydraulic Elements

Description



The Constant Area Hydraulic Orifice block models a sharp-edged constant-area orifice. The model distinguishes between the laminar and turbulent flow regimes by comparing the Reynolds number with its critical value. The flow rate through the orifice is proportional to the pressure differential across the orifice, and is determined according to the following equations:

$$q = \begin{cases} C_D \cdot A \sqrt{\frac{2}{\rho} |p|} \cdot sign(p) & \text{for } Re >= Re_{\text{cr}} \\ 2C_{DL} \cdot A \frac{D_H}{\nu \cdot \rho} p & \text{for } Re < Re_{\text{cr}} \end{cases}$$

$$p = p_A - p_B$$

$$\text{Re} = \frac{q \cdot D_H}{A \cdot \nu}$$

$$C_{DL} = \left(\frac{C_D}{\sqrt{\text{Re}_{cr}}} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

q	Flow rate
p	Pressure differential
p_A, p_B	Gauge pressures at the block terminals

C_D	Flow discharge coefficient
A	Orifice passage area
D_H	Orifice hydraulic diameter
ρ	Fluid density
ν	Fluid kinematic viscosity
Re	Reynolds number
Re_{cr}	Critical Reynolds number

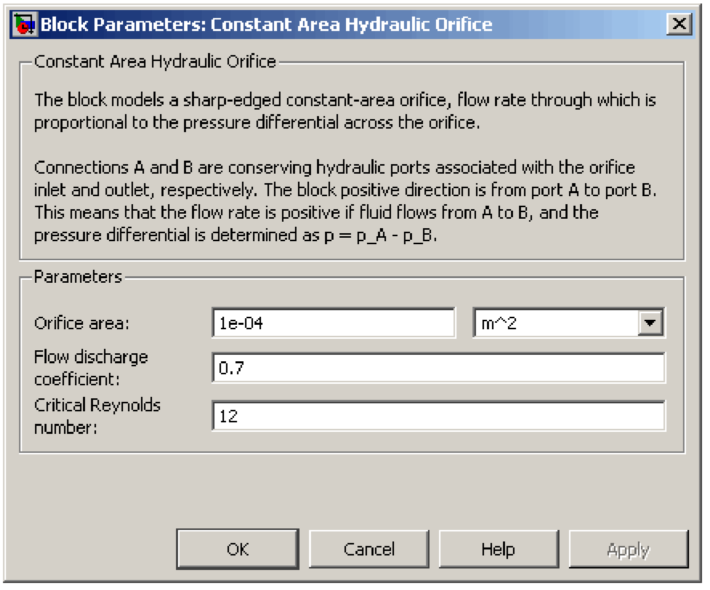
The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure differential is determined as $p = p_A - p_B$.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- Fluid inertia is not taken into account.
- The transition between laminar and turbulent regimes is assumed to be sharp and taking place exactly at $Re=Re_{cr}$.

Dialog Box and Parameters



Orifice area

Orifice passage area. The default value is `1e-4` m^2.

Flow discharge coefficient

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is `0.7`.

Critical Reynolds number

The maximum Reynolds number for laminar flow. The transition from laminar to turbulent regime is supposed to take place when the Reynolds number reaches this value. The value of the parameter depends on orifice geometrical profile, and the recommendations on the parameter value can be found in hydraulic textbooks. The default value is `12`, which corresponds to a round orifice in thin material with sharp edges.

Global Parameters

Fluid density

The parameter is determined by the type of working fluid selected for the system under design. Use the Custom Hydraulic Fluid block, or the Hydraulic Fluid block available with SimHydraulics® block libraries, to specify the fluid properties.

Fluid kinematic viscosity

The parameter is determined by the type of working fluid selected for the system under design. Use the Custom Hydraulic Fluid block, or the Hydraulic Fluid block available with SimHydraulics block libraries, to specify the fluid properties.

Ports

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

See Also

Variable Area Hydraulic Orifice

Purpose

Simulate sharp-edged orifice in pneumatic systems

Library

Pneumatic Elements

Description

The Constant Area Pneumatic Orifice block models the flow rate of an ideal gas through a sharp-edged orifice.

The flow rate through the orifice is proportional to the orifice area and the pressure differential across the orifice.

$$G = C_d \cdot A \cdot p_i \sqrt{\frac{2\gamma}{\gamma - 1} \cdot \frac{1}{RT_i} \left[\left(\frac{p_o}{p_i} \right)^{\frac{2}{\gamma}} - \left(\frac{p_o}{p_i} \right)^{\frac{\gamma+1}{\gamma}} \right]}$$

where

G	Mass flow rate
C_d	Discharge coefficient, to account for effective loss of area due to orifice shape
A	Orifice cross-sectional area
p_i, p_o	Absolute pressures at the orifice inlet and outlet, respectively. The inlet and outlet change depending on flow direction. For positive flow ($G > 0$), $p_i = p_A$, otherwise $p_i = p_B$.
γ	The ratio of specific heats at constant pressure and constant volume, $c_p \,/\, c_v$
R	Specific gas constant
T	Absolute gas temperature

The choked flow occurs at the critical pressure ratio defined by

$$\beta_{cr} = \frac{p_o}{p_i} = \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma}{\gamma - 1}}$$

after which the flow rate depends on the inlet pressure only and is computed with the expression

$$G = C_d \bullet A \bullet p_i \sqrt{\frac{\gamma}{RT_i} \bullet \beta_{cr}^{\frac{\gamma+1}{\gamma}}}$$

The square root relationship has infinite gradient at zero flow, which can present numerical solver difficulties. Therefore, for very small pressure differences, defined by $p_o \ / \ p_i > 0.999$, the flow equation is replaced by a linear flow-pressure relationship

$$G = kC_d \bullet A \bullet T_i^{-0.5} \left(p_i - p_o \right)$$

where k is a constant such that the flow predicted for $p_o \ / \ p_i$ is the same as that predicted by the original flow equation for $p_o \ / \ p_i = 0.999$.

The heat flow out of the orifice is assumed equal to the heat flow into the orifice, based on the following considerations:

- The orifice is square-edged or sharp-edged, and as such is characterized by an abrupt change of the downstream area. This means that practically all the dynamic pressure is lost in the expansion.
- The lost energy appears in the form of internal energy that rises the output temperature and makes it very close to the inlet temperature.

Therefore, $q_i = q_o$, where q_i and q_o are the input and output heat flows, respectively.

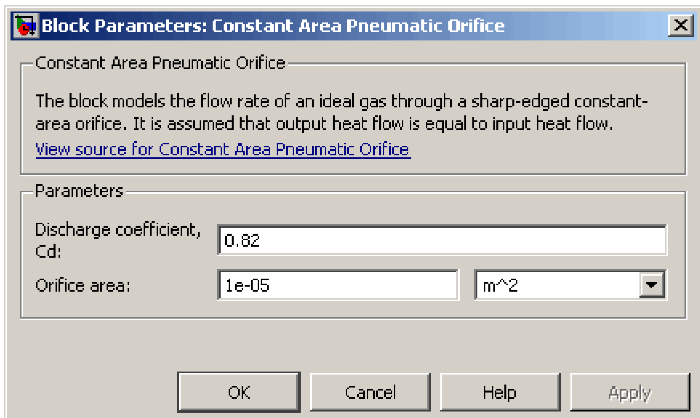
The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The gas is ideal.
- Specific heats at constant pressure and constant volume, c_p and c_v, are constant.
- The process is adiabatic, that is, there is no heat transfer with the environment.
- Gravitational effects can be neglected.
- The orifice adds no net heat to the flow.

Dialog Box and Parameters



Discharge coefficient, Cd

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is `0.82`.

Orifice area

Specify the orifice cross-sectional area. The default value is `1e-5` m^2.

Ports

The block has the following ports:

A

Pneumatic conserving port associated with the orifice inlet for positive flow.

B

Pneumatic conserving port associated with the orifice outlet for positive flow.

See Also

Constant Area Pneumatic Orifice (ISO 6358)

Variable Area Pneumatic Orifice

Purpose

Simulate fixed-area pneumatic orifice complying with ISO 6358 standard

Library

Pneumatic Elements

Description

The Constant Area Pneumatic Orifice (ISO 6358) block models the flow rate of an ideal gas through a fixed-area sharp-edged orifice. The model conforms to the ISO 6358 standard and is based on the following flow equations, originally proposed by Sanville [1]:

$$G = \begin{cases} k_1 \cdot p_i \left(1 - \dfrac{p_o}{p_i}\right)\sqrt{\dfrac{T_{ref}}{T_i}} \cdot sign(p_i - p_o) & \text{if } \dfrac{p_o}{p_i} > \beta_{lam} \text{ (laminar)} \\ p_i \cdot C \cdot \rho_{ref}\sqrt{\dfrac{T_{ref}}{T_i}} \cdot \sqrt{1 - \left(\dfrac{\dfrac{p_o}{p_i} - b}{1-b}\right)^2} & \text{if } \beta_{lam} > \dfrac{p_o}{p_i} > b \text{ (subsonic)} \\ p_i \cdot C \cdot \rho_{ref}\sqrt{\dfrac{T_{ref}}{T_i}} & \text{if } \dfrac{p_o}{p_i} <= b \text{ (choked)} \end{cases}$$

$$k_1 = \frac{1}{1-\beta_{lam}} \cdot C \cdot \rho_{ref}\sqrt{1 - \left(\frac{\beta_{lam} - b}{1-b}\right)^2}$$

where

G	Mass flow rate
β_{lam}	Pressure ratio at laminar flow, a value between 0.999 and 0.995
b	Critical pressure ratio, that is, the ratio between the outlet pressure p_o and inlet pressure p_i at which the gas velocity achieves sonic speed

C	Sonic conductance of the component, that is, the ratio between the mass flow rate and the product of inlet pressure p_1 and the mass density at standard conditions when the flow is choked
ρ_{ref}	Gas density at standard conditions (1.185 kg/m^3 for air)
p_i, p_o	Absolute pressures at the orifice inlet and outlet, respectively. The inlet and outlet change depending on flow direction. For positive flow ($G > 0$), $p_i = p_A$, otherwise $p_i = p_B$.
T_i, T_o	Absolute gas temperatures at the orifice inlet and outlet, respectively
T_{ref}	Gas temperature at standard conditions (T_{ref} = 293.15 K)

The equation itself, parameters b and C, and the heuristic on how to measure these parameters experimentally form the basis for the standard ISO 6358 (1989). The values of the critical pressure ratio b and the sonic conductance C depend on a particular design of a component. Typically, they are determined experimentally and are sometimes given on a manufacturer data sheet.

The block can also be parameterized in terms of orifice effective area or flow coefficient, instead of sonic conductance. When doing so, block parameters are converted into an equivalent value for sonic conductance. When specifying effective area, the following formula proposed by Gidlund and detailed in [2] is used:

$$C = 0.128\, d^{\,2}$$

where

C	Sonic conductance in dm^3/(s*bar)
d	Inner diameter of restriction in mm

The effective area (whether specified directly, or calculated when the orifice is parameterized in terms of C_v or K_v, as described below) is used to determine the inner diameter d in the Gidlund formula, assuming a circular cross section.

Gidlund also gives an approximate formula for the critical pressure ratio in terms of the pneumatic line diameter D,

$$b = 0.41 + 0.272\, d / D$$

This equation is not used by the block and you must specify the critical pressure ratio directly.

If the orifice is parameterized in terms of the C_v [2] coefficient, then the C_v coefficient is turned into an equivalent effective orifice area for use in the Gidlund formula:

$$A = 1.6986e - 5\ C_v$$

By definition, an opening or restriction has a C_v coefficient of 1 if it passes 1 gpm (gallon per minute) of water at pressure drop of 1 psi.

If the orifice is parameterized in terms of the K_v [2] coefficient, then the K_v coefficient is turned into an equivalent effective orifice area for use in the Gidlund formula:

$$A = 1.1785e - 6\ C_v$$

K_v is the SI counterpart of C_v. An opening or restriction has a K_v coefficient of 1 if it passes 1 lpm (liter per minute) of water at pressure drop of 1 bar.

The heat flow out of the orifice is assumed equal to the heat flow into the orifice, based on the following considerations:

- The orifice is square-edged or sharp-edged, and as such is characterized by an abrupt change of the downstream area. This means that practically all the dynamic pressure is lost in the expansion.

- The lost energy appears in the form of internal energy that rises the output temperature and makes it very close to the inlet temperature.

Therefore, $q_i = q_o$, where q_i and q_o are the input and output heat flows, respectively.

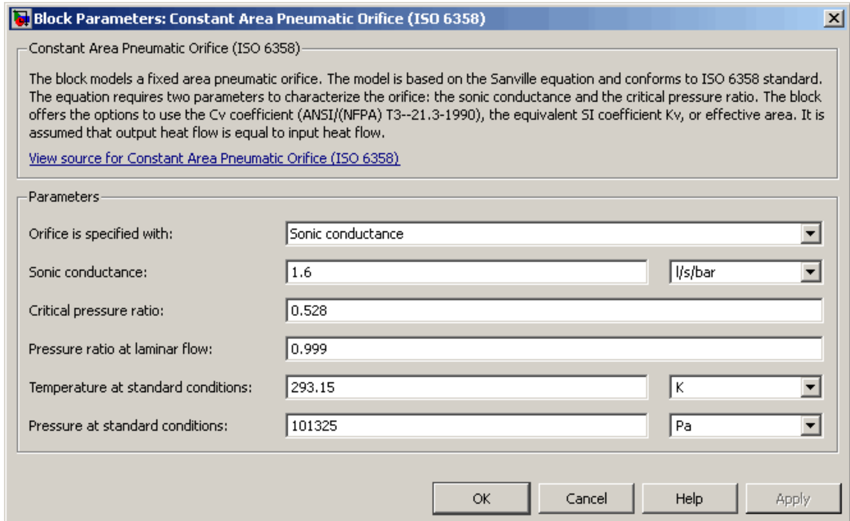
The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B.

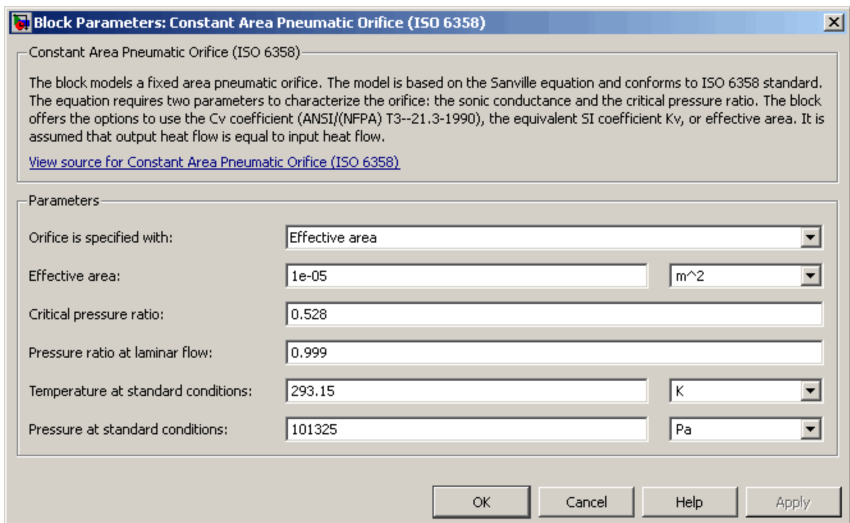
Basic Assumptions and Limitations

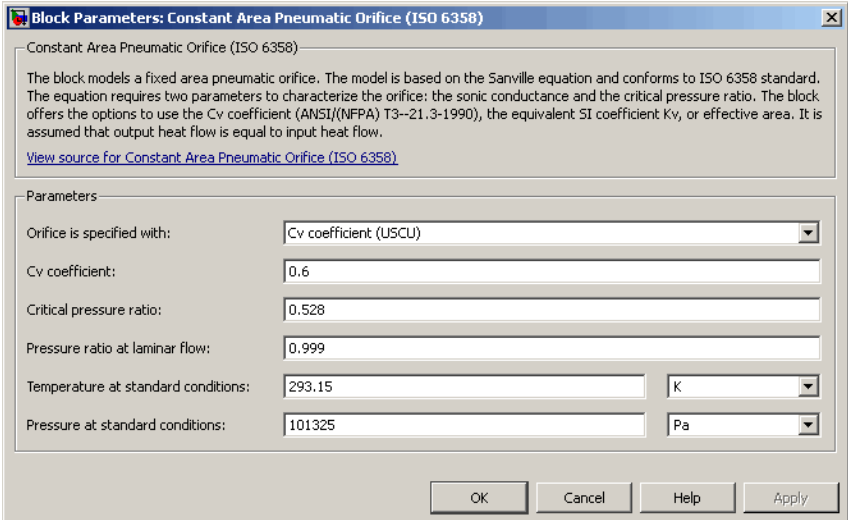
The model is based on the following assumptions:

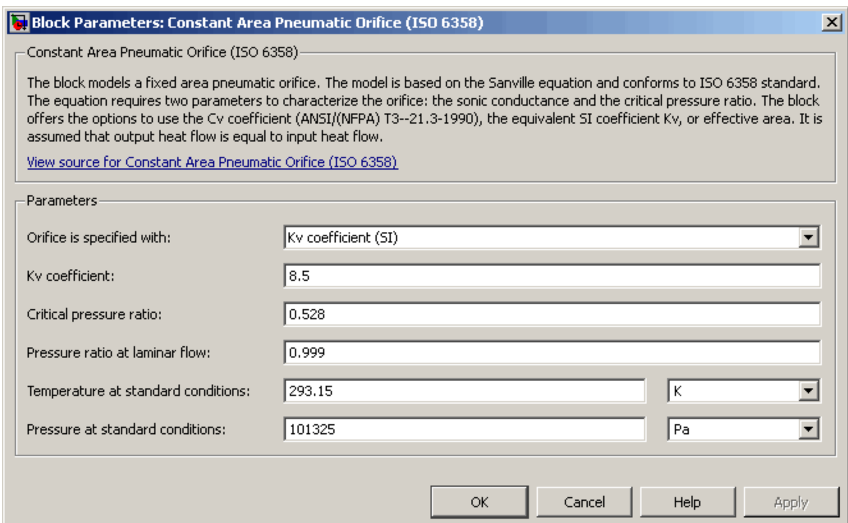
- The gas is ideal.
- Specific heats at constant pressure and constant volume, c_p and c_v, are constant.
- The process is adiabatic, that is, there is no heat transfer with the environment.
- Gravitational effects can be neglected.
- The orifice adds no net heat to the flow.

Dialog Box and Parameters









Orifice is specified with

Select one of the following model parameterization methods:

- Sonic conductance — Provide value for the sonic conductance of the orifice. The values of the sonic conductance and the critical pressure ratio form the basis for the ISO 6358 compliant flow equations for the orifice. This is the default method.
- Effective area — Provide value for the orifice effective area. This value is internally converted by the block into an equivalent value for sonic conductance.
- Cv coefficient (USCU) — Provide value for the flow coefficient specified in US units. This value is internally converted by the block into an equivalent value for the orifice effective area.
- Kv coefficient (SI) — Provide value for the flow coefficient specified in SI units. This value is internally converted by the block into an equivalent value for the orifice effective area.

Sonic conductance
Specify the sonic conductance of the orifice, that is, the ratio between the mass flow rate and the product of upstream pressure and the mass density at standard conditions when the flow is choked. This value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is 1.6 l/s/bar. This parameter appears in the dialog box if **Orifice is specified with** parameter is set to Sonic conductance.

Effective area
Specify the orifice cross-sectional area. The default value is 1e-5 m^2. This parameter appears in the dialog box if **Orifice is specified with** parameter is set to Effective area.

Cv coefficient
Specify the value for the flow coefficient in US units. The default value is 0.6. This parameter appears in the dialog box if **Orifice is specified with** parameter is set to Cv coefficient (USCU).

Kv coefficient
: Specify the value for the flow coefficient in SI units. The default value is `8.5`. This parameter appears in the dialog box if **Orifice is specified with** parameter is set to `Kv coefficient (SI)`.

Critical pressure ratio
: Specify the critical pressure ratio, that is, the ratio between the downstream pressure and the upstream pressure at which the gas velocity achieves sonic speed. The default value is `0.528`.

Pressure ratio at laminar flow
: Specify the ratio between the downstream pressure and the upstream pressure at laminar flow. This value can be in the range between 0.995 and 0.999. The default value is `0.999`.

Temperature at standard conditions
: Specify the gas temperature at which the sonic conductance was measured. The default value is `293.15` K.

Pressure at standard conditions
: Specify the gas pressure at which the sonic conductance was measured. The default value is `101325` Pa.

Ports

The block has the following ports:

A
: Pneumatic conserving port associated with the orifice inlet for positive flow.

B
: Pneumatic conserving port associated with the orifice outlet for positive flow.

References

[1] Sanville, F. E. "A New Method of Specifying the Flow Capacity of Pneumatic Fluid Power Valves." Paper D3, p.37-47. BHRA. Second International Fluid Power Symposium, Guildford, England, 1971.

[2] Beater, P. *Pneumatic Drives. System Design, Modeling, and Control.* New York: Springer, 2007.

See Also

Constant Area Pneumatic Orifice

Variable Area Pneumatic Orifice

Constant Volume Hydraulic Chamber

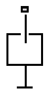
Purpose

Simulate hydraulic capacity of constant volume

Library

Hydraulic Elements

Description



The Constant Volume Hydraulic Chamber block models a fixed-volume chamber with rigid or flexible walls, to be used in hydraulic valves, pumps, manifolds, pipes, hoses, and so on. Use this block in models where you have to account for some form of fluid compressibility. You can select the appropriate representation of fluid compressibility using the block parameters.

Fluid compressibility in its simplest form is simulated according to the following equations:

$$V_f = V_c + \frac{V_c}{E} p$$

$$q = \frac{dV_f}{dt}$$

where

q	Flow rate into the chamber
V_f	Volume of fluid in the chamber
V_c	Geometrical chamber volume
E	Fluid bulk modulus
p	Gauge pressure of fluid in the chamber

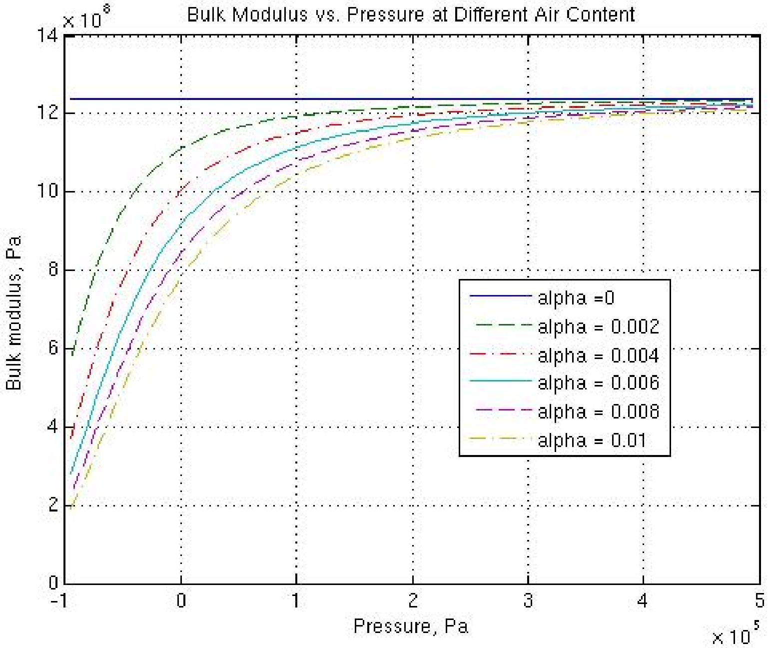
If pressure in the chamber is likely to fall to negative values and approach cavitation limit, the above equations must be enhanced. In this block, it is done by representing the fluid in the chamber as a mixture of liquid and a small amount of entrained, nondissolved gas. The mixture bulk modulus is determined as:

$$E = E_l \frac{1+\alpha\left(\frac{p_a}{p_a+p}\right)^{1/n}}{1+\alpha\frac{p_a^{1/n}}{n\cdot(p_a+p)^{\frac{n+1}{n}}}E_l}$$

where

E_1	Pure liquid bulk modulus
p_α	Atmospheric pressure
α	Relative gas content at atmospheric pressure, $\alpha = V_G/V_L$
V_G	Gas volume at atmospheric pressure
V_L	Volume of liquid
n	Gas-specific heat ratio

The main objective of representing fluid as a mixture of liquid and gas is to introduce an approximate model of cavitation, which takes place in a chamber if pressure drops below fluid vapor saturation level. As it is seen in the graph below, the bulk modulus of a mixture decreases at $p \to p_a$, thus considerably slowing down further pressure change. At high pressure, $p >> p_a$, a small amount of nondissolved gas has practically no effect on the system behavior.



Cavitation is an inherently thermodynamic process, requiring consideration of multiple-phase fluids, heat transfers, etc., and as such cannot be accurately simulated with Simscape software. But the simplified version implemented in the block is good enough to signal if pressure falls below dangerous level, and to prevent computation failure that normally occurs at negative pressures.

If it is known that cavitation is unlikely in the system under design, you can set the relative gas content in the fluid properties to zero, thus increasing the speed of computations. Use the Hydraulic Fluid or the Custom Hydraulic Fluid block to set the fluid properties.

If chamber walls have noticeable compliance, the above equations must be further enhanced by representing geometrical chamber volume as a function of pressure:

$$V_c = \pi d^2 / 4 \bullet L$$

$$d(s) = \frac{K_p}{1 + \tau s} p(s)$$

where

d	Internal diameter of the cylindrical chamber
L	Length of the cylindrical chamber
K_p	Proportionality coefficient (m/Pa)
τ	Time constant
s	Laplace operator

Coefficient K_p establishes relationship between pressure and the internal diameter at steady-state conditions. For metal tubes, the coefficient can be computed as (see [1]):

$$K_p = \frac{d}{E_M}\left(\frac{D^2 + d^2}{D^2 - d^2} + \nu\right)$$

where

D	Pipe external diameter
E_M	Modulus of elasticity (Young's modulus) for the pipe material
	Poisson's ratio for the pipe material

For hoses, the coefficient can be provided by the manufacturer.

The process of expansion and contraction in pipes and especially in hoses is a complex combination of nonlinear elastic and viscoelastic deformations. This process is approximated in the block with the first-order lag, whose time constant is determined empirically (for example, see [2]).

As a result, by selecting appropriate values, you can implement four different models of fluid compressibility with this block:

- Chamber with rigid walls, no entrained gas in the fluid
- Cylindrical chamber with compliant walls, no entrained gas in the fluid
- Chamber with rigid walls, fluid with entrained gas
- Cylindrical chamber with compliant walls, fluid with entrained gas

The block allows two methods of specifying the chamber size:

- By volume — Use this option for cylindrical or non-cylindrical chambers with rigid walls. You only need to know the volume of the chamber. This chamber type does not account for wall compliance.
- By length and diameter — Use this option for cylindrical chambers with rigid or compliant walls, such as circular pipes or hoses.

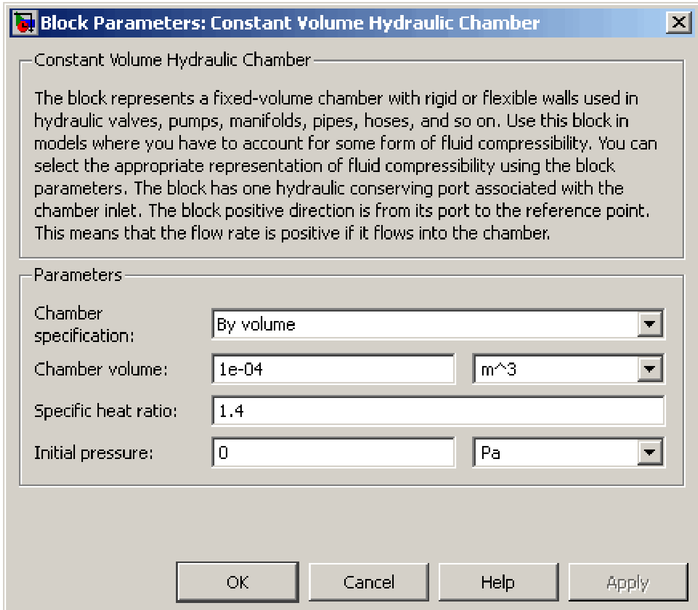
The block has one hydraulic conserving port associated with the chamber inlet. The block positive direction is from its port to the reference point. This means that the flow rate is positive if it flows into the chamber.

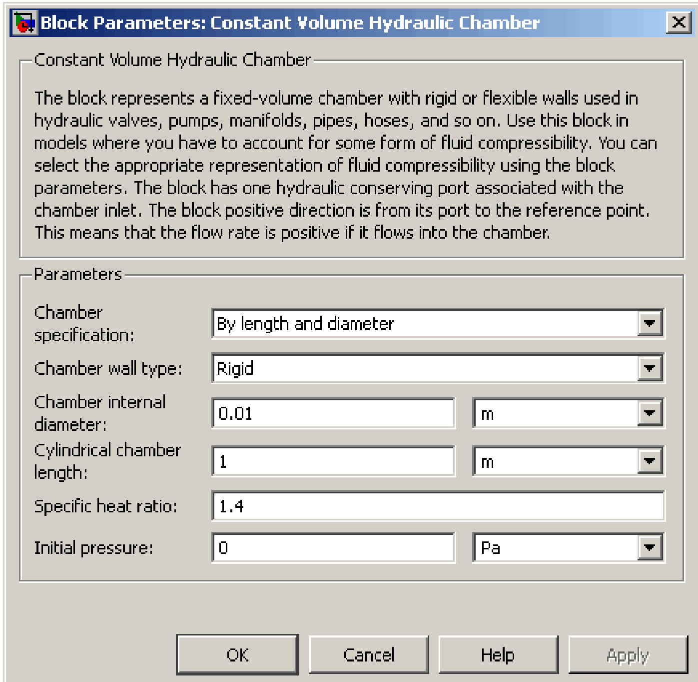
Basic Assumptions and Limitations

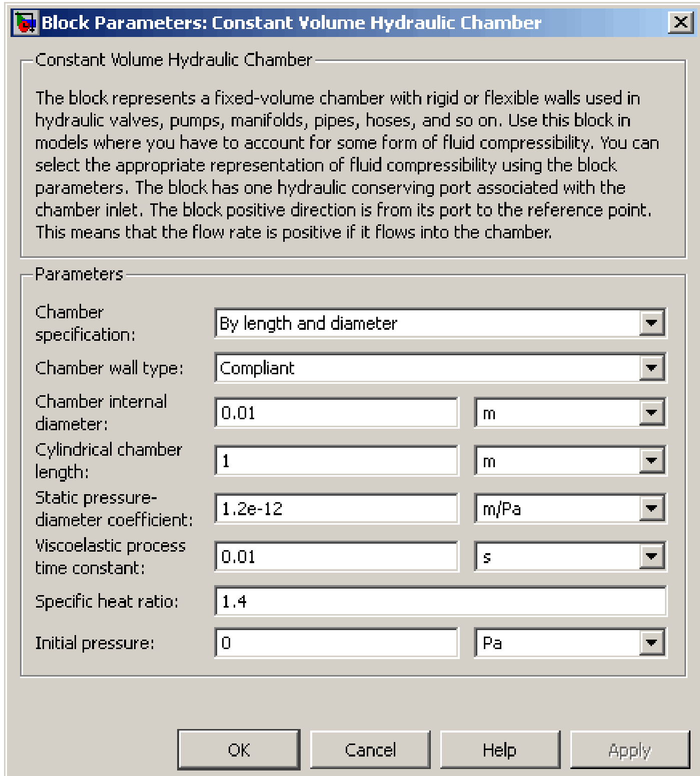
The model is based on the following assumptions:

- No inertia associated with pipe walls is taken into account.
- Chamber with compliant walls is assumed to have a cylindrical shape. Chamber with rigid wall can have any shape.

Dialog Box and Parameters




Block Parameters: Constant Volume Hydraulic Chamber
Constant Volume Hydraulic Chamber
The block represents a fixed-volume chamber with rigid or flexible walls used in hydraulic valves, pumps, manifolds, pipes, hoses, and so on. Use this block in models where you have to account for some form of fluid compressibility. You can select the appropriate representation of fluid compressibility using the block parameters. The block has one hydraulic conserving port associated with the chamber inlet. The block positive direction is from its port to the reference point. This means that the flow rate is positive if it flows into the chamber.
Parameters
Chamber specification:
By length and diameter
Chamber wall type:
Rigid
Chamber internal diameter:
0.01
m
Cylindrical chamber length:
1
m
Specific heat ratio:
1.4
Initial pressure:
0
Pa
OK
Cancel
Help
Apply



Chamber specification

The parameter can have one of two values: `By volume` or `By length and diameter`. The value `By length and diameter` is recommended if a chamber is formed by a circular pipe. If the parameter is set to `By volume`, wall compliance is not taken into account. The default value of the parameter is `By volume`.

Chamber wall type

The parameter can have one of two values: `Rigid` or `Compliant`. If the parameter is set to `Rigid`, wall compliance is not taken into account, which can improve computational efficiency. The value `Compliant` is recommended for hoses and metal pipes, where compliance can affect the system behavior. The default value of the parameter is `Rigid`. The parameter is used if the **Chamber specification** parameter is set to `By length and diameter`.

Chamber volume
Volume of fluid in the chamber. The default value is `1e-4` m^3. The parameter is used if the **Chamber specification** parameter is set to `By volume`.

Chamber internal diameter
Internal diameter of the cylindrical chamber. The default value is `0.01` m. The parameter is used if the **Chamber specification** parameter is set to `By length and diameter`.

Cylindrical chamber length
Length of the cylindrical chamber. The default value is `1` m. The parameter is used if the **Chamber specification** parameter is set to `By length and diameter`.

Static pressure-diameter coefficient
Coefficient K_p that establishes relationship between pressure and the internal diameter at steady-state conditions. The parameter can be determined analytically or experimentally. The default value is `1.2e-12` m/Pa. The parameter is used if **Chamber wall type** is set to `Compliant`.

Viscoelastic process time constant
Time constant in the transfer function relating pipe internal diameter to pressure variations. With this parameter, the simulated elastic or viscoelastic process is approximated with the first-order lag. The parameter is determined experimentally or provided by the manufacturer. The default value is `0.01` s. The parameter is used if **Chamber wall type** is set to `Compliant`.

Specific heat ratio
Gas-specific heat ratio. The default value is `1.4`.

Initial pressure
Initial pressure in the chamber. This parameter specifies the initial condition for use in computing the block's initial state at

the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `0`.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Chamber specification**
- **Chamber wall type**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the values of the **Tube cross section type** and **Chamber wall type** parameters at the time the model entered Restricted mode.

Global Parameters

Fluid bulk modulus
The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Nondissolved gas ratio
Nondissolved gas relative content determined as a ratio of gas volume to the liquid volume. The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Ports

The block has one hydraulic conserving port associated with the chamber inlet.

References

[1] Meritt, H.E., *Hydraulic Control Systems*, John Wiley & Sons, New York, 1967

[2] Holcke, Jan, *Frequency Response of Hydraulic Hoses*, RIT, FTH, Stockholm, 2002

See Also

Hydraulic Piston Chamber

Variable Hydraulic Chamber

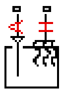
Purpose

Simulate constant volume pneumatic chamber based on ideal gas law

Library

Pneumatic Elements

Description



The Constant Volume Pneumatic Chamber block models a constant volume pneumatic chamber based on the ideal gas law and assuming constant specific heats.

The continuity equation for the network representation of the constant chamber is

$$G = \frac{V}{RT}\left(\frac{dp}{dt} - \frac{p}{T}\frac{dT}{dt}\right)$$

where

G	Mass flow rate at input port
V	Chamber volume
p	Absolute pressure in the chamber
R	Specific gas constant
T	Absolute gas temperature
t	Time

The energy equation is

$$q = \frac{c_v V}{R} \bullet \frac{dp}{dt} - q_w$$

where

q	Heat flow due to gas inflow in the chamber (through the pneumatic port)
q_w	Heat flow through the chamber walls (through the thermal port)
c_v	Specific heat at constant volume

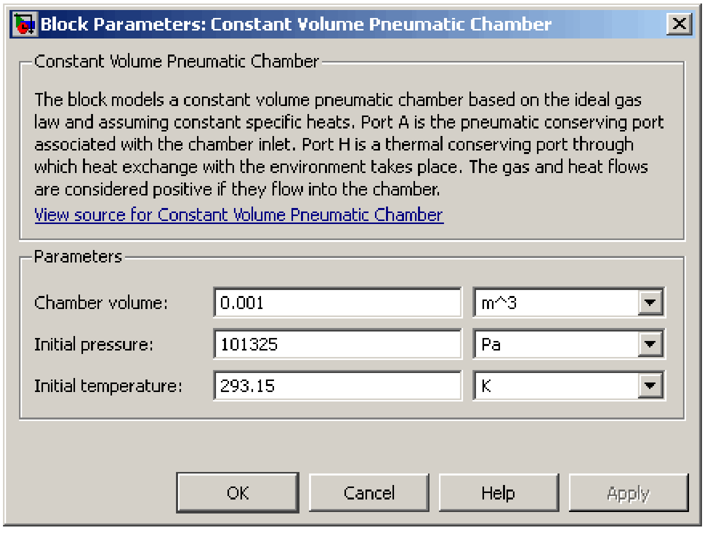
Port A is the pneumatic conserving port associated with the chamber inlet. Port H is a thermal conserving port through which heat exchange with the environment takes place. The gas flow and the heat flow are considered positive if they flow into the chamber.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The gas is ideal.
- Specific heats at constant pressure and constant volume, c_p and c_v, are constant.

Dialog Box and Parameters



Chamber volume
Specify the volume of the chamber. The default value is `.001` m^3.

Initial pressure
Specify the initial pressure in the chamber. This parameter specifies the initial condition for use in computing the initial state at the beginning of a simulation run. For more information, see “Computing Initial Conditions”. The default value is `101235` Pa.

Initial temperature
Specify the initial temperature of the gas in the chamber. This parameter specifies the initial condition for use in computing the initial state at the beginning of a simulation run. For more information, see “Computing Initial Conditions”. The default value is `293.15` K.

Ports

The block has the following ports:

A
Pneumatic conserving port associated with the chamber inlet.

H
Thermal conserving port through which heat exchange with the environment takes place.

See Also

Pneumatic Piston Chamber

Rotary Pneumatic Piston Chamber

Controlled Current Source

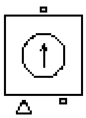
Purpose

Simulate ideal current source driven by input signal

Library

Electrical Sources

Description

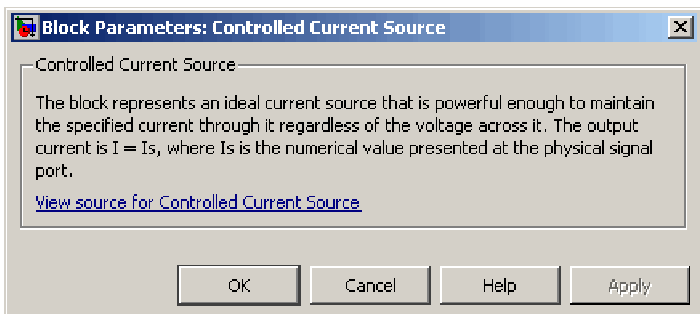


The Controlled Current Source block represents an ideal current source that is powerful enough to maintain the specified current through it regardless of the voltage across the source.

The output current is $I = Is$, where Is is the numerical value presented at the physical signal port.

The positive direction of the current flow is indicated by the arrow.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has one physical signal input port and two electrical conserving ports associated with its electrical terminals.

See Also

Controlled Voltage Source

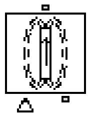
Purpose

Simulate ideal flux source driven by input signal

Library

Magnetic Sources

Description

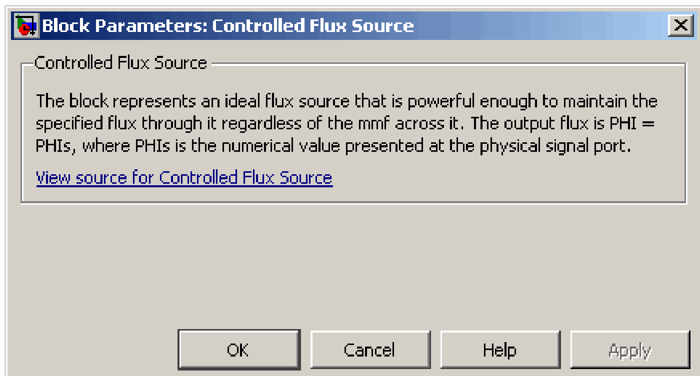


The Controlled Flux Source block represents an ideal flux source that is powerful enough to maintain the specified flux through it regardless of the mmf across the source.

The output flux is *PHI* = *PHIs*, where *PHIs* is the numerical value presented at the physical signal port.

The positive direction of the flux flow is indicated by the arrow.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has one physical signal input port and two magnetic conserving ports associated with its magnetic terminals.

See Also

Controlled MMF Source

Flux Source

MMF Source

Controlled MMF Source

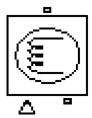
Purpose

Simulate ideal magnetomotive force source driven by input signal

Library

Magnetic Sources

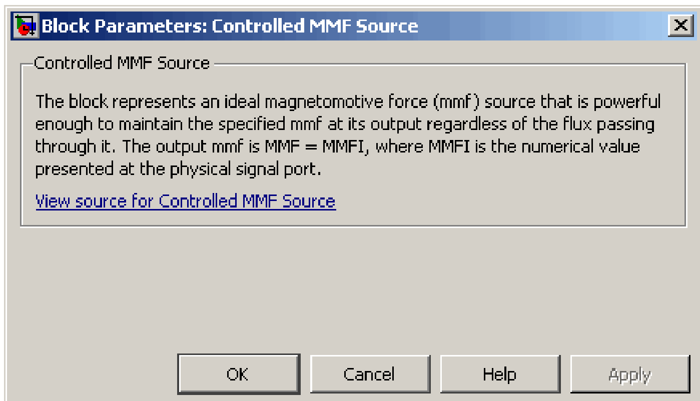
Description



The Controlled MMF Source block represents an ideal magnetomotive force (mmf) source that is powerful enough to maintain the specified mmf at its output regardless of the flux passing through it.

The output mmf is $MMF = MMFI$, where $MMFI$ is the numerical value presented at the physical signal port.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has one physical signal input port and two magnetic conserving ports associated with its magnetic terminals.

See Also

Controlled Flux Source

Flux Source

MMF Source

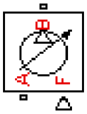
Purpose

Simulate ideal compressor with signal-controlled mass flow rate

Library

Pneumatic Sources

Description



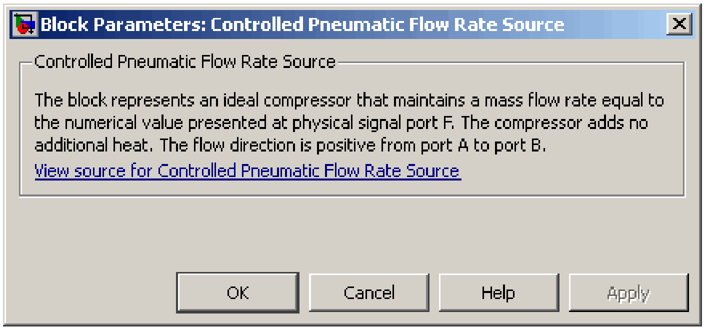
The Controlled Pneumatic Flow Rate Source block represents an ideal compressor that maintains a mass flow rate equal to the numerical value presented at physical signal port F. The compressor adds no heat. Block connections A and B correspond to the pneumatic inlet and outlet ports, respectively, and connection F represents a control signal port.

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B. The pressure differential is determined as $p = p_A - p_B$ and is negative if pressure at the source outlet is greater than pressure at its inlet. The power generated by the source is negative if the source adds energy to the flow.

Warning

Be careful when driving an orifice directly from a flow rate source. The choked flow condition limits the flow that is possible through an orifice as a function of upstream pressure and temperature. Hence the flow rate value produced by the flow rate source must be compatible with upstream pressure and temperature. Specifying a flow rate that is too high will result in an unsolvable set of equations.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A
: Pneumatic conserving port associated with the source inlet.

B
: Pneumatic conserving port associated with the source outlet.

F
: Control signal port.

See Also

Pneumatic Flow Rate Source

Pneumatic Mass & Heat Flow Sensor

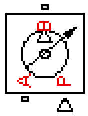
Purpose

Simulate ideal compressor with signal-controlled pressure difference

Library

Pneumatic Sources

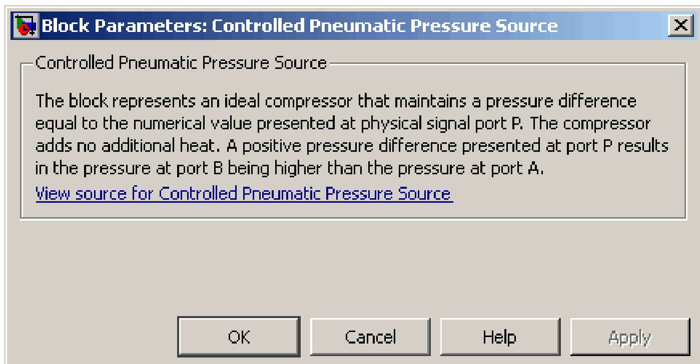
Description



The Controlled Pneumatic Pressure Source block represents an ideal compressor that maintains a pressure difference equal to the numerical value presented at physical signal port F. The compressor adds no heat. Block connections A and B correspond to the pneumatic inlet and outlet ports, respectively, and connection F represents a control signal port.

A positive pressure difference results in the pressure at port B being higher than the pressure at port A.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A
: Pneumatic conserving port associated with the source inlet.

B
: Pneumatic conserving port associated with the source outlet.

F
: Control signal port.

See Also

Pneumatic Pressure Source

Pneumatic Pressure & Temperature Sensor

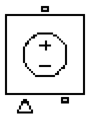
Purpose

Simulate ideal voltage source driven by input signal

Library

Electrical Sources

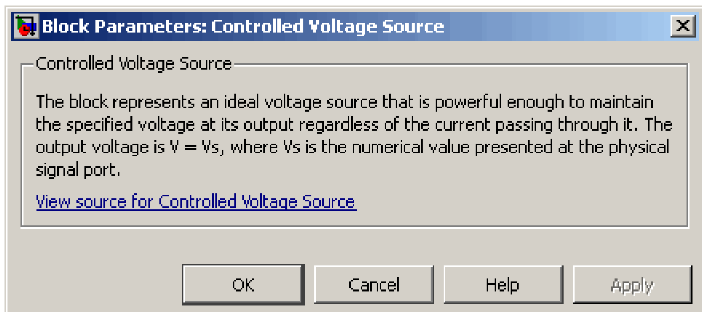
Description



The Controlled Voltage Source block represents an ideal voltage source that is powerful enough to maintain the specified voltage at its output regardless of the current flowing through the source.

The output current is $V = Vs$, where Vs is the numerical value presented at the physical signal port.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has one physical signal input port and two electrical conserving ports associated with its electrical terminals.

See Also

Controlled Current Source

Convective Heat Transfer

Purpose Simulate heat transfer by convection

Library Thermal Elements

Description

The Convective Heat Transfer block represents a heat transfer by convection between two bodies by means of fluid motion. The transfer is governed by the Newton law of cooling and is described with the following equation:

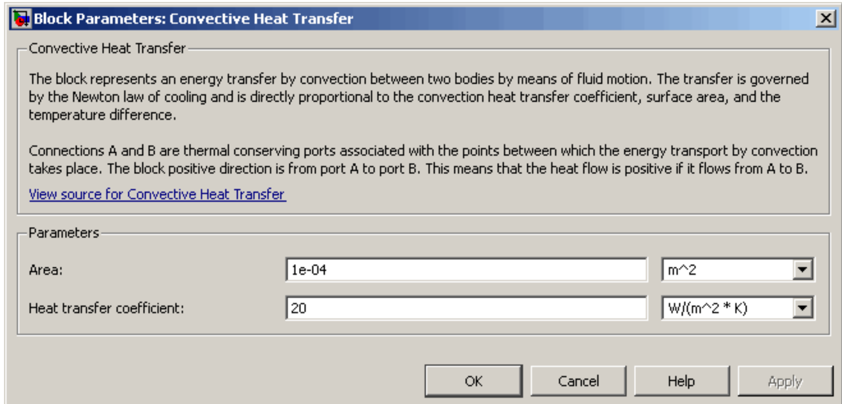
$$Q = k \cdot A \cdot (T_A - T_B)$$

where

Q	Heat flow
k	Convection heat transfer coefficient
A	Surface area
T_A, T_B	Temperatures of the bodies

Connections A and B are thermal conserving ports associated with the points between which the heat transfer by convection takes place. The block positive direction is from port A to port B. This means that the heat flow is positive if it flows from A to B.

Dialog Box and Parameters



Area

Surface area of heat transfer. The default value is `0.0001` m^2.

Heat transfer coefficient

Convection heat transfer coefficient. The default value is `20` W/m^2/K.

Ports

The block has the following ports:

A

Thermal conserving port associated with body A.

B

Thermal conserving port associated with body B.

See Also

Conductive Heat Transfer

Radiative Heat Transfer

Current-Controlled Current Source

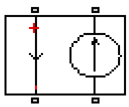
Purpose

Simulate linear current-controlled current source

Library

Electrical Sources

Description



The Current-Controlled Current Source block models a linear current-controlled current source, described with the following equation:

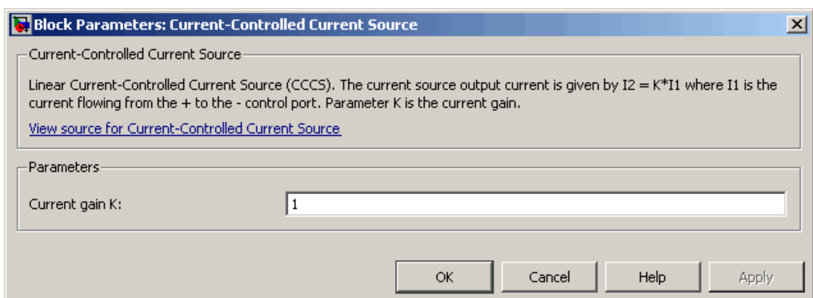
$$I2 = K \bullet I1$$

where

$I2$	Output current
K	Current gain
$I1$	Current flowing from the + to the – control port

To use the block, connect the + and – ports on the left side of the block (the control ports) to the control current source. The arrow between these ports indicates the positive direction of the control current flow. The two ports on the right side of the block (the output ports) generate the output current, with the arrow between them indicating the positive direction of the output current flow.

Dialog Box and Parameters



Current gain K
Ratio of the current between the two output terminals to the current passing between the two control terminals. The default value is 1.

Ports

The block has four electrical conserving ports. Connections + and – on the left side of the block are the control ports. The other two ports are the electrical terminals that provide the output current. The arrows between each pair of ports indicate the positive direction of the current flow.

See Also

Current-Controlled Voltage Source

Voltage-Controlled Current Source

Voltage-Controlled Voltage Source

Current-Controlled Voltage Source

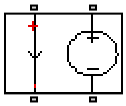
Purpose

Simulate linear current-controlled voltage source

Library

Electrical Sources

Description



The Current-Controlled Voltage Source block models a linear current-controlled voltage source, described with the following equation:

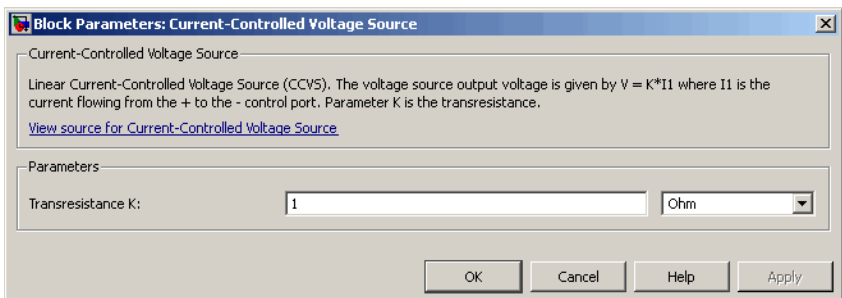
$$V = K \bullet I1$$

where

V	Voltage
K	Transresistance
I1	Current flowing from the + to the – control port

To use the block, connect the + and – ports on the left side of the block (the control ports) to the control current source. The arrow indicates the positive direction of the current flow. The two ports on the right side of the block (the output ports) generate the output voltage. Polarity is indicated by the + and – signs.

Dialog Box and Parameters



Transresistance K

Ratio of the voltage between the two output terminals to the current passing between the two control terminals. The default value is 1 Ω.

Ports

The block has four electrical conserving ports. Connections + and – on the left side of the block are the control ports. The arrow indicates the positive direction of the current flow. The other two ports are the electrical terminals that provide the output voltage. Polarity is indicated by the + and – signs.

See Also

Current-Controlled Current Source

Voltage-Controlled Current Source

Voltage-Controlled Voltage Source

Current Sensor

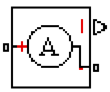
Purpose

Simulate current sensor in electrical systems

Library

Electrical Sensors

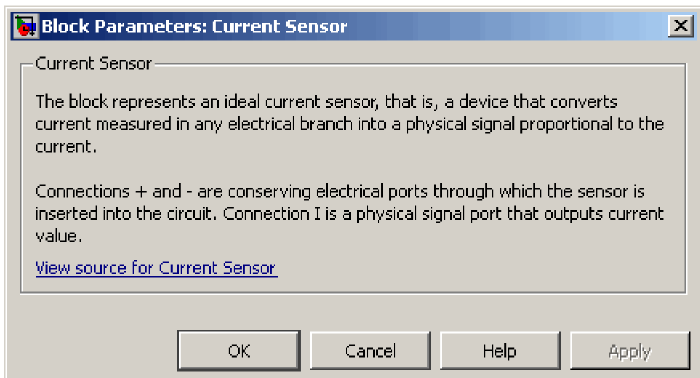
Description



The Current Sensor block represents an ideal current sensor, that is, a device that converts current measured in any electrical branch into a physical signal proportional to the current.

Connections + and – are electrical conserving ports through which the sensor is inserted into the circuit. Connection I is a physical signal port that outputs the measurement result.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

+

Electrical conserving port associated with the sensor positive terminal.

-

Electrical conserving port associated with the sensor negative terminal.

`I`

Physical signal output port for current.

See Also

Voltage Sensor

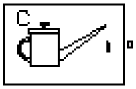
Purpose

Set working fluid properties by specifying parameter values

Library

Hydraulic Utilities

Description



The Custom Hydraulic Fluid block lets you specify the type of hydraulic fluid used in a loop of hydraulic blocks. It provides the hydraulic fluid properties, such as kinematic viscosity, density, and bulk modulus, for all the hydraulic blocks in the loop. These fluid properties are assumed to be constant during simulation time.

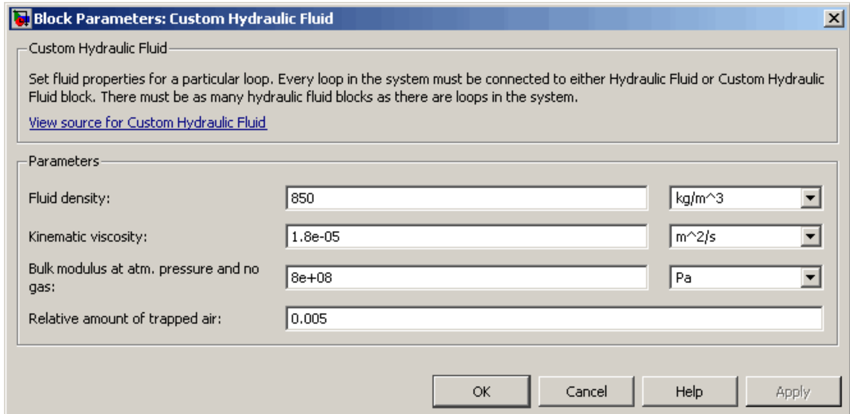
The Custom Hydraulic Fluid block lets you specify the fluid properties, such as kinematic viscosity, density, bulk modulus, and relative amount of entrapped air, as block parameters.

The Custom Hydraulic Fluid block has one port. You can connect it to a hydraulic diagram by branching a connection line off the main line and connecting it to the port. When you connect the Custom Hydraulic Fluid block to a hydraulic line, the software automatically identifies the hydraulic blocks connected to the particular loop and propagates the hydraulic fluid properties to all the hydraulic blocks in the loop.

Each topologically distinct hydraulic loop in a diagram requires exactly one Custom Hydraulic Fluid block or Hydraulic Fluid block, available with SimHydraulics libraries, to be connected to it. Therefore, there must be as many Custom Hydraulic Fluid blocks (or Hydraulic Fluid blocks) as there are loops in the system.

Note If no Hydraulic Fluid block or Custom Hydraulic Fluid block is attached to a loop, the hydraulic blocks in this loop use the default fluid, which is Skydrol LD-4 at 60°C and with a 0.005 ratio of entrapped air. See the Hydraulic Fluid block reference page for more information.

Dialog Box and Parameters



Fluid density
: Density of the working fluid. The default value is 850 kg/m^3.

Kinematic viscosity
: Kinematic viscosity of the working fluid. The default value is 1.8e-5 m^2/s.

Bulk modulus at atm. pressure and no gas
: Bulk modulus of the working fluid, at atmospheric pressure and with no entrapped air. The default value is 8e8 Pa.

Relative amount of trapped air
: Amount of entrained, nondissolved gas in the fluid. The amount is specified as the ratio of gas volume at normal conditions to the fluid volume in the chamber. If set to 0, ideal fluid is assumed. The default value is 0.005.

Ports

The block has one hydraulic conserving port.

See Also

Hydraulic Fluid

DC Current Source

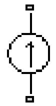
Purpose

Simulate ideal constant current source

Library

Electrical Sources

Description

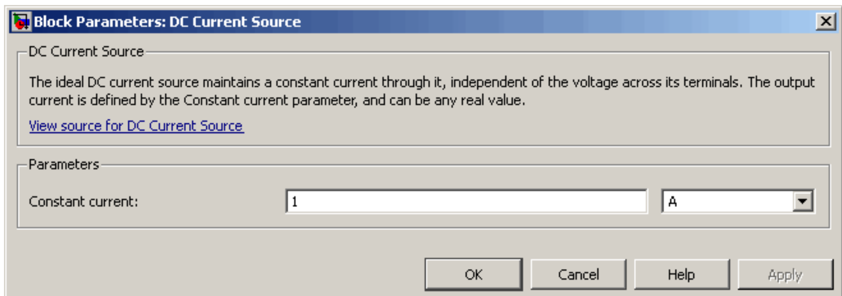


The DC Current Source block represents an ideal current source that is powerful enough to maintain specified current through it regardless of the voltage across the source.

You specify the output current by using the **Constant current** parameter, which can be positive or negative.

The positive direction of the current flow is indicated by the arrow.

Dialog Box and Parameters



Constant current

Output current. You can specify positive or negative values. The default value is 1 A.

Ports

The block has two electrical conserving ports associated with its terminals.

See Also

DC Voltage Source

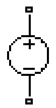
Purpose

Simulate ideal constant voltage source

Library

Electrical Sources

Description

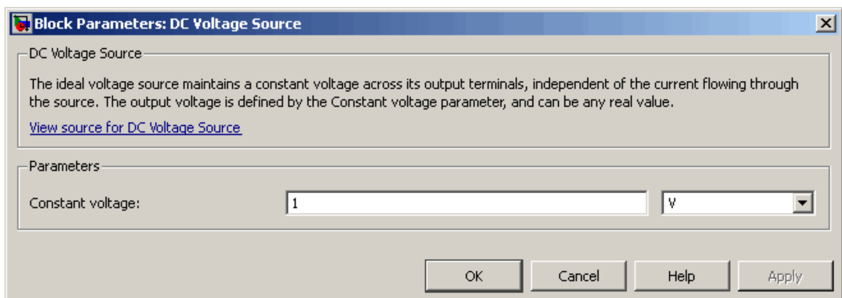


The DC Voltage Source block represents an ideal voltage source that is powerful enough to maintain specified voltage at its output regardless of the current flowing through the source.

You specify the output voltage by using the **Constant voltage** parameter, which can be positive or negative.

Connections + and – are conserving electrical ports corresponding to the positive and negative terminals of the voltage source, respectively. The current is positive if it flows from positive to negative, and the voltage across the source is equal to the difference between the voltage at the positive and the negative terminal, $V(+) - V(-)$.

Dialog Box and Parameters



Constant voltage

Output voltage. You can specify positive or negative values. The default value is 1 V.

Ports

The block has the following ports:

+

Electrical conserving port associated with the source positive terminal.

-
: Electrical conserving port associated with the source negative terminal.

See Also

DC Current Source

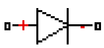
Purpose

Simulate piecewise linear diode in electrical systems

Library

Electrical Elements

Description



The Diode block models a piecewise linear diode. If the voltage across the diode is bigger than the **Forward voltage** parameter value, then the diode behaves like a linear resistor with low resistance, given by the **On resistance** parameter value, plus a series voltage source. If the voltage across the diode is less than the forward voltage, then the diode behaves like a linear resistor with low conductance given by the **Off conductance** parameter value.

When forward biased, the series voltage source is described with the following equation:

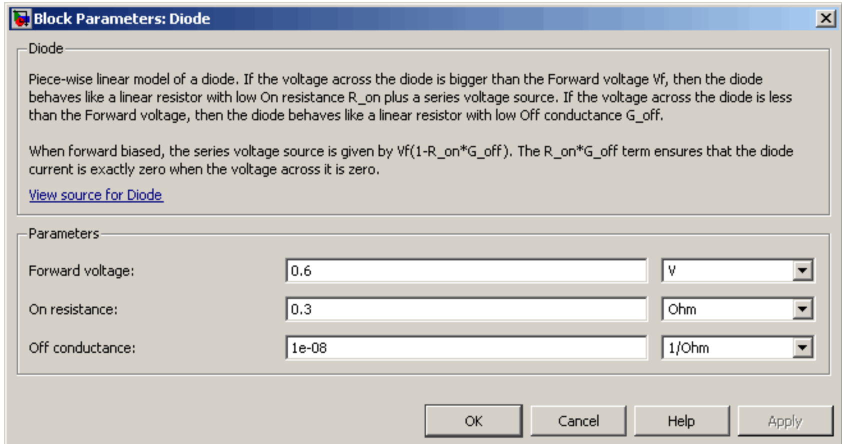
$$V = Vf(1 - R_{on} \cdot G_{off})$$

where

V	Voltage
Vf	Forward voltage
R_{on}	On resistance
G_{off}	Off conductance

The $R_{on} \cdot G_{off}$ term ensures that the diode current is exactly zero when the voltage across it is zero.

Dialog Box and Parameters



Forward voltage

Minimum voltage that needs to be applied for the diode to become forward-biased. The default value is `0.6` V.

On resistance

The resistance of a forward-biased diode. The default value is `0.3` Ω.

Off conductance

The conductance of a reverse-biased diode. The default value is `1e-8` 1/Ω.

Ports

The block has the following ports:

+

Electrical conserving port associated with the diode positive terminal.

-

Electrical conserving port associated with the diode negative terminal.

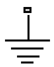
Purpose

Simulate connection to electrical ground

Library

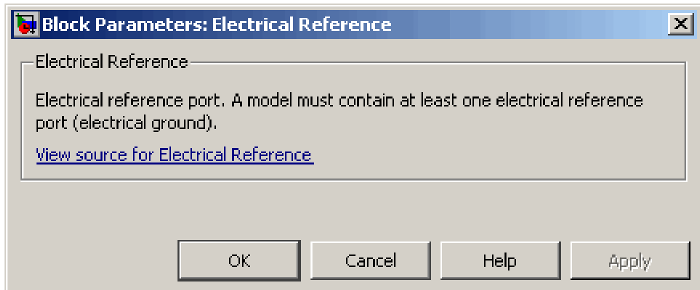
Electrical Elements

Description



The Electrical Reference block represents an electrical ground. Electrical conserving ports of all the blocks that are directly connected to ground must be connected to an Electrical Reference block. A model with electrical elements must contain at least one Electrical Reference block.

Dialog Box and Parameters



The Electrical Reference block has no parameters.

Ports

The block has one electrical conserving port.

See Also

Hydraulic Reference

Mechanical Rotational Reference

Mechanical Translational Reference

Thermal Reference

Electromagnetic Converter

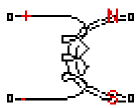
Purpose

Simulate lossless electromagnetic energy conversion device

Library

Magnetic Elements

Description



The Electromagnetic Converter block provides a generic interface between the electrical and magnetic domains.

The block is based on the following equations:

$$\mathrm{F} = N \cdot I$$

$$V = -N \cdot \frac{d\Phi}{dt}$$

where

F	Magnetomotive force (mmf) across the magnetic ports
Φ	Flux through the magnetic ports
I	Current through the electrical ports
V	Voltage across the electrical ports
N	Number of electrical winding turns
t	Simulation time

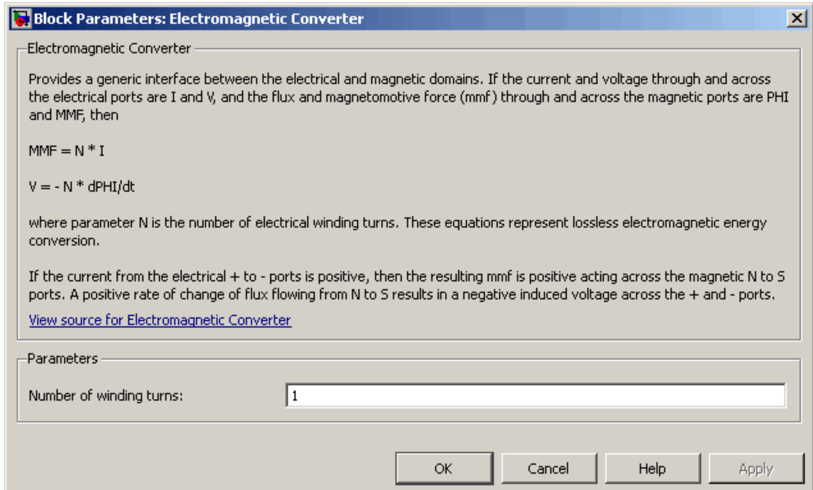
Connections N and S are magnetic conserving ports, and connections + and – are electrical conserving ports. If the current from the electrical + to – ports is positive, then the resulting mmf is positive acting across the magnetic N to S ports. A positive rate of change of flux flowing from N to S results in a negative induced voltage across the + and – ports.

Basic Assumptions and Limitations

The model is based on the following assumption:

- Electromagnetic energy conversion is lossless.

Dialog Box and Parameters



Number of winding turns

Number of electrical winding turns. The default value is 1.

Ports

The block has the following ports:

N

Magnetic conserving port associated with the block North terminal.

S

Magnetic conserving port associated with the block South terminal.

+

Positive electrical conserving port.

-

Negative electrical conserving port.

See Also

Reluctance Force Actuator

Fluid Inertia

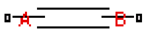
Purpose

Simulate pressure differential across tube or channel due to change in fluid velocity

Library

Hydraulic Elements

Description



The Fluid Inertia block models pressure differential, due to change in fluid velocity, across a fluid passage of constant cross-sectional area. The pressure differential is determined according to the following equation:

$$p = \rho \frac{L}{A} \frac{dq}{dt}$$

where

p	Pressure differential
ρ	Fluid density
L	Passage length
A	Passage area
q	Flow rate
t	Time

Use this block in various pipe or channel models that require fluid inertia to be accounted for.

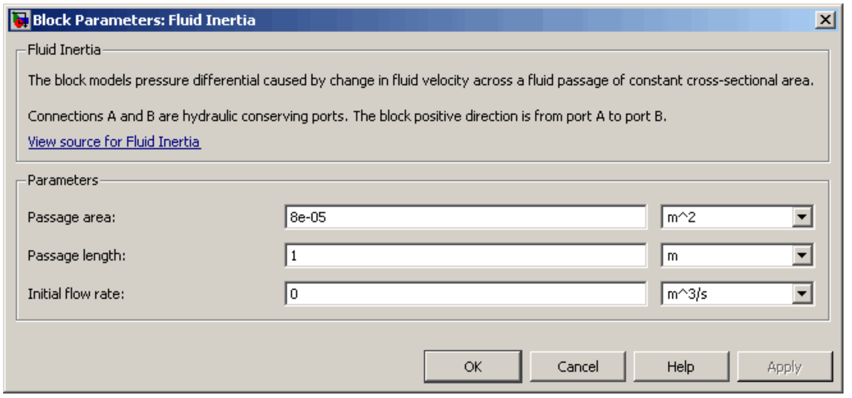
The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B.

Assumptions and Limitations

The model is based on the following assumptions:

- Fluid density remains constant.

Dialog Box and Parameters



Passage area
: Fluid passage cross-sectional area. The default value is `8e-5` m^2.

Passage length
: Length of the fluid passage. The default value is `1` m.

Initial flow rate
: Initial flow rate through the passage. This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `0`.

Global Parameters

Fluid density
: The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Ports

The block has the following ports:

A
: Hydraulic conserving port associated with the passage inlet.

B
: Hydraulic conserving port associated with the passage outlet.

Flux Sensor

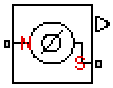
Purpose

Simulate ideal flux sensor

Library

Magnetic Sensors

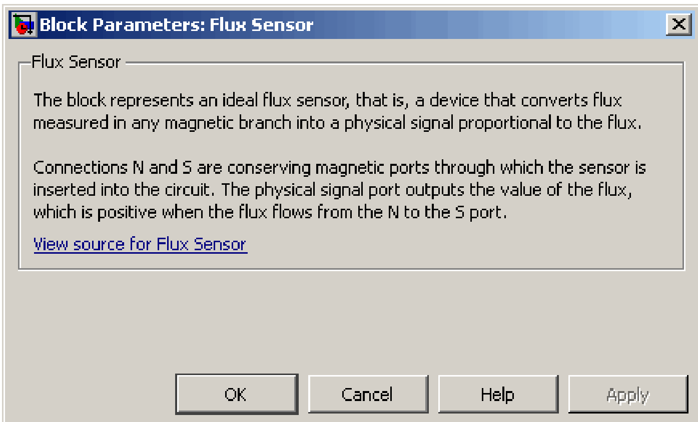
Description



The Flux Sensor block represents an ideal flux sensor, that is, a device that converts flux measured in any magnetic branch into a physical signal proportional to the flux.

Connections N and S are conserving magnetic ports through which the sensor is inserted into the circuit. The physical signal port outputs the value of the flux, which is positive when the flux flows from the N to the S port.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

N
: Magnetic conserving port associated with the sensor North terminal.

`S`
: Magnetic conserving port associated with the sensor South terminal.

The block also has a physical signal output port, which outputs the value of the flux.

See Also

Controlled Flux Source

Flux Source

Flux Source

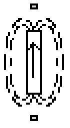
Purpose

Simulate ideal flux source

Library

Magnetic Sources

Description



The Flux Source block represents an ideal flux source that is powerful enough to maintain specified constant flux through it, regardless of the mmf across its terminals.

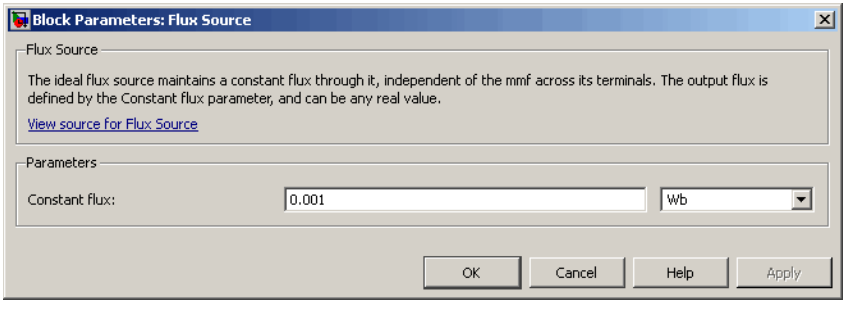
You specify the output flux by using the **Constant flux** parameter, which can be positive, negative, or zero.

You can also model permanent magnets with this block, using the following equation:

$$Constant\ flux = Gauss\ strength * Cross\text{-}sectional\ area$$

The positive direction of the flux flow is indicated by the arrow.

Dialog Box and Parameters



Constant flux

Output flux. You can specify any real value. The default value is `0.001` Wb.

Ports

The block has two magnetic conserving ports associated with its terminals.

See Also

Controlled Flux Source

Controlled MMF Source

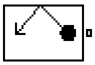
MMF Source

Gas Properties

Purpose Specify pneumatic domain properties for attached circuit

Library Pneumatic Utilities

Description



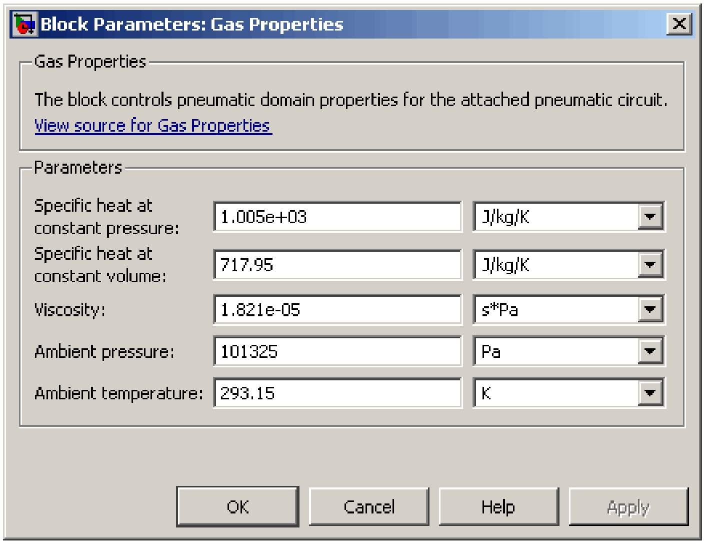
The Gas Properties block defines pneumatic domain properties for a circuit, that is, the gas properties that act as global parameters for all the blocks connected to the pneumatic circuit. These gas properties are assumed to be constant during simulation time.

The Gas Properties block lets you specify the gas properties, such as specific heat at constant pressure and constant volume, as well as viscosity, as block parameters. It also lets you specify ambient pressure and ambient temperature.

The Gas Properties block has one port. You can connect it to a pneumatic diagram by branching a connection line off the main line and connecting it to the port. When you connect the Gas Properties block to a pneumatic line, the software automatically identifies the pneumatic blocks connected to the particular circuit and propagates the gas properties to all the pneumatic blocks in the circuit.

Each topologically distinct pneumatic circuit in a diagram requires exactly one Gas Properties block to be connected to it. Therefore, there must be as many Gas Properties blocks as there are pneumatic circuits in the system. If no Gas Properties block is attached to a circuit, the pneumatic blocks in this circuit use the gas properties corresponding to the default Gas Properties block parameter values.

Dialog Box and Parameters



Specific heat at constant pressure
: Specify the gas specific heat at constant pressure. The default value is `1.005e3` J/kg/K.

Specific heat at constant volume
: Specify the gas specific heat at constant volume. The default value is `717.95` J/kg/K.

Viscosity
: Specify the gas viscosity. The default value is `1.821e-5` s*Pa.

Ambient pressure
: Specify the gas ambient pressure. The default value is `101325` Pa.

Ambient temperature
: Specify the gas ambient temperature. The default value is `293.15` K.

Ports

The block has one pneumatic conserving port.

Gear Box

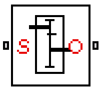
Purpose

Simulate gear boxes in mechanical systems

Library

Mechanisms

Description



The Gear Box block represents an ideal, nonplanetary, fixed gear ratio gear box. The gear ratio is determined as the ratio of the input shaft angular velocity to that of the output shaft.

The gear box is described with the following equations:

$$\omega_1 = N \cdot \omega_2$$

$$T_2 = N \cdot T_1$$

$$P_1 = \omega_1 \cdot T_1$$

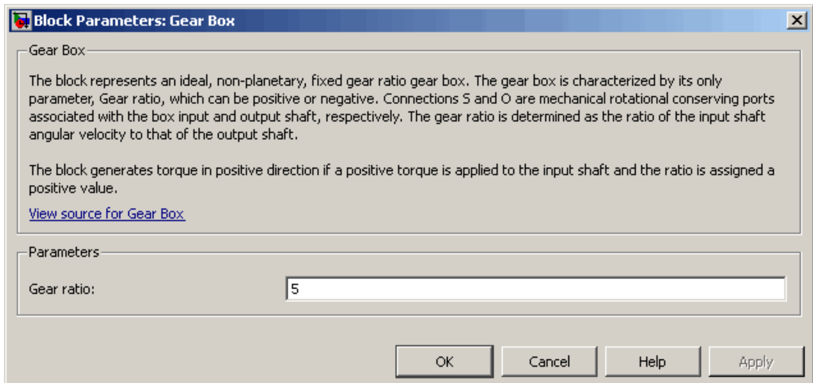
$$P_2 = -\omega_2 \cdot T_2$$

where

ω_1	Input shaft angular velocity
ω_2	Output shaft angular velocity
N	Gear ratio
T_1	Torque on the input shaft
T_2	Torque on the output shaft
P_1	Power on the input shaft
P_2	Power on the output shaft. Notice the minus sign in computing P_2. One of the network rules is that the power flowing through a conserving port is positive if it is removed (dissipated) from the circuit, and is negative if the component generates power into the system.

Connections S and O are mechanical rotational conserving ports associated with the box input and output shaft, respectively. The block positive directions are from S to the reference point and from the reference point to O.

Dialog Box and Parameters



Gear ratio

The ratio of the input shaft angular velocity to that of the output shaft. You can specify both positive and negative values. The default value is 5.

Ports

The block has the following ports:

S

Mechanical rotational conserving port associated with input shaft.

O

Mechanical rotational conserving port associated with the output shaft.

Gyrator

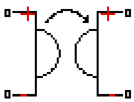
Purpose

Simulate ideal gyrator in electrical systems

Library

Electrical Elements

Description



Gyrators can be used to implement an inductor with a capacitor. The main benefit is that an equivalent inductance can be created with a much smaller physically sized capacitance. In practice, a gyrator is implemented with an op-amp plus additional passive components.

The Gyrator block models an ideal gyrator with no losses, described with the following equations:

$$I1 = G \bullet V2$$

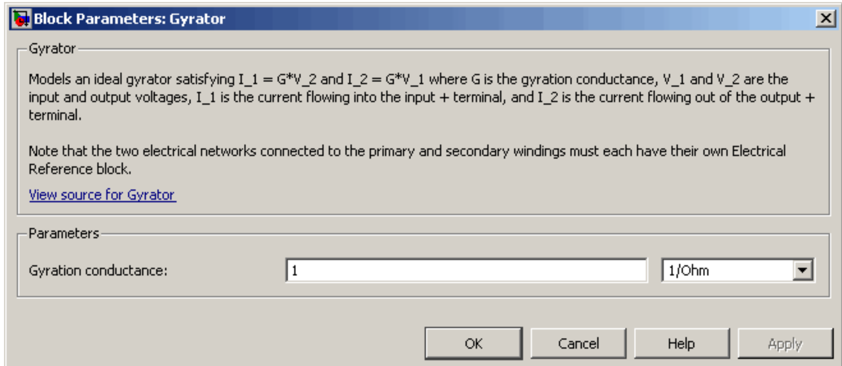
$$I2 = G \bullet V1$$

where

V1	Input voltage
V2	Output voltage
I1	Current flowing into the input + terminal
I2	Current flowing out of the output + terminal
G	Gyration conductance

The two electrical networks connected to the primary and secondary windings must each have their own Electrical Reference block.

Dialog Box and Parameters



Gyration conductance

The gyration conductance constant *G*. The default value is 1.

Ports

The block has four electrical conserving ports. Polarity is indicated by the + and – signs.

Hydraulic Flow Rate Sensor

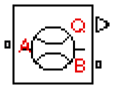
Purpose

Simulate ideal flow meter

Library

Hydraulic Sensors

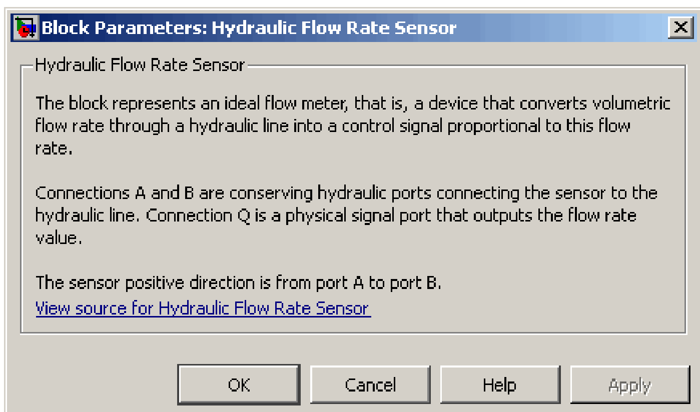
Description



The Hydraulic Flow Rate Sensor block represents an ideal flow meter, that is, a device that converts volumetric flow rate through a hydraulic line into a control signal proportional to this flow rate. The sensor is ideal because it does not account for inertia, friction, delays, pressure loss, and so on.

Connections A and B are conserving hydraulic ports connecting the sensor to the hydraulic line. Connection Q is a physical signal port that outputs the flow rate value. The sensor positive direction is from A to B. This means that the flow rate is positive if it flows from A to B.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A
: Hydraulic conserving port associated with the sensor positive probe.

B
: Hydraulic conserving port associated with the sensor negative (reference) probe.

Q
: Physical signal port that outputs the flow rate value.

See Also

Hydraulic Flow Rate Source

Hydraulic Pressure Sensor

Hydraulic Flow Rate Source

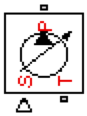
Purpose

Simulate ideal source of hydraulic energy, characterized by flow rate

Library

Hydraulic Sources

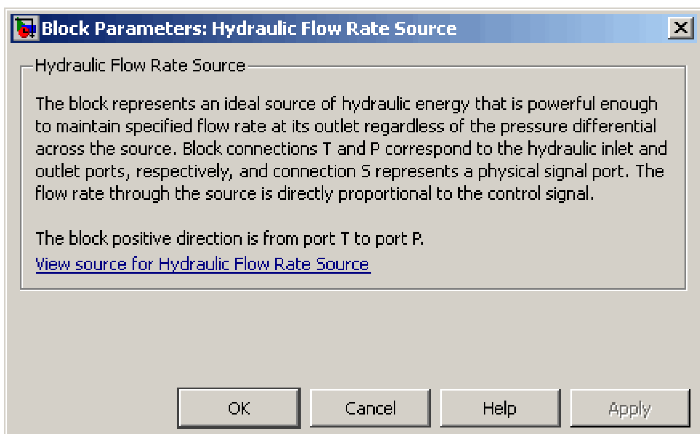
Description



The Hydraulic Flow Rate Source block represents an ideal source of hydraulic energy that is powerful enough to maintain specified flow rate at its outlet regardless of the pressure differential across the source. Block connections T and P correspond to the hydraulic inlet and outlet ports, respectively, and connection S represents a control signal port. The flow rate through the source is directly proportional to the signal at the control port S. The entire variety of Simulink signal sources can be used to generate desired flow rate variation profile.

The block positive direction is from port T to port P. This means that the flow rate is positive if it flows from T to P. The pressure differential is determined as $p = p_T - p_P$ and is negative if pressure at the source outlet is greater than pressure at its inlet. The power generated by the source is negative if the source delivers energy to port P.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

T
: Hydraulic conserving port associated with the source inlet.

P
: Hydraulic conserving port associated with the source outlet.

S
: Control signal port.

See Also

Hydraulic Flow Rate Sensor

Hydraulic Pressure Source

Hydraulic Piston Chamber

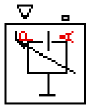
Purpose

Simulate variable volume hydraulic capacity in cylinders

Library

Hydraulic Elements

Description



The Hydraulic Piston Chamber block models fluid compressibility in a chamber created by a piston of a cylinder. The fluid is considered to be a mixture of liquid and a small amount of entrained, nondissolved gas. Use this block together with the Translational Hydro-Mechanical Converter block.

Note The Hydraulic Piston Chamber block takes into account only the flow rate caused by fluid compressibility. The fluid volume consumed to create piston velocity is accounted for in the Translational Hydro-Mechanical Converter block.

The chamber is simulated according to the following equations:

$$q = \frac{A(x_0 + x \bullet or)}{E} \bullet \frac{dp}{dt}$$

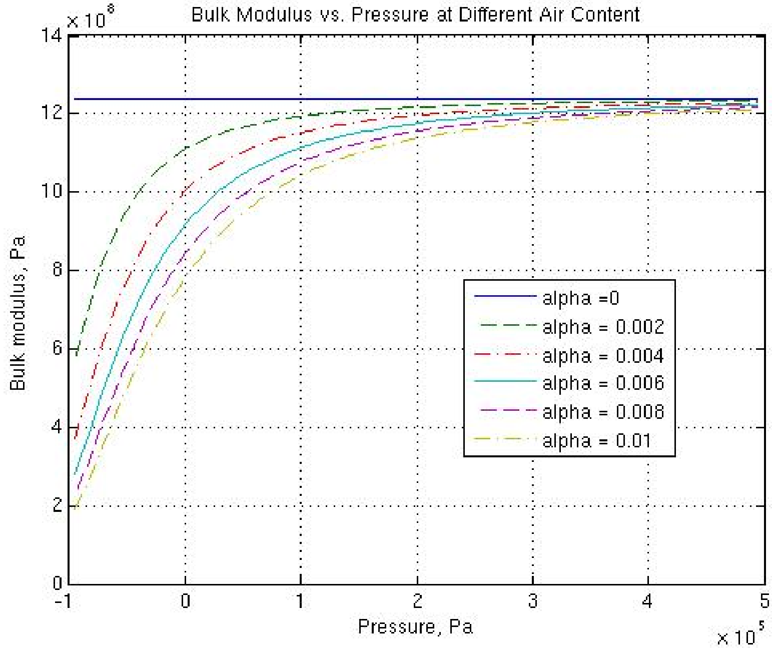
$$E = E_l \frac{1 + \alpha \left(\frac{p_a}{p_a + p} \right)^{1/n}}{1 + \alpha \frac{p_a^{1/n}}{n \bullet (p_a + p)^{\frac{n+1}{n}}} E_l}$$

where

q	Flow rate due to fluid compressibility
A	Effective piston area
x_0	Piston initial position
x	Piston displacement from initial position

or	Chamber orientation with respect to the globally assigned positive direction. If displacement in positive direction increases the volume of the chamber, *or* equals 1. If displacement in positive direction decreases the volume of the chamber, *or* equals –1.
E	Fluid bulk modulus
E_1	Pure liquid bulk modulus
p	Gauge pressure of fluid in the chamber
p_α	Atmospheric pressure
α	Relative gas content at atmospheric pressure, $\alpha = V_G/V_L$
V_G	Gas volume at atmospheric pressure
V_L	Volume of liquid
n	Gas-specific heat ratio

The main objective of representing fluid as a mixture of liquid and gas is to introduce an approximate model of cavitation, which takes place in a chamber if pressure drops below fluid vapor saturation level. As it is seen in the graph below, the bulk modulus of a mixture decreases at $p \to p_a$, thus considerably slowing down further pressure change. At high pressure, $p >> p_a$, a small amount of nondissolved gas has practically no effect on the system behavior.



Cavitation is an inherently thermodynamic process, requiring consideration of multiple-phase fluids, heat transfers, etc., and as such cannot be accurately simulated with Simscape software. But the simplified version implemented in the block is good enough to signal if pressure falls below dangerous level, and to prevent computation failure that normally occurs at negative pressures.

Port A is a hydraulic conserving port associated with the chamber inlet. Port P is a physical signal port that controls piston displacement.

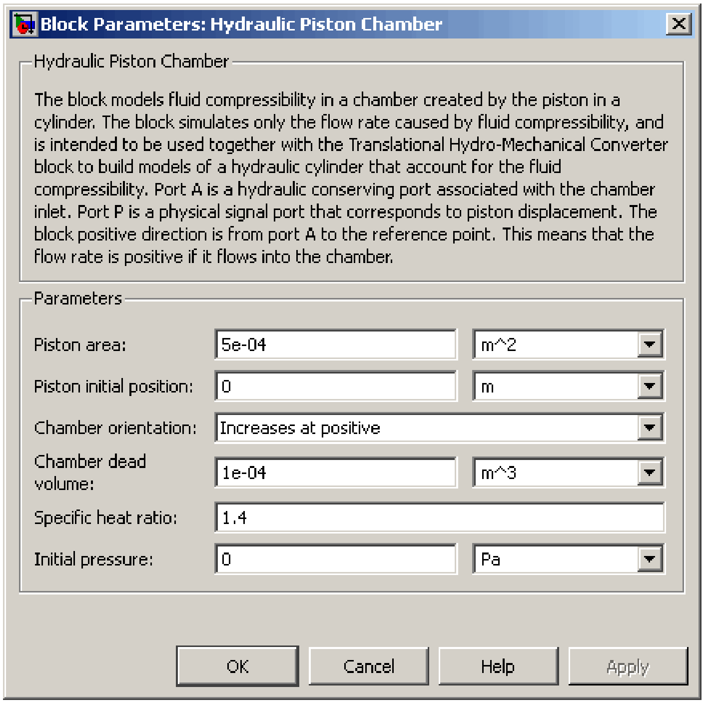
The block positive direction is from port A to the reference point. This means that the flow rate is positive if it flows into the chamber.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- Fluid density remains constant.
- Chamber volume can not be less that the dead volume.
- Fluid fills the entire chamber volume.

Dialog Box and Parameters



Piston area

Effective piston area. The default value is `5e-4` m^2.

Piston initial position

Initial offset of the piston from the cylinder cap. The default value is 0.

Chamber orientation
Specifies chamber orientation with respect to the globally assigned positive direction. The chamber can be installed in two different ways, depending upon whether the piston motion in the positive direction increases or decreases the volume of the chamber. If piston motion in the positive direction decreases the chamber volume, set the parameter to `Decreases at positive`. The default value is `Increases at positive`.

Chamber dead volume
Volume of fluid in the chamber at zero piston position. The default value is `1e-4` m^3.

Specific heat ratio
Gas-specific heat ratio. The default value is `1.4`.

Initial pressure
Initial pressure in the chamber. This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `0`.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Chamber orientation**

All other block parameters are available for modification.

Global Parameters

Fluid bulk modulus
The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Nondissolved gas ratio
Nondissolved gas relative content determined as a ratio of gas volume to the liquid volume. The parameter is determined by the

type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Ports

The block has the following ports:

A
: Hydraulic conserving port associated with the chamber inlet.

P
: Physical signal port that controls piston displacement.

See Also

Constant Volume Hydraulic Chamber

Translational Hydro-Mechanical Converter

Variable Hydraulic Chamber

Hydraulic Pressure Sensor

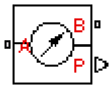
Purpose

Simulate ideal pressure sensing device

Library

Hydraulic Sensors

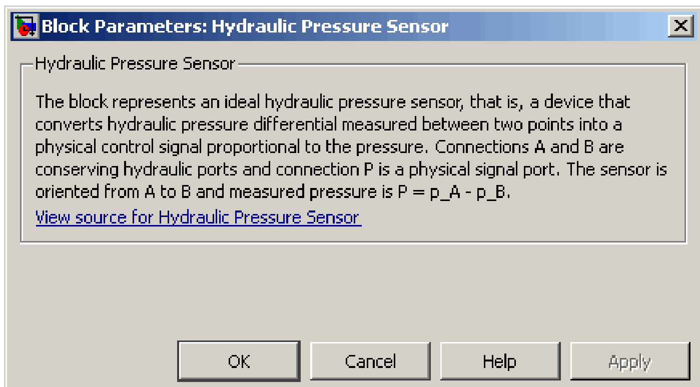
Description



The Hydraulic Pressure Sensor block represents an ideal hydraulic pressure sensor, that is, a device that converts hydraulic pressure differential measured between two points into a control signal proportional to this pressure. The sensor is ideal because it does not account for inertia, friction, delays, pressure loss, and so on.

Connections A and B are conserving hydraulic ports connecting the sensor to the hydraulic line. Connection P is a physical signal port that outputs the pressure value. The sensor positive direction is from A to B. This means that the pressure differential is determined as $p = p_A - p_B$.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A
: Hydraulic conserving port associated with the sensor positive probe.

B

Hydraulic conserving port associated with the sensor negative (reference) probe.

P

Physical signal port that outputs the pressure value.

See Also

Hydraulic Flow Rate Sensor

Hydraulic Pressure Source

Hydraulic Pressure Source

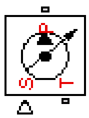
Purpose

Simulate ideal source of hydraulic energy, characterized by pressure

Library

Hydraulic Sources

Description



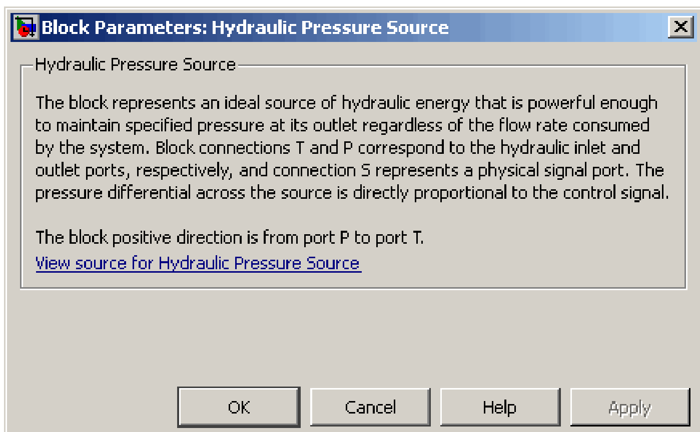
The Hydraulic Pressure Source block represents an ideal source of hydraulic energy that is powerful enough to maintain specified pressure at its outlet regardless of the flow rate consumed by the system. Block connections T and P correspond to the hydraulic inlet and outlet ports, respectively, and connection S represents a control signal port. The pressure differential across the source

$$p = p_P - p_T$$

where p_P, p_T are the gauge pressures at the source ports, is directly proportional to the signal at the control port S. The entire variety of Simulink signal sources can be used to generate desired pressure variation profile.

The block positive direction is from port P to port T. This means that the flow rate is positive if it flows from P to T. The power generated by the source is negative if the source delivers energy to port P.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

P
: Hydraulic conserving port associated with the source inlet.

T
: Hydraulic conserving port associated with the source outlet.

S
: Control signal port.

See Also

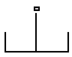
Hydraulic Flow Rate Source

Hydraulic Pressure Sensor

Purpose Simulate connection to atmospheric pressure

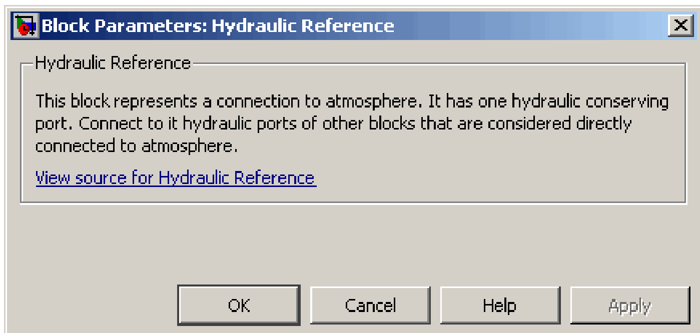
Library Hydraulic Elements

Description



The Hydraulic Reference block represents a connection to atmospheric pressure. Hydraulic conserving ports of all the blocks that are referenced to atmosphere (for example, suction ports of hydraulic pumps, or return ports of valves, cylinders, pipelines, if they are considered directly connected to atmosphere) must be connected to a Hydraulic Reference block.

Dialog Box and Parameters



The Hydraulic Reference block has no parameters.

Ports The block has one hydraulic conserving port.

See Also

Electrical Reference

Mechanical Rotational Reference

Mechanical Translational Reference

Thermal Reference

Purpose

Simulate hydraulic pipeline which accounts for friction losses only

Library

Hydraulic Elements

Description

The Hydraulic Resistive Tube block models hydraulic pipelines with circular and noncircular cross sections and accounts for resistive property only. In other words, the block is developed with the basic assumption of the steady state fluid momentum conditions. Neither fluid compressibility nor fluid inertia is considered in the model, meaning that features such as water hammer cannot be investigated. If necessary, you can add fluid compressibility, fluid inertia, and other effects to your model using other blocks, thus producing a more comprehensive model.

The end effects are also not considered, assuming that the flow is fully developed along the entire pipe length. To account for local resistances, such as bends, fittings, inlet and outlet losses, and so on, all the resistances are converted into their equivalent lengths, and then the total length of all the resistances is added to the pipe geometrical length.

Pressure loss due to friction is computed with the Darcy equation, in which losses are proportional to the flow regime-dependable friction factor and the square of the flow rate. The friction factor in turbulent regime is determined with the Haaland approximation (see [1]). The friction factor during transition from laminar to turbulent regimes is determined with the linear interpolation between extreme points of the regimes. As a result of these assumptions, the tube is simulated according to the following equations:

$$p = f \frac{\left(L + L_{eq}\right)}{D_H} \frac{\rho}{2A^2} q \cdot |q|$$

$$
f = \begin{cases} K_s / Re & \text{for } Re <= Re_L \\ f_L + \dfrac{f_T - f_L}{Re_T - Re_L}(Re - Re_L) & \text{for } Re_L < Re < Re_T \\ \dfrac{1}{\left(-1.8\log_{10}\left(\dfrac{6.9}{Re} + \left(\dfrac{r / D_H}{3.7}\right)^{1.11}\right)\right)^2} & \text{for } Re >= Re_T \end{cases}
$$

$$
\mathrm{Re} = \frac{q \cdot D_H}{A \cdot \nu}
$$

where

p	Pressure loss along the pipe due to friction
q	Flow rate through the pipe
Re	Reynolds number
Re_L	Maximum Reynolds number at laminar flow
Re_T	Minimum Reynolds number at turbulent flow
K_s	Shape factor that characterizes the pipe cross section
f_L	Friction factor at laminar border
f_T	Friction factor at turbulent border
A	Pipe cross-sectional area
D_H	Pipe hydraulic diameter
L	Pipe geometrical length
L_{eq}	Aggregate equivalent length of local resistances

r	Height of the roughness on the pipe internal surface
ν	Fluid kinematic viscosity

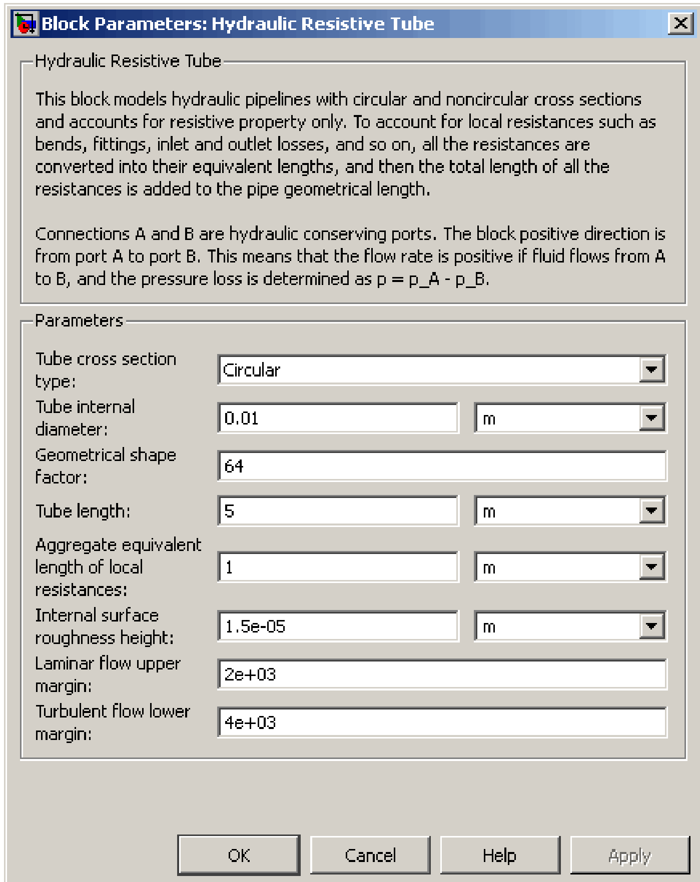
The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B, and the pressure loss is determined as $p = p_A - p_B$.

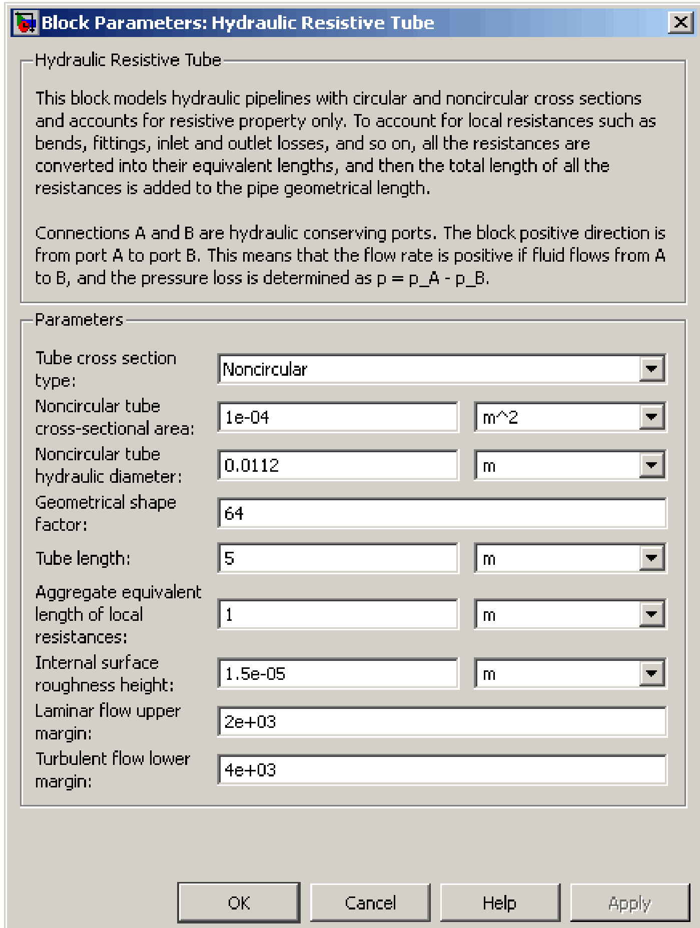
Basic Assumptions and Limitations

The model is based on the following assumptions:

- Flow is assumed to be fully developed along the pipe length.
- Fluid inertia, fluid compressibility, and wall compliance are not taken into account.

Dialog Box and Parameters





Tube cross section type

The parameter can have one of two values: `Circular` or `Noncircular`. For a circular tube, you need to specify its internal diameter. For a noncircular tube, you need to specify its hydraulic diameter and tube cross-sectional area. The default value of the parameter is `Circular`.

Tube internal diameter
Tube internal diameter. The parameter is used if **Tube cross section type** is set to `Circular`. The default value is `0.01` m.

Noncircular tube cross-sectional area
Tube cross-sectional area. The parameter is used if **Tube cross section type** is set to `Noncircular`. The default value is `1e-4` m^2.

Noncircular tube hydraulic diameter
Hydraulic diameter of the tube cross section. The parameter is used if **Tube cross section type** is set to `Noncircular`. The default value is `0.0112` m.

Geometrical shape factor
The parameter is used for computing friction factor at laminar flow and depends of the shape of the tube cross section. For a tube with noncircular cross section, you must set the factor to an appropriate value, for example, 56 for a square, 96 for concentric annulus, 62 for rectangle (2:1), and so on (see [1]). The default value is `64`, which corresponds to a tube with a circular cross section.

Tube length
Tube geometrical length. The default value is `5` m.

Aggregate equivalent length of local resistances
This parameter represents total equivalent length of all local resistances associated with the tube. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. The default value is `1` m.

Internal surface roughness height
Roughness height on the tube internal surface. The parameter is typically provided in data sheets or manufacturer's catalogs. The default value is `1.5e-5` m, which corresponds to drawn tubing.

Laminar flow upper margin
Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent. Mathematically, this is the maximum Reynolds number at fully developed laminar flow. The default value is 2000.

Turbulent flow lower margin
Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this is the minimum Reynolds number at turbulent flow. The default value is 4000.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Tube cross section type**

All other block parameters are available for modification. The actual set of modifiable block parameters depends on the value of the **Tube cross section type** parameter at the time the model entered Restricted mode.

Global Parameters

Fluid density
The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Fluid kinematic viscosity
The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Ports

The block has the following ports:

A
Hydraulic conserving port associated with the tube inlet.

B

Hydraulic conserving port associated with the tube outlet.

References

[1] White, F.M., *Viscous Fluid Flow*, McGraw-Hill, 1991

See Also

Linear Hydraulic Resistance

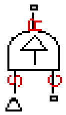
Purpose

Simulate ideal angular velocity source in mechanical rotational systems

Library

Mechanical Sources

Description

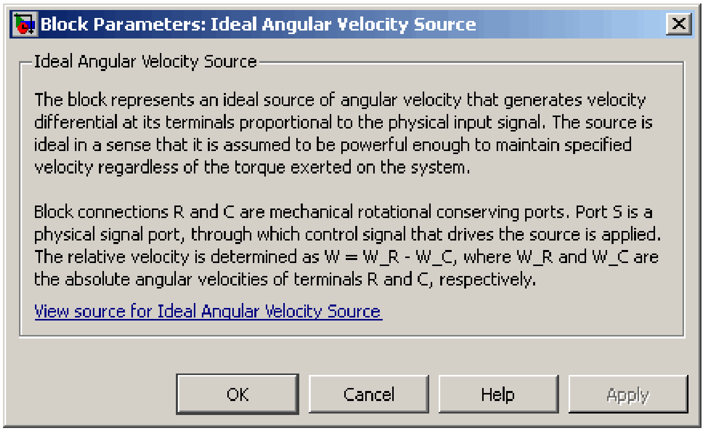


The Ideal Angular Velocity Source block represents an ideal source of angular velocity that generates velocity differential at its terminals proportional to the input physical signal. The source is ideal in a sense that it is assumed to be powerful enough to maintain specified velocity regardless of the torque exerted on the system.

Connections R and C are mechanical rotational conserving ports. Port S is a physical signal port, through which the control signal that drives the source is applied. The relative velocity (velocity differential) across the source is directly proportional to the signal at the control port S. The entire variety of Simulink signal sources can be used to generate the desired velocity variation profile.

The block positive direction is from port R to port C. This means that the velocity is measured as $\omega = \omega_R - \omega_C$, where ω_R, ω_C are the absolute angular velocities at ports R and C, respectively, and torque through the source is positive if it is directed from R to C. The power generated by the source is negative if the source delivers energy to port R.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

R
: Mechanical rotational conserving port.

C
: Mechanical rotational conserving port associated with the source reference point (case).

S
: Physical signal input port, through which the control signal that drives the source is applied.

See Also

Ideal Force Source

Ideal Torque Source

Ideal Translational Velocity Source

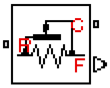
Purpose

Simulate force sensor in mechanical translational systems

Library

Mechanical Sensors

Description

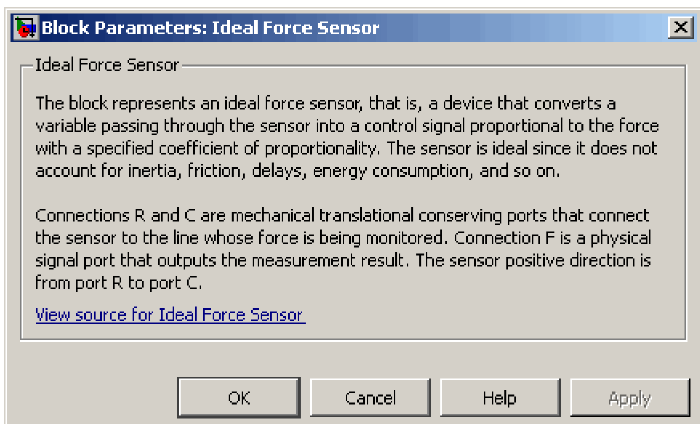


The Ideal Force Sensor block represents a device that converts a variable passing through the sensor into a control signal proportional to the force. The sensor is ideal since it does not account for inertia, friction, delays, energy consumption, and so on.

Connections R and C are mechanical translational conserving ports that connect the block to the line where force is being monitored. Connection F is a physical signal port that outputs the measurement result.

The block positive direction is from port R to port C. This means that positive force applied to port R (the sensor positive probe) generates a positive output signal.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

`R`
: Mechanical translational conserving port associated with the sensor positive probe.

`C`
: Mechanical translational conserving port associated with the sensor negative (reference) probe.

`F`
: Physical signal output port for force.

See Also

Ideal Rotational Motion Sensor

Ideal Torque Sensor

Ideal Translational Motion Sensor

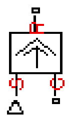
Purpose

Simulate ideal source of mechanical energy that generates force proportional to the input signal

Library

Mechanical Sources

Description

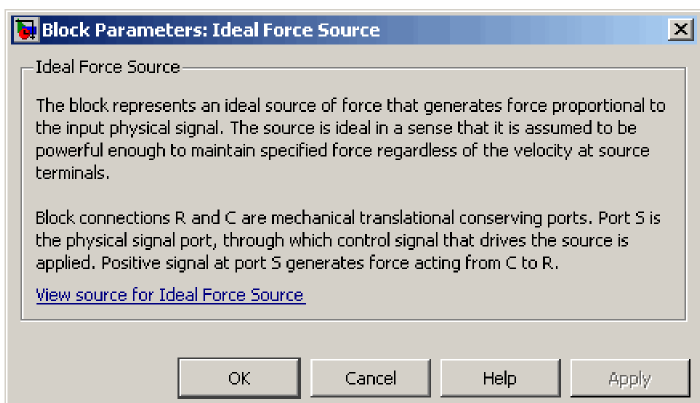


The Ideal Force Source block represents an ideal source of mechanical energy that generates force proportional to the input physical signal. The source is ideal in a sense that it is assumed to be powerful enough to maintain specified force at its output regardless of the velocity at source terminals.

Connections R and C are mechanical translational conserving ports. Port S is a physical signal port, through which the control signal that drives the source is applied. You can use the entire variety of Simulink signal sources to generate the desired force variation profile. Positive signal at port S generates force acting from C to R. The force generated by the source is directly proportional to the signal at the control port S.

The block positive direction is from port C to port R. This means that the force is positive if it acts in the direction from C to R. The relative velocity is determined as $v = v_R - v_C$, where v_R, v_C are the absolute velocities at ports R and C, respectively, and it is negative if velocity at port R is greater than that at port C. The power generated by the source is negative if the source delivers energy to port R.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

R
: Mechanical translational conserving port.

C
: Mechanical translational conserving port associated with the source reference point (case).

S
: Physical signal input port, through which the control signal that drives the source is applied.

See Also

Ideal Angular Velocity Source

Ideal Torque Source

Ideal Translational Velocity Source

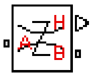
Purpose

Simulate ideal heat flow meter

Library

Thermal Sensors

Description

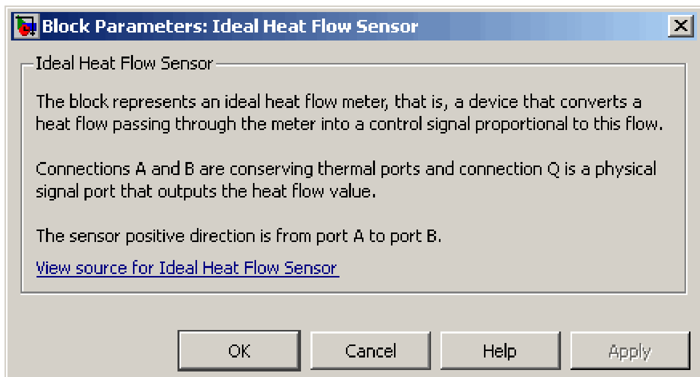


The Ideal Heat Flow Sensor block represents an ideal heat flow meter, that is, a device that converts a heat flow passing through the meter into a control signal proportional to this flow. The meter must be connected in series with the component whose heat flow is being monitored.

Connections A and B are thermal conserving ports. Port Q is a physical signal port that outputs the heat flow value.

The block positive direction is from port A to port B.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A
: Thermal conserving port associated with the sensor positive probe.

B
: Thermal conserving port associated with the sensor negative probe.

`Q`

Physical signal output port for heat flow.

See Also

Ideal Heat Flow Source

Ideal Temperature Sensor

Ideal Temperature Source

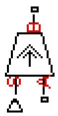
Purpose

Simulate ideal source of thermal energy, characterized by heat flow

Library

Thermal Sources

Description

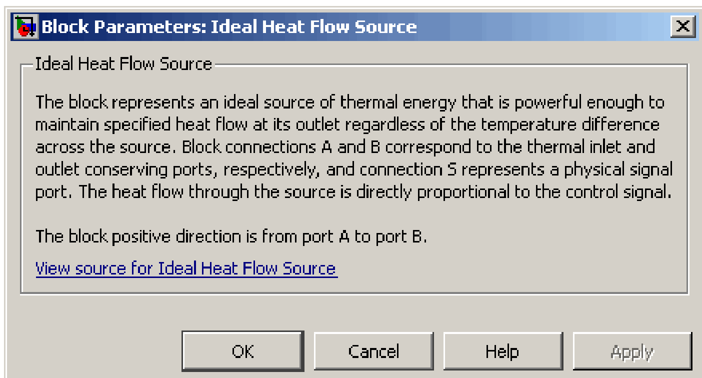


The Ideal Heat Flow Source block represents an ideal source of thermal energy that is powerful enough to maintain specified heat flow at its outlet regardless of the temperature difference across the source.

Connections A and B are thermal conserving ports corresponding to the source inlet and outlet, respectively. Port S is a physical signal port, through which the control signal that drives the source is applied. You can use the entire variety of Simulink signal sources to generate the desired heat flow variation profile. The heat flow through the source is directly proportional to the signal at the control port S.

The block positive direction is from port A to port B. This means that positive signal at port S generates heat flow in the direction from A to B.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A

Thermal conserving port associated with the source inlet.

B
: Thermal conserving port associated with the source outlet.

S
: Physical signal input port, through which the control signal that drives the source is applied.

See Also

Ideal Heat Flow Sensor

Ideal Temperature Sensor

Ideal Temperature Source

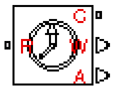
Purpose

Simulate motion sensor in mechanical rotational systems

Library

Mechanical Sensors

Description



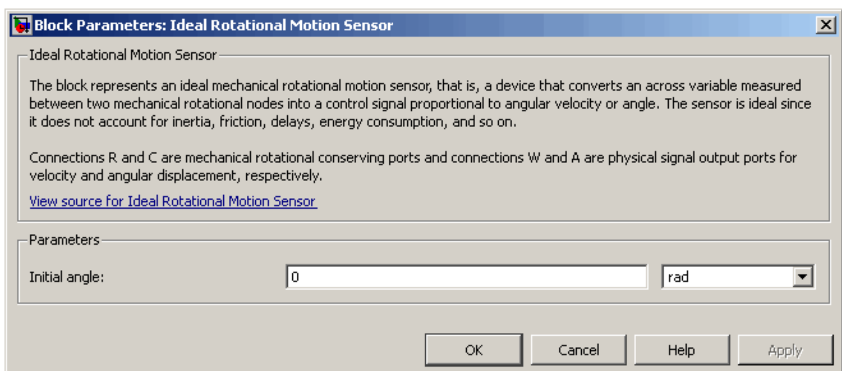
The Ideal Rotational Motion Sensor block represents an ideal mechanical rotational motion sensor, that is, a device that converts an across variable measured between two mechanical rotational nodes into a control signal proportional to angular velocity or angle. You can specify the initial angular position (offset) as a block parameter.

The sensor is ideal since it does not account for inertia, friction, delays, energy consumption, and so on.

Connections R and C are mechanical rotational conserving ports that connect the block to the nodes whose motion is being monitored. Connections W and A are physical signal output ports for velocity and angular displacement, respectively.

The block positive direction is from port R to port C. This means that the velocity is measured as $\omega = \omega_R - \omega_C$, where ω_R, ω_C are the absolute angular velocities at ports R and C, respectively.

Dialog Box and Parameters



Initial angle

Sensor initial angle, or offset (rad). The default value is 0.

Ports

The block has the following ports:

`R`
: Mechanical rotational conserving port associated with the sensor positive probe.

`C`
: Mechanical rotational conserving port associated with the sensor negative (reference) probe.

`W`
: Physical signal output port for angular velocity.

`A`
: Physical signal output port for angular displacement.

See Also

Ideal Force Sensor

Ideal Torque Sensor

Ideal Translational Motion Sensor

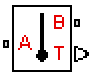
Purpose

Simulate ideal temperature sensor

Library

Thermal Sensors

Description

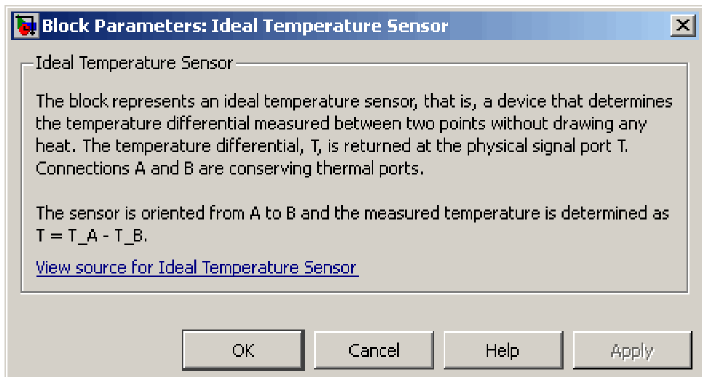


The Ideal Temperature Sensor block represents an ideal temperature sensor, that is, a device that determines the temperature differential measured between two points without drawing any heat.

Connections A and B are thermal conserving ports that connect to the two points where temperature is being monitored. Port T is a physical signal port that outputs the temperature differential value.

The block positive direction is from port A to port B. The measured temperature is determined as $T = T_A - T_B$.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A
: Thermal conserving port associated with the sensor positive probe.

B
: Thermal conserving port associated with the sensor negative probe.

T

Physical signal output port for temperature.

See Also

Ideal Heat Flow Sensor

Ideal Heat Flow Source

Ideal Temperature Source

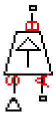
Purpose

Simulate ideal source of thermal energy, characterized by temperature

Library

Thermal Sources

Description

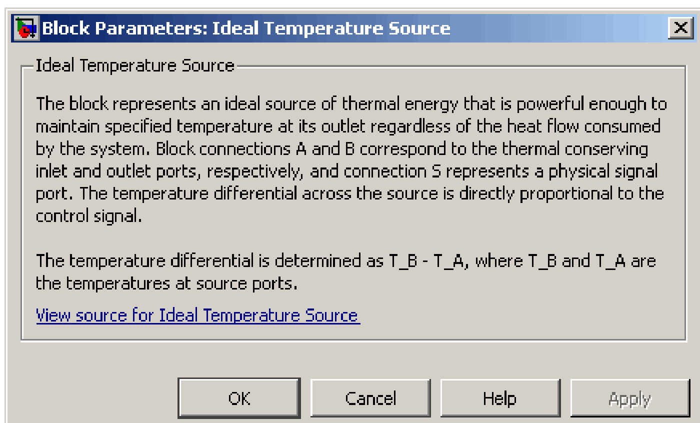


The Ideal Temperature Source block represents an ideal source of thermal energy that is powerful enough to maintain specified temperature at its outlet regardless of the heat flow consumed by the system.

Connections A and B are thermal conserving ports corresponding to the source inlet and outlet, respectively. Port S is a physical signal port, through which the control signal that drives the source is applied. You can use the entire variety of Simulink signal sources to generate the desired heat flow variation profile. The temperature differential across the source is directly proportional to the signal at the control port S.

The block positive direction is from port A to port B. This means that the temperature differential is determined as $T_B - T_A$, where T_B and T_A are the temperatures at source ports.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A
: Thermal conserving port associated with the source inlet.

B
: Thermal conserving port associated with the source outlet.

S
: Physical signal input port, through which the control signal that drives the source is applied.

See Also

Ideal Heat Flow Sensor

Ideal Heat Flow Source

Ideal Temperature Sensor

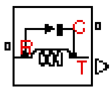
Purpose

Simulate torque sensor in mechanical rotational systems

Library

Mechanical Sensors

Description

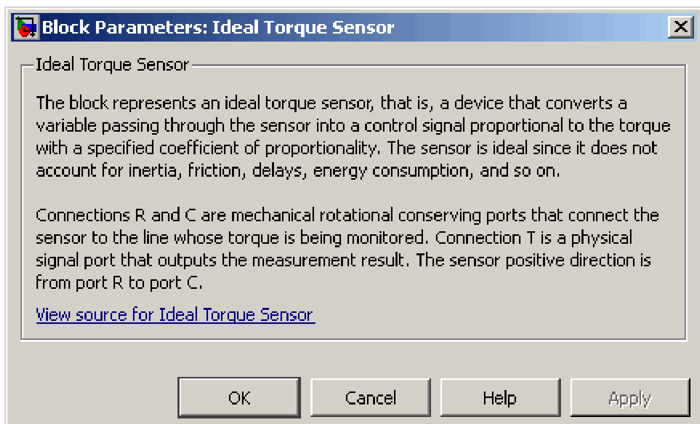


The Ideal Torque Sensor block represents a device that converts a variable passing through the sensor into a control signal proportional to the torque. The sensor is ideal since it does not account for inertia, friction, delays, energy consumption, and so on.

Connections R and C are mechanical rotational conserving ports that connect the block to the line where torque is being monitored. Connection T is a physical signal port that outputs the measurement result.

The block positive direction is from port R to port C.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

R
: Mechanical rotational conserving port associated with the sensor positive probe.

`C`

Mechanical rotational conserving port associated with the sensor negative (reference) probe.

`T`

Physical signal output port for torque.

See Also

Ideal Force Sensor

Ideal Rotational Motion Sensor

Ideal Translational Motion Sensor

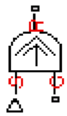
Purpose

Simulate ideal source of mechanical energy that generates torque proportional to the input signal

Library

Mechanical Sources

Description

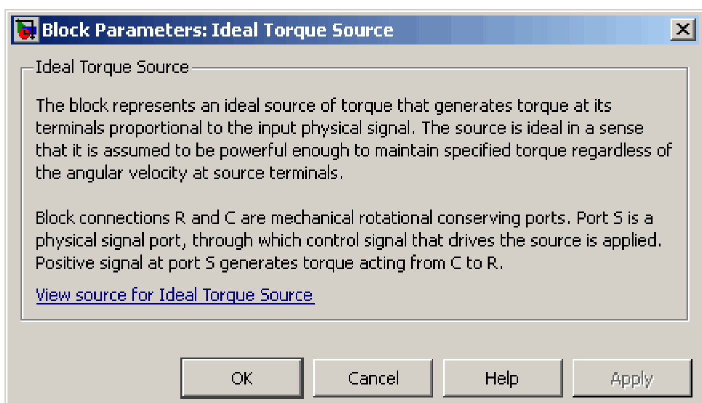


The Ideal Torque Source block represents an ideal source of mechanical energy that generates torque proportional to the input physical signal. The source is ideal in a sense that it is assumed to be powerful enough to maintain specified torque regardless of the angular velocity at source terminals.

Connections R and C are mechanical rotational conserving ports. Port S is a physical signal port, through which the control signal that drives the source is applied. You can use the entire variety of Simulink signal sources to generate the desired torque variation profile. Positive signal at port S generates torque acting from C to R. The torque generated by the source is directly proportional to the signal at the control port S.

The block positive direction is from port C to port R. This means that the torque is positive if it acts in the direction from C to R. The relative velocity is determined as $\omega = \omega_R - \omega_C$, where ω_R, ω_C are the absolute angular velocities at ports R and C, respectively, and it is negative if velocity at port R is greater than that at port C. The power generated by the source is negative if the source delivers energy to port R.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

R
: Mechanical rotational conserving port.

C
: Mechanical rotational conserving port associated with the source reference point (case).

S
: Physical signal input port, through which the control signal that drives the source is applied.

See Also

Ideal Angular Velocity Source

Ideal Force Source

Ideal Translational Velocity Source

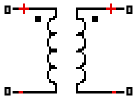
Purpose

Simulate ideal transformer in electrical systems

Library

Electrical Elements

Description



The Ideal Transformer block models an ideal power-conserving transformer, described with the following equations:

$$V1 = N \bullet V2$$

$$I2 = N \bullet I1$$

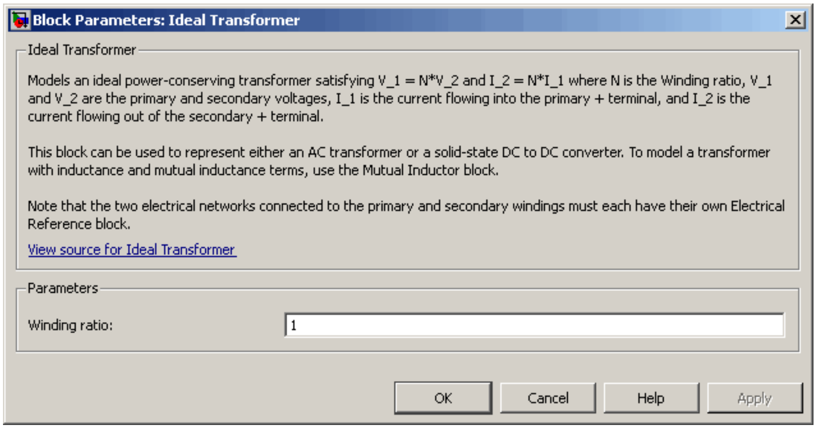
where

V1	Primary voltage
V2	Secondary voltage
I1	Current flowing into the primary + terminal
I2	Current flowing out of the secondary + terminal
N	Winding ratio

This block can be used to represent either an AC transformer or a solid-state DC to DC converter. To model a transformer with inductance and mutual inductance terms, use the Mutual Inductor block.

The two electrical networks connected to the primary and secondary windings must each have their own Electrical Reference block.

Dialog Box and Parameters



Winding ratio

Winding ratio of the transformer, or ratio of primary coil turns to secondary coil turns. The default value is 1.

Ports

The block has four electrical conserving ports. Polarity is indicated by the + and – signs.

See Also

Mutual Inductor

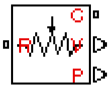
Purpose

Simulate motion sensor in mechanical translational systems

Library

Mechanical Sensors

Description



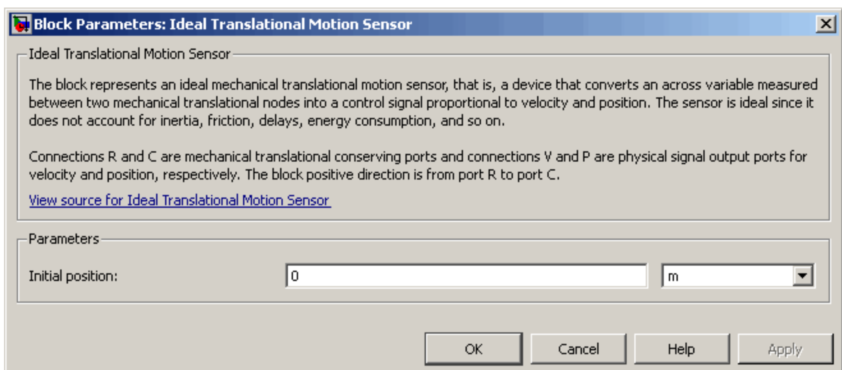
The Ideal Translational Motion Sensor block represents a device that converts an across variable measured between two mechanical translational nodes into a control signal proportional to velocity or position. You can specify the initial position (offset) as a block parameter.

The sensor is ideal since it does not account for inertia, friction, delays, energy consumption, and so on.

Connections R and C are mechanical translational conserving ports that connect the block to the nodes whose motion is being monitored. Connections V and P are physical signal output ports for velocity and position, respectively.

The block positive direction is from port R to port C. This means that the velocity is measured as $v = v_R - v_C$, where v_R,v_C are the absolute velocities at ports R and C, respectively.

Dialog Box and Parameters



Initial position

Sensor initial position, or offset (m). The default value is `0`.

Ports

The block has the following ports:

`R`
: Mechanical translational conserving port associated with the sensor positive probe.

`C`
: Mechanical translational conserving port associated with the sensor negative (reference) probe.

`V`
: Physical signal output port for velocity.

`P`
: Physical signal output port for position.

See Also

Ideal Force Sensor

Ideal Rotational Motion Sensor

Ideal Torque Sensor

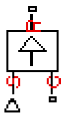
Purpose

Simulate ideal velocity source in mechanical translational systems

Library

Mechanical Sources

Description

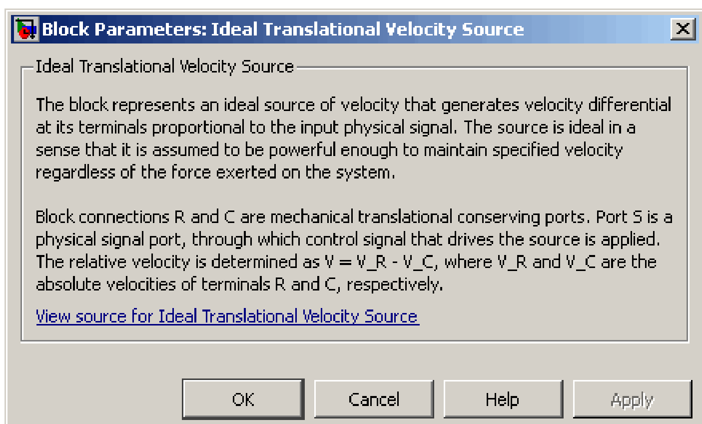


The Ideal Translational Velocity Source block represents an ideal source of velocity that generates velocity differential at its terminals proportional to the input physical signal. The source is ideal in a sense that it is assumed to be powerful enough to maintain specified velocity regardless of the force exerted on the system.

Connections R and C are mechanical translational conserving ports. Port S is a physical signal port, through which the control signal that drives the source is applied. The relative velocity (velocity differential) across the source is directly proportional to the signal at the control port S. The entire variety of Simulink signal sources can be used to generate the desired velocity variation profile.

The block positive direction is from port R to port C. This means that the velocity is measured as $v = v_R - v_C$, where v_R, v_C are the absolute velocities at ports R and C, respectively, and force through the source is negative if it is acts from C to R. The power generated by the source is negative if the source delivers energy to port R.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

R
: Mechanical translational conserving port.

C
: Mechanical translational conserving port associated with the source reference point (case).

S
: Physical signal input port, through which the control signal that drives the source is applied.

See Also

Ideal Angular Velocity Source

Ideal Force Source

Ideal Torque Source

Purpose

Simulate linear inductor in electrical systems

Library

Electrical Elements

Description

The Inductor block models a linear inductor, described with the following equation:

$$V = L\frac{dI}{dt}$$

where

I	Current
V	Voltage
L	Inductance
t	Time

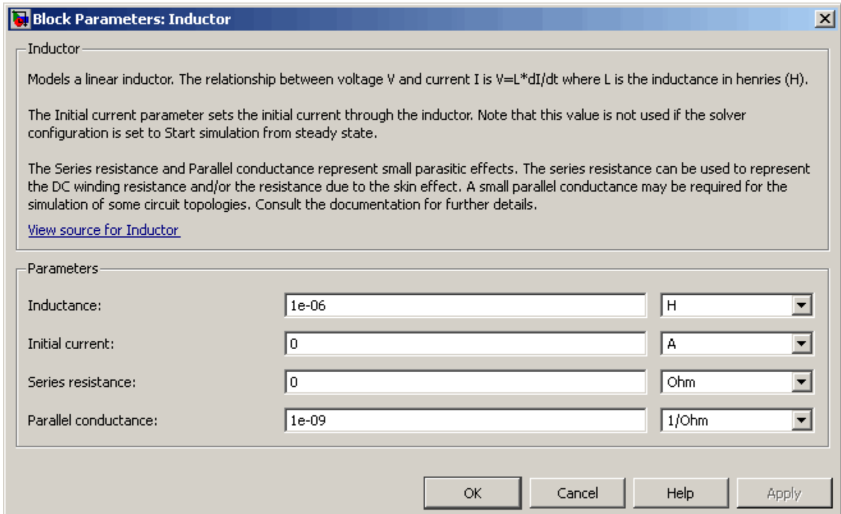
The **Initial current** parameter sets the initial current through the inductor.

Note This value is not used if the solver configuration is set to **Start simulation from steady state**.

The **Series resistance** and **Parallel conductance** parameters represent small parasitic effects. The series resistance can be used to represent the DC winding resistance or the resistance due to the skin effect. Simulation of some circuits may require the presence of a small parallel conductance. For more information, see “Modeling Best Practices” in the Simscape User’s Guide.

Connections + and – are conserving electrical ports corresponding to the positive and negative terminals of the inductor, respectively. The current is positive if it flows from positive to negative, and the voltage across the inductor is equal to the difference between the voltage at the positive and the negative terminal, $V(+) - V(-)$.

Dialog Box and Parameters



Inductance
Inductance, in henries. The default value is `1` μH.

Initial current
Initial current through the inductor. This parameter is not used if the solver configuration is set to **Start simulation from steady state**. The default value is `0`.

Series resistance
Represents small parasitic effects. The series resistance can be used to represent the DC winding resistance. The default value is `0`.

Parallel conductance
Represents small parasitic effects. The parallel conductance across the inductor can be used to model insulation conductance. Simulation of some circuits may require the presence of a small parallel conductance. The default value is `1e-9` 1/Ω.

Ports

The block has the following ports:

+
: Electrical conserving port associated with the inductor positive terminal.

-
: Electrical conserving port associated with the inductor negative terminal.

Inertia

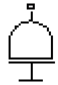
Purpose

Simulate inertia in mechanical rotational systems

Library

Mechanical Rotational Elements

Description



The Inertia block represents an ideal mechanical rotational inertia, described with the following equation:

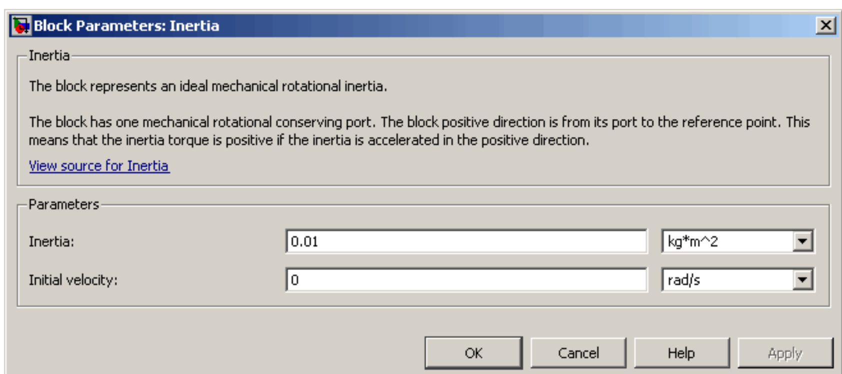
$$T = J \frac{d\omega}{dt}$$

where

T	Inertia torque
J	Inertia
ω	Angular velocity
t	Time

The block has one mechanical rotational conserving port. The block positive direction is from its port to the reference point. This means that the inertia torque is positive if inertia is accelerated in positive direction.

Dialog Box and Parameters



Inertia

Inertia. The default value is 0.001 kg*m^2.

Initial velocity

Initial angular velocity of the inertia. This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is 0.

Ports

The block has one mechanical rotational conserving port, associated with the inertia connection to the system.

See Also

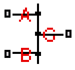
Mass

Lever

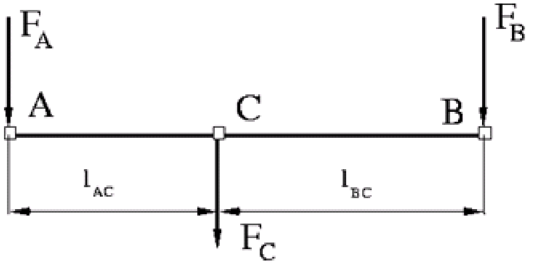
Purpose Simulate lever in mechanical systems

Library Mechanisms

Description



The Lever block represents a mechanical lever in its generic form, known as a free or summing lever, shown in the following schematic.



The summing lever equations are derived with the assumption of small angle deviation from initial position:

$$v_C = K_{AC} \cdot v_A + K_{BC} \cdot v_B$$

$$F_A = K_{AC} \cdot F_C$$

$$F_B = K_{BC} \cdot F_C$$

$$K_{AC} = \frac{l_{BC}}{l_{AC} + l_{BC}}$$

$$K_{BC} = \frac{l_{AC}}{l_{AC} + l_{BC}}$$

where

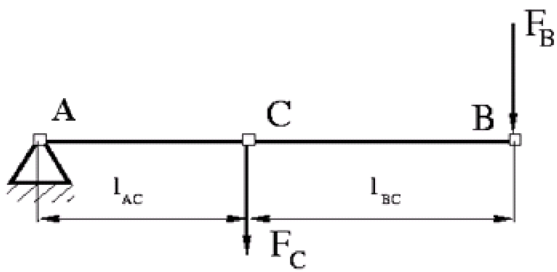
v_A, v_B, v_C Lever joints velocities

F_A, F_B, F_C Lever joints forces

l_{AC}, l_{BC} Arm lengths

The above equations were derived with the assumption that the lever sums forces and motions at node C. The assumption was arbitrary and does not impose any limitations on how the forces or motions are applied to the lever. In other words, any of the lever nodes can be "input" or "output" nodes, depending on the value of the force. Moreover, any of the block nodes can be connected to the reference point, thus converting a three-node lever into a first-class lever, with the fulcrum at the end, or a second-class lever, with the fulcrum in the middle.

The following illustration shows a schematic of a two-node first-class lever, with the fulcrum at node A.

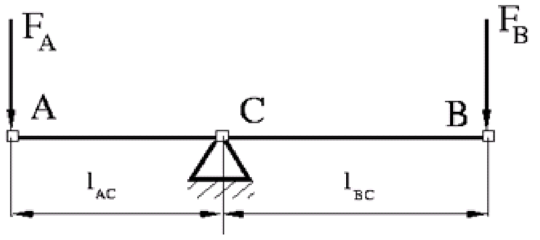


It is described with the following equations:

$$v_C = K_{BC} \cdot v_B$$

$$F_B = K_{BC} \cdot F_C$$

The next illustration shows a schematic of a second-class lever, with the fulcrum in the middle.



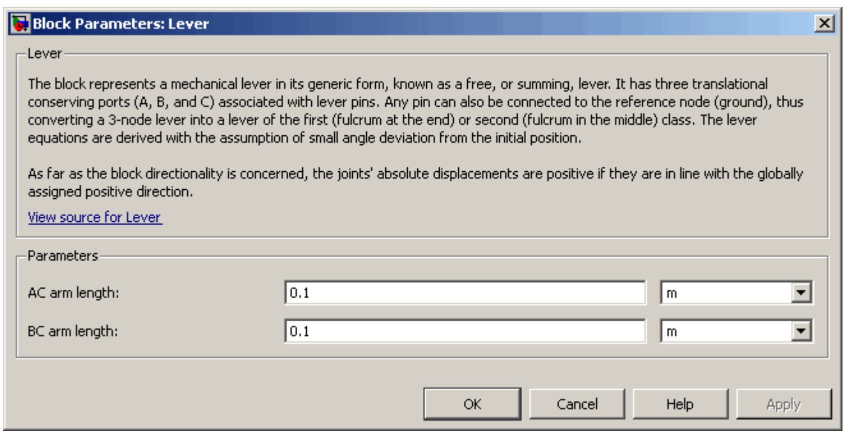
It is described with the following equations:

$$v_A = -\frac{l_{AC}}{l_{BC}} \cdot v_B$$

$$F_B = -\frac{l_{AC}}{l_{BC}} \cdot F_A$$

As far as the block directionality is concerned, the joints' absolute displacements are positive if they are in line with the globally assigned positive direction.

Dialog Box and Parameters



AC arm length
Arm length between nodes A and C. The default value is `0.1` m.

BC arm length
Arm length between nodes B and C. The default value is `0.1` m.

Ports

The block has the following ports:

A
Mechanical translational conserving port associated with the node A of the lever.

B
Mechanical translational conserving port associated with the node B of the lever.

C
Mechanical translational conserving port associated with the node C of the lever.

Examples

The Linkage Mechanism demo (`ssc_linkage_mechanism`) illustrates the use of the Lever block in three different modes. Linkages L_1 and L_4 simulate first-class levers with the fulcrum at the end. Linkage L_2 represents a summing lever. Linkage L_3 simulates a second-class lever with the fulcrum in the middle.

Linear Hydraulic Resistance

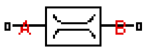
Purpose

Simulate hydraulic pipeline with linear resistance losses

Library

Hydraulic Elements

Description

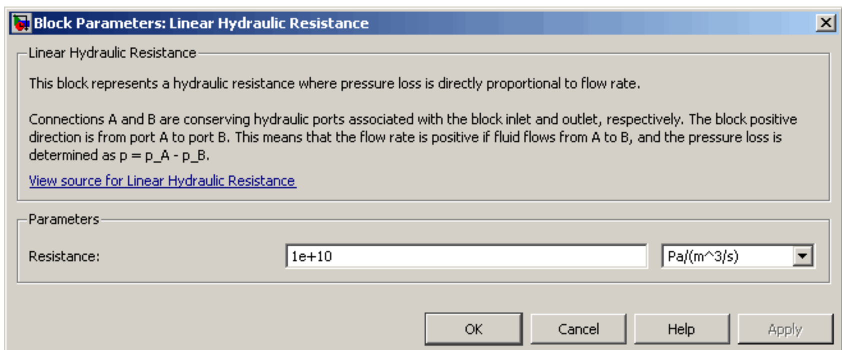


The Linear Hydraulic Resistance block represents a hydraulic resistance where pressure loss is directly proportional to flow rate. This block can be useful at preliminary stages of development, or as a powerful means to speed up the simulation, especially if the flow rate varies insignificantly with respect to the operating point.

Connections A and B are conserving hydraulic ports associated with the block inlet and outlet, respectively.

The block positive direction is from port A to port B. This means that the flow rate is positive if fluid flows from A to B, and the pressure loss is determined as $p = p_A - p_B$.

Dialog Box and Parameters



Resistance
: The linear resistance coefficient. The default value is `10e9` Pa/(m^3/s).

Ports

The block has the following ports:

A
: Hydraulic conserving port associated with the resistance inlet.

B

Hydraulic conserving port associated with the resistance outlet.

See Also

Hydraulic Resistive Tube

Magnetic Reference

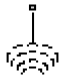
Purpose

Simulate reference for magnetic ports

Library

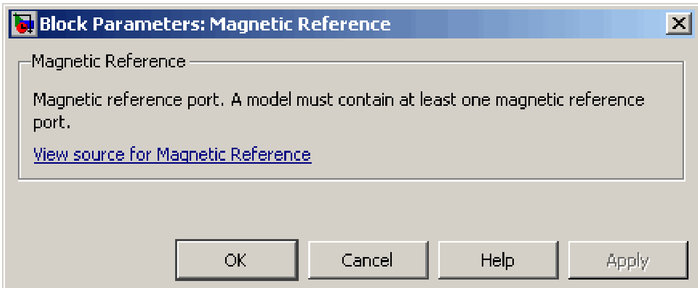
Magnetic Elements

Description



The Magnetic Reference block represents a reference point for all magnetic conserving ports. A model with magnetic elements must contain at least one Magnetic Reference block.

Dialog Box and Parameters



The Magnetic Reference block has no parameters.

Ports

The block has one magnetic conserving port.

See Also

Electrical Reference

Hydraulic Reference

Mechanical Rotational Reference

Mechanical Translational Reference

Thermal Reference

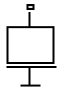
Purpose

Simulate mass in mechanical translational systems

Library

Mechanical Translational Elements

Description



The Mass block represents an ideal mechanical translational mass, described with the following equation:

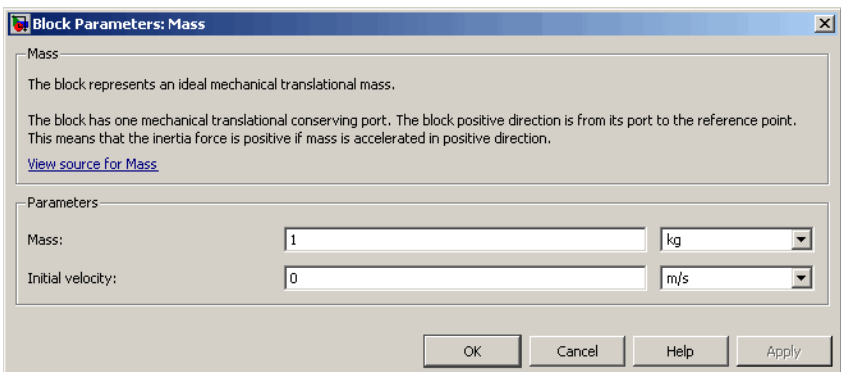
$$F = m\frac{dv}{dt}$$

where

F	Inertia force
m	Mass
v	Velocity
t	Time

The block has one mechanical translational conserving port. The block positive direction is from its port to the reference point. This means that the inertia force is positive if mass is accelerated in positive direction.

Dialog Box and Parameters



Mass

Mass. The default value is 1 kg.

Initial velocity

Initial velocity of the mass. This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is 0.

Ports

The block has one mechanical translational conserving port, associated with the mass connection to the system.

See Also

Inertia

Purpose

Simulate reference for mechanical rotational ports

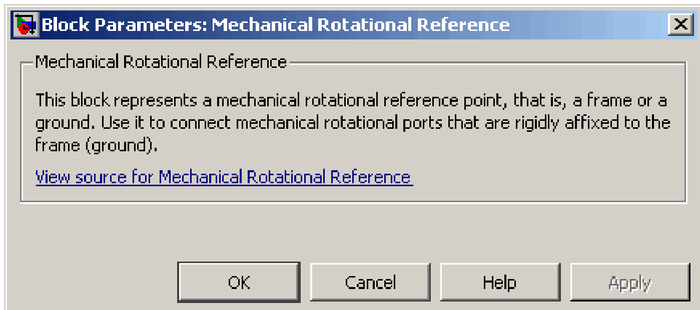
Library

Mechanical Rotational Elements

Description

The Mechanical Rotational Reference block represents a reference point, or frame, for all mechanical rotational ports. All rotational ports that are rigidly clamped to the frame (ground) must be connected to a Mechanical Rotational Reference block.

Dialog Box and Parameters



The Mechanical Rotational Reference block has no parameters.

Ports

The block has one mechanical rotational port.

See Also

Electrical Reference

Hydraulic Reference

Mechanical Translational Reference

Thermal Reference

Mechanical Translational Reference

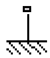
Purpose

Simulate reference for mechanical translational ports

Library

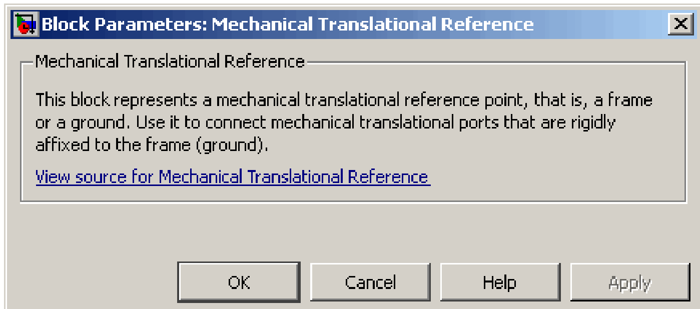
Mechanical Translational Elements

Description



The Mechanical Translational Reference block represents a reference point, or frame, for all mechanical translational ports. All translational ports that are rigidly clamped to the frame (ground) must be connected to a Mechanical Translational Reference block.

Dialog Box and Parameters



The Mechanical Translational Reference block has no parameters.

Ports

The block has one mechanical translational port.

See Also

Electrical Reference

Hydraulic Reference

Mechanical Rotational Reference

Thermal Reference

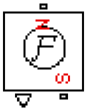
Purpose

Simulate ideal magnetomotive force sensor

Library

Magnetic Sensors

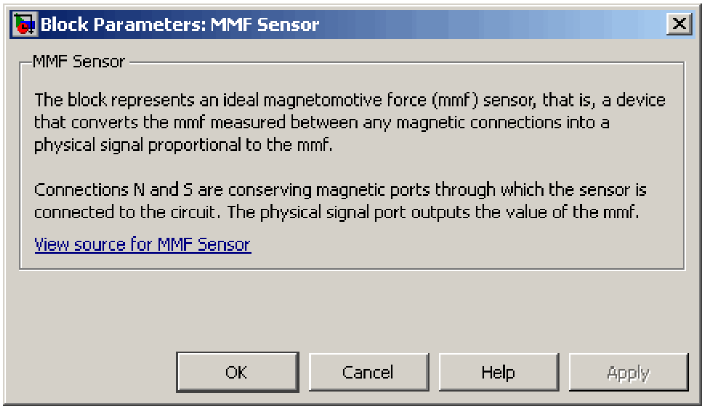
Description



The MMF Sensor block represents an ideal magnetomotive force (mmf) sensor, that is, a device that converts the mmf measured between any magnetic connections into a physical signal proportional to the mmf.

Connections N and S are conserving magnetic ports through which the sensor is connected to the circuit. The physical signal port outputs the value of the mmf.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

`N`
: Magnetic conserving port associated with the sensor North terminal.

`S`
: Magnetic conserving port associated with the sensor South terminal.

The block also has a physical signal output port, which outputs the value of the mmf.

See Also

Controlled MMF Source

MMF Source

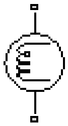
Purpose

Simulate ideal magnetomotive force source

Library

Magnetic Sources

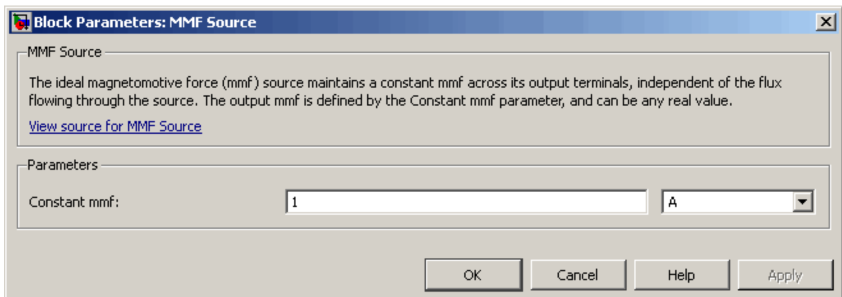
Description



The MMF Source block represents an ideal magnetomotive force (mmf) source that is powerful enough to maintain specified constant mmf across its output terminals, regardless of the flux flowing through the source.

You specify the output mmf by using the **Constant mmf** parameter, which can be positive, negative, or zero.

Dialog Box and Parameters



Constant mmf

Output mmf. You can specify any real value. The default value is 1 A.

Ports

The block has two magnetic conserving ports associated with its terminals.

See Also

Controlled Flux Source

Controlled MMF Source

Flux Source

Mutual Inductor

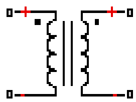
Purpose

Simulate mutual inductor in electrical systems

Library

Electrical Elements

Description



The Mutual Inductor block models a mutual inductor, described with the following equations:

$$V1 = L1\frac{dI1}{dt} + M\frac{dI2}{dt}$$

$$V2 = L2\frac{dI2}{dt} + M\frac{dI1}{dt}$$

$$M = k\sqrt{L1 \bullet L2}$$

where

V1	Voltage across winding 1
V2	Voltage across winding 2
I1	Current flowing into the + terminal of winding 1
I2	Current flowing into the + terminal of winding 2
L1, *L2*	Winding self-inductances
M	Mutual inductance
k	Coefficient of coupling, $0 < k < 1$
t	Time

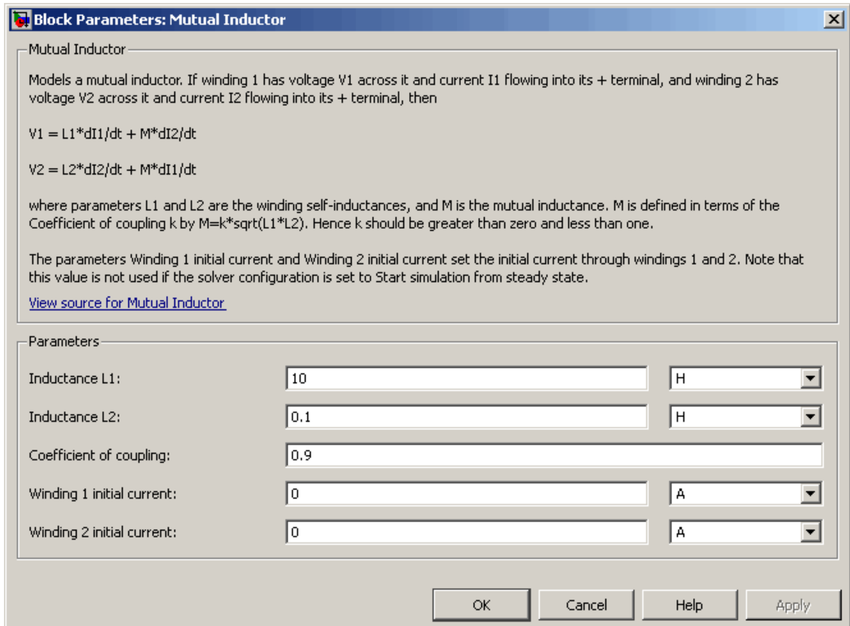
The **Winding 1 initial current** and **Winding 2 initial current** parameters set the initial current through windings 1 and 2.

Note These values are not used if the solver configuration is set to **Start simulation from steady state**.

This block can be used to represent an AC transformer. If inductance and mutual inductance terms are not important in a model, or are unknown, you can use the Ideal Transformer block instead.

The two electrical networks connected to the primary and secondary windings must each have their own Electrical Reference block.

Dialog Box and Parameters



Inductance L1
: Self-inductance of the first winding. The default value is `10` H.

Inductance L2
: Self-inductance of the second winding. The default value is `0.1` H.

Coefficient of coupling
: Coefficient of coupling, which defines the mutual inductance. The parameter value should be greater than zero and less than 1. The default value is `0.9`.

Winding 1 initial current
Initial current through the first winding. This parameter is not used if the solver configuration is set to **Start simulation from steady state**. The default value is `0`.

Winding 2 initial current
Initial current through the second winding. This parameter is not used if the solver configuration is set to **Start simulation from steady state**. The default value is `0`.

Ports

The block has four electrical conserving ports. Polarity is indicated by the + and – signs.

See Also

Ideal Transformer

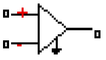
Purpose

Simulate ideal operational amplifier

Library

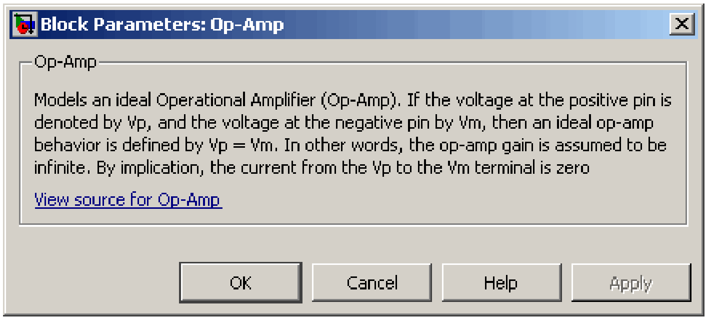
Electrical Elements

Description



The Op-Amp block models an ideal operational amplifier (op-amp). If the voltage at the positive pin is denoted by *Vp*, and the voltage at the negative pin by *Vm*, then an ideal op-amp behavior is defined by *Vp* = *Vm*. In other words, the op-amp gain is assumed to be infinite. By implication, the current from the Vp to the Vm terminal is zero.

Dialog Box and Parameters



The Op-Amp block has no parameters.

Ports

The block has three electrical conserving ports.

Pneumatic Absolute Reference

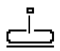
Purpose

Simulate reference to zero absolute pressure and temperature for pneumatic ports

Library

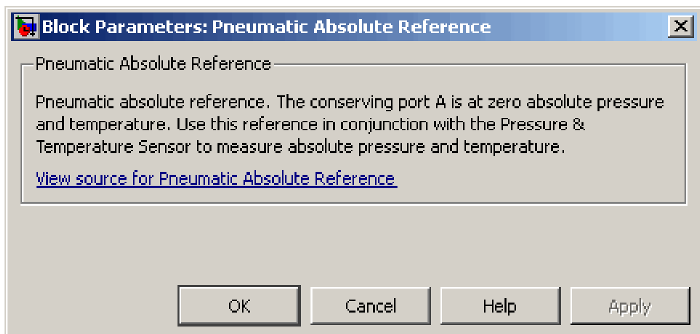
Pneumatic Elements

Description



The Pneumatic Absolute Reference block provides a pneumatic reference port at zero absolute pressure and temperature. Use this block with the Pneumatic Pressure & Temperature Sensor block to create Physical Signals corresponding to absolute pressure and temperature.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has one pneumatic conserving port, which is at zero absolute pressure and temperature.

See Also

Pneumatic Atmospheric Reference

Pneumatic Pressure & Temperature Sensor

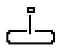
Purpose

Simulate reference to ambient pressure and temperature for pneumatic ports

Library

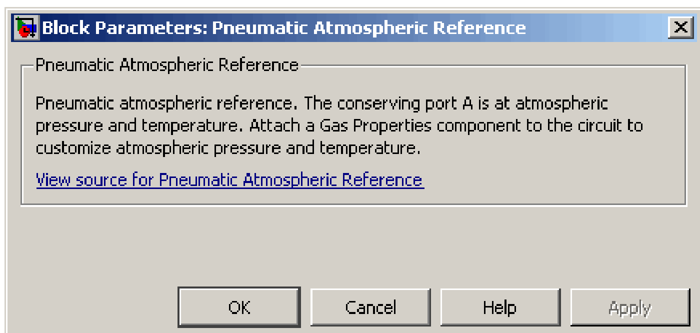
Pneumatic Elements

Description



The Pneumatic Atmospheric Reference block provides a pneumatic reference port with pressure and temperature values set to the ambient temperature and pressure. The Gas Properties block, if present, specifies the values for ambient temperature and pressure for all pneumatic blocks in the circuit. If a pneumatic circuit does not contain a Gas Properties block, ambient temperature and pressure are set to default values of 293.15 K and 101,325 Pa. Use the Pneumatic Atmospheric Reference block with the Pneumatic Pressure Source block to model an ideal pressure source that takes atmospheric air, and increases the pressure by a constant amount.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has one pneumatic conserving port.

See Also

Gas Properties

Pneumatic Absolute Reference

Pneumatic Pressure Source

Pneumatic Flow Rate Source

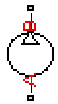
Purpose

Simulate ideal compressor with constant mass flow rate

Library

Pneumatic Sources

Description



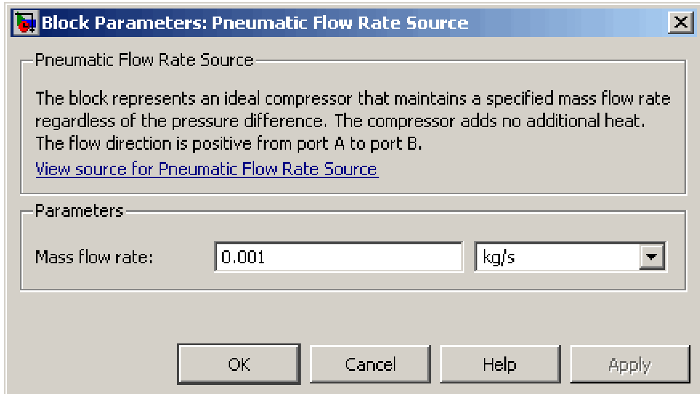
The Pneumatic Flow Rate Source block represents an ideal compressor that maintains a specified mass flow rate regardless of the pressure difference. Use this block when delivery of an actual device is practically independent of the source pressure, for example, in positive displacement compressors. The compressor adds no heat. Block connections A and B correspond to the pneumatic inlet and outlet ports, respectively.

The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B. The pressure differential is determined as $p = p_A - p_B$ and is negative if pressure at the source outlet is greater than pressure at its inlet. The power generated by the source is negative if the source adds energy to the flow.

Warning

Be careful when driving an orifice directly from a flow rate source. The choked flow condition limits the flow that is possible through an orifice as a function of upstream pressure and temperature. Hence the flow rate value produced by the flow rate source must be compatible with upstream pressure and temperature. Specifying a flow rate that is too high will result in an unsolvable set of equations.

Dialog Box and Parameters



Mass flow rate

Specify the mass flow rate of the source. The default value is `0.001` kg/s.

Ports

The block has the following ports:

A

Pneumatic conserving port associated with the source inlet.

B

Pneumatic conserving port associated with the source outlet.

See Also

Controlled Pneumatic Flow Rate Source

Pneumatic Mass & Heat Flow Sensor

Pneumatic Mass & Heat Flow Sensor

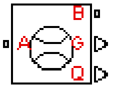
Purpose

Simulate ideal mass flow and heat flow sensor

Library

Pneumatic Sensors

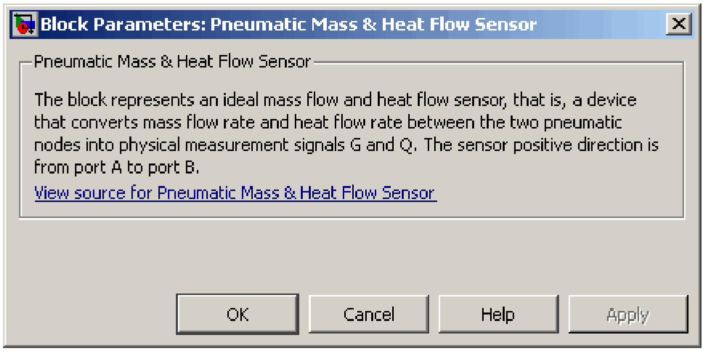
Description



The Pneumatic Mass & Heat Flow Sensor block represents an ideal mass flow and heat flow sensor, that is, a device that converts mass flow rate and heat flow rate between the two pneumatic nodes into physical measurement signals G and Q, respectively.

The sensor positive direction is from port A to port B.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A
: Pneumatic conserving port associated with the sensor inlet.

B
: Pneumatic conserving port associated with the sensor outlet.

See Also

Controlled Pneumatic Flow Rate Source

Pneumatic Flow Rate Source

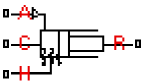
Purpose

Simulate translational pneumatic piston chamber based on ideal gas law

Library

Pneumatic Elements

Description



The Pneumatic Piston Chamber block models a pneumatic piston chamber based on the ideal gas law and assuming constant specific heats. Use this model as a building block for pneumatic translational actuators. The piston can exert force in one direction only, and the direction is set by the **Chamber orientation** parameter.

The continuity equation for the network representation of the piston chamber is

$$G = \frac{V_0 + A \bullet x}{RT}\left(\frac{dp}{dt} - \frac{p}{T}\frac{dT}{dt}\right) + \frac{A}{RT} \bullet p \bullet \frac{dx}{dt}$$

where

G	Mass flow rate at input port
V_0	Initial chamber volume
A	Piston effective area
x	Piston displacement
p	Absolute pressure in the chamber
R	Specific gas constant
T	Absolute gas temperature
t	Time

The energy equation is

$$q = \frac{c_v}{R}(V_0 + A \bullet x)\frac{dp}{dt} + \frac{c_p \bullet A}{R} p \frac{dx}{dt} - q_w$$

where

q	Heat flow due to gas inflow in the chamber (through the pneumatic port)
q_w	Heat flow through the chamber walls (through the thermal port)
c_v	Specific heat at constant volume
c_p	Specific heat at constant pressure

The force equation is

$$F = (p - p_a) \cdot A$$

where p_a is the atmospheric pressure acting on the outside of the piston.

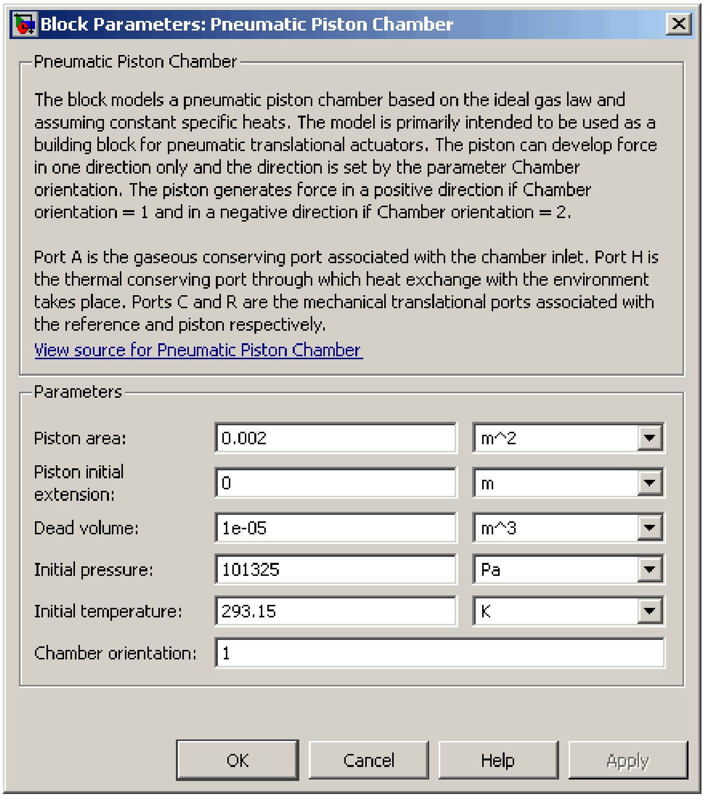
Port A is the pneumatic conserving port associated with the chamber inlet. Port H is a thermal conserving port through which heat exchange with the environment takes place. Ports C and R are mechanical translational conserving ports associated with the piston case and rod, respectively. The gas flow and the heat flow are considered positive if they flow into the chamber.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The gas is ideal.
- Specific heats at constant pressure and constant volume, c_p and c_v, are constant.

Dialog Box and Parameters



Piston area

Specify the effective piston area. The default value is `.002` m^2.

Piston initial extension

Specify the initial offset of the piston from the cylinder cap. The default value is `0`.

Dead volume

Specify the volume of gas in the chamber at zero piston position. The default value is `1e-5` m^3.

Initial pressure
: Specify the initial pressure in the chamber. This parameter specifies the initial condition for use in computing the initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `101235` Pa.

Initial temperature
: Specify the initial temperature of the gas in the chamber. This parameter specifies the initial condition for use in computing the initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `293.15` K.

Chamber orientation
: Specify the direction of force generation. The piston generates force in a positive direction if this parameter is set to `1` (the default). If you set this parameter to `2`, the piston generates force in a negative direction.

Ports

The block has the following ports:

`A`
: Pneumatic conserving port associated with the chamber inlet.

`H`
: Thermal conserving port through which heat exchange with the environment takes place.

`R`
: Mechanical translational conserving port associated with the piston (rod).

`C`
: Mechanical translational conserving port associated with the reference (case).

See Also

Constant Volume Pneumatic Chamber

Rotary Pneumatic Piston Chamber

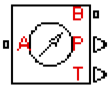
Purpose

Simulate ideal pressure and temperature sensor

Library

Pneumatic Sensors

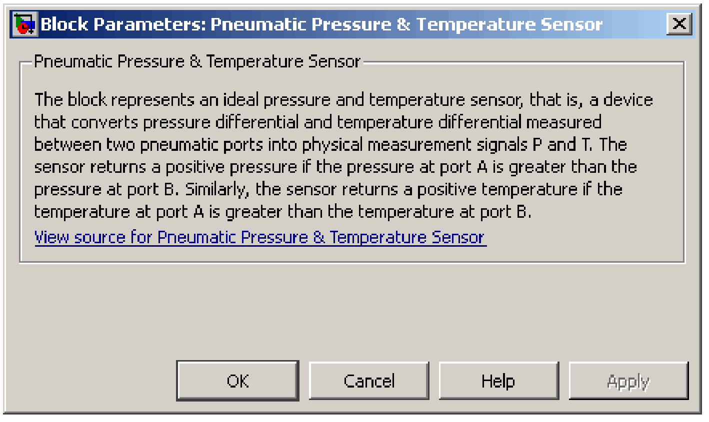
Description



The Pneumatic Pressure & Temperature Sensor block represents an ideal pressure and temperature sensor, that is, a device that converts pressure differential and temperature differential measured between two pneumatic ports into physical measurement signals P and T, respectively.

The sensor positive direction is from port A to port B. This means that the sensor returns a positive pressure if the pressure at port A is greater than the pressure at port B. Similarly, the sensor returns a positive temperature if the temperature at port A is greater than the temperature at port B.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

A

Pneumatic conserving port associated with the sensor inlet.

B

Pneumatic conserving port associated with the sensor outlet.

See Also

Controlled Pneumatic Pressure Source

Pneumatic Pressure Source

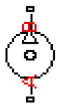
Purpose

Simulate ideal compressor with constant pressure difference

Library

Pneumatic Sources

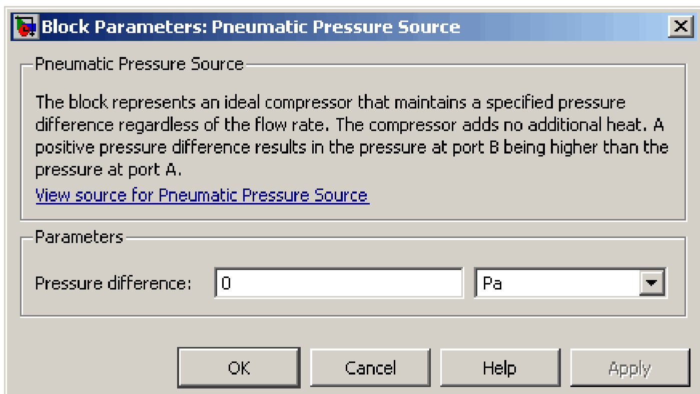
Description



The Pneumatic Pressure Source block represents an ideal compressor that maintains a specified pressure difference regardless of the flow rate. Use this block when pressure of an actual device is practically independent of the source flow rate, for example, in factory network outlets or large capacity receivers. The compressor adds no heat. Block connections A and B correspond to the pneumatic inlet and outlet ports, respectively.

A positive pressure difference results in the pressure at port B being higher than the pressure at port A.

Dialog Box and Parameters



Pressure difference

Specify the pressure difference across the source. The default value is `0`.

Ports

The block has the following ports:

A

Pneumatic conserving port associated with the source inlet.

B

Pneumatic conserving port associated with the source outlet.

See Also

Controlled Pneumatic Pressure Source

Pneumatic Pressure & Temperature Sensor

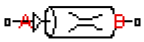
Purpose

Simulate pressure loss and added heat due to flow resistance in pneumatic pipe

Library

Pneumatic Elements

Description



The Pneumatic Resistive Tube block models the loss in pressure and heating due to viscous friction along a short stretch of pipe with circular cross section. Use this block with the Constant Volume Pneumatic Chamber block to build a model of a pneumatic transmission line.

The tube is simulated according to the following equations:

$$p_i - p_o = \begin{cases} \dfrac{RT_i}{p_i} \cdot \dfrac{32\mu L}{AD^2} \cdot G & \text{for } Re < Re_{lam} \text{ (laminar flow)} \\ f \cdot \dfrac{RT_i}{p_i} \cdot \dfrac{L}{D} \cdot \dfrac{G^2}{2A^2} & \text{for } Re > Re_{turb} \text{ (turbulent flow)} \end{cases}$$

where

p_i, p_o	Absolute pressures at the tube inlet and outlet, respectively. The inlet and outlet change depending on flow direction. For positive flow ($G > 0$), $p_i = p_A$, otherwise $p_i = p_B$.
T_i, T_o	Absolute gas temperatures at the tube inlet and outlet, respectively
G	Mass flow rate
μ	Gas viscosity
f	Friction factor for turbulent flow
D	Tube internal diameter
A	Tube cross-sectional area
L	Tube length
Re	Reynolds number

The friction factor for turbulent flow is approximated by the Haarland function

$$f = \left(-1.8 \log_{10} \left(\frac{6.9}{\mathrm{Re}} + \left(\frac{e}{3.7D} \right)^{1.11} \right) \right)^{-2}$$

where e is the surface roughness for the pipe material.

The Reynolds number is defined as:

$$\mathrm{Re} = \rho v D / \mu$$

where ρ is the gas density and v is the gas velocity. Gas velocity is related to mass flow rate by

$$G = \rho v A$$

For flows between Re_{lam} and Re_{turb}, a linear blend is implemented between the flow predicted by the two equations.

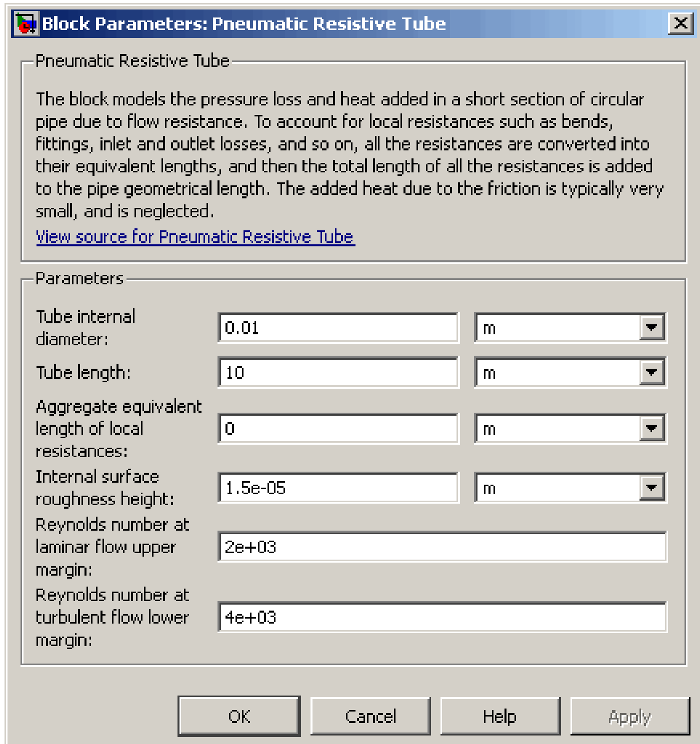
In a real pipe, loss in kinetic energy due to friction is turned into added heat energy. However, the amount of heat is very small, and is neglected in the Pneumatic Resistive Tube block. Therefore, $q_i = q_o$, where q_i and q_o are the input and output heat flows, respectively.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The gas is ideal.
- The pipe has a circular cross section.
- The process is adiabatic, that is, there is no heat transfer with the environment.
- Gravitational effects can be neglected.
- The flow resistance adds no net heat to the flow.

Dialog Box and Parameters



Tube internal diameter
: Internal diameter of the tube. The default value is `0.01` m.

Tube length
: Tube geometrical length. The default value is `10` m.

Aggregate equivalent length of local resistances
: This parameter represents total equivalent length of all local resistances associated with the tube. You can account for the pressure loss caused by local resistances, such as bends, fittings, armature, inlet/outlet losses, and so on, by adding to the pipe geometrical length an aggregate equivalent length of all the local resistances. The default value is `0`.

Internal surface roughness height
Roughness height on the tube internal surface. The parameter is typically provided in data sheets or manufacturer catalogs. The default value is `1.5e-5` m, which corresponds to drawn tubing.

Reynolds number at laminar flow upper margin
Specifies the Reynolds number at which the laminar flow regime is assumed to start converting into turbulent flow. Mathematically, this value is the maximum Reynolds number at fully developed laminar flow. The default value is `2000`.

Reynolds number at turbulent flow lower margin
Specifies the Reynolds number at which the turbulent flow regime is assumed to be fully developed. Mathematically, this value is the minimum Reynolds number at turbulent flow. The default value is `4000`.

Ports

The block has the following ports:

A
Pneumatic conserving port associated with the tube inlet for positive flow.

B
Pneumatic conserving port associated with the tube outlet for positive flow.

See Also

Constant Volume Pneumatic Chamber

Purpose

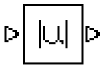
Output absolute value of input physical signal

Library

Physical Signals/Nonlinear Operators

Description

The PS Abs block returns the absolute value of the input physical signal:



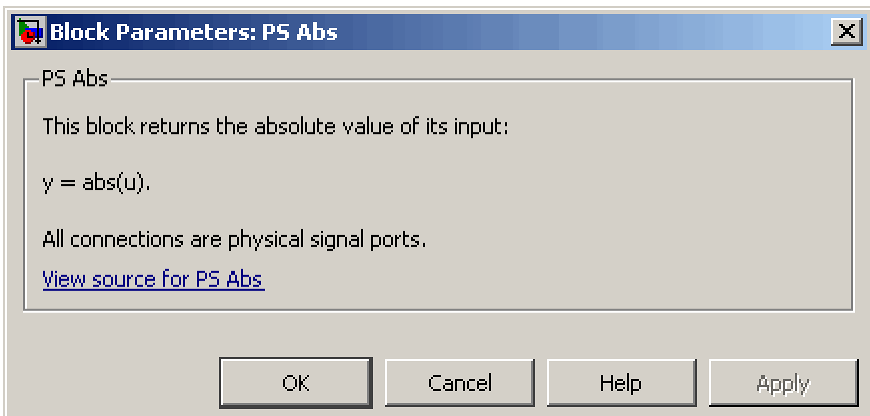
$$y = |u|$$

where

u	Physical signal at the input port
y	Physical signal at the output port

Both the input and the output are physical signals.

Dialog Box and Parameters



The PS Abs block has no parameters.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

PS Dead Zone

PS Max

PS Min

PS Saturation

PS Sign

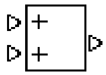
Purpose

Add two physical signal inputs

Library

Physical Signals/Functions

Description



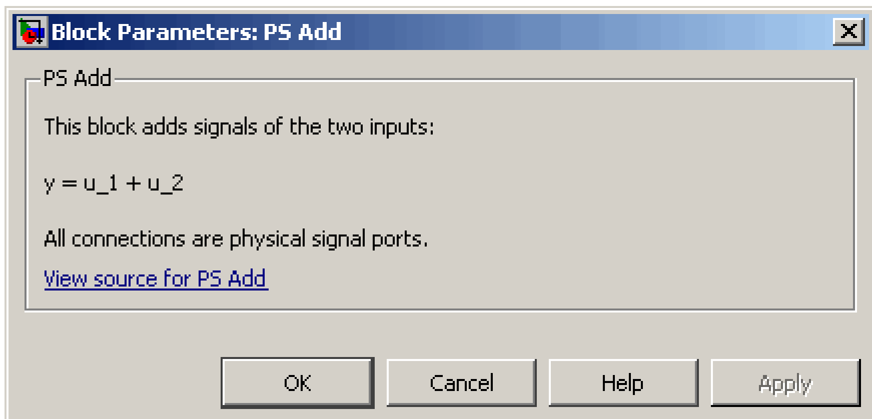
The PS Add block outputs the sum of two input physical signals:

$$y = u_1 + u_2$$

where

u_1	Physical signal at the first input port
u_2	Physical signal at the second input port
y	Physical signal at the output port

Dialog Box and Parameters



The PS Add block has no parameters.

Ports

The block has two physical signal input ports and one physical signal output port.

See Also

PS Divide

PS Gain

PS Math Function

PS Product

PS Subtract

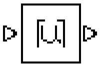
Purpose

Output the smallest integer larger than or equal to input physical signal

Library

Physical Signals/Nonlinear Operators

Description



The PS Ceil block rounds the input physical signal toward positive infinity, that is, to the nearest integer larger than or equal to the input value:

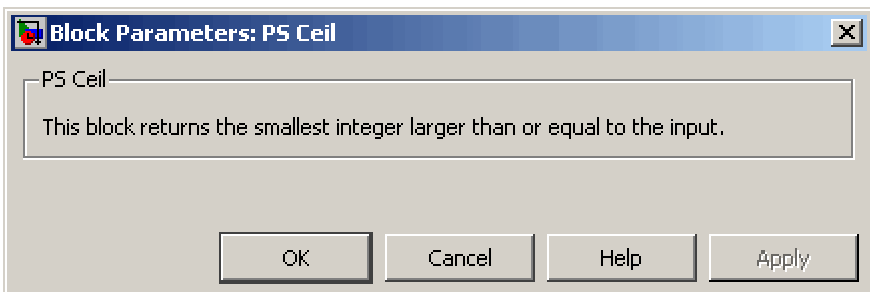
$$y = ceil(u)$$

where

u	Physical signal at the input port
y	Physical signal at the output port

Both the input and the output are physical signals.

Dialog Box and Parameters



The PS Ceil block has no parameters.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

`ceil`

PS Fix

PS Floor

PS Constant

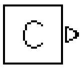
Purpose

Generate constant physical signal

Library

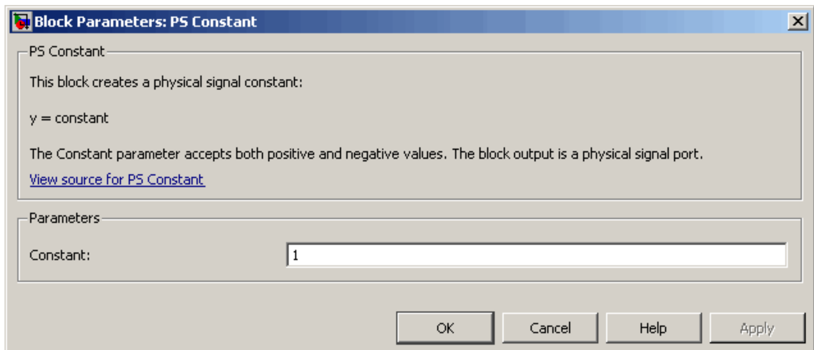
Physical Signals/Sources

Description



The PS Constant block generates a physical signal of a constant value. You specify the value of the signal as the **Constant** parameter.

Dialog Box and Parameters



Constant

The signal value. You can specify both positive and negative values.

Ports

The block has one physical signal output port.

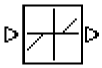
Purpose

Provide region of zero output for physical signals

Library

Physical Signals/Nonlinear Operators

Description

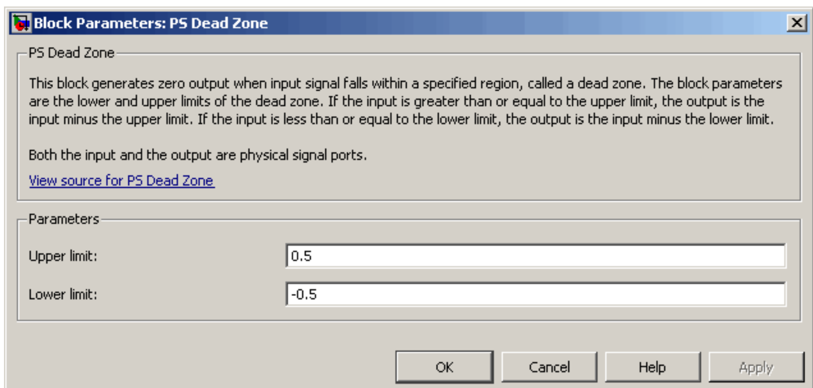


The PS Dead Zone block generates zero output when input signal falls within a specified region, called a dead zone. You can specify the lower and upper limits of the dead zone as block parameters. The block output depends on the input and dead zone:

- If the input is within the dead zone (greater than the lower limit and less than the upper limit), the output is zero.
- If the input is greater than or equal to the upper limit, the output is the input minus the upper limit.
- If the input is less than or equal to the lower limit, the output is the input minus the lower limit.

Both the input and the output are physical signals.

Dialog Box and Parameters



Upper limit
: The upper limit, or end, of the dead zone. The default value is `0.5`.

Lower limit

The lower limit, or start, of the dead zone. The default value is `-0.5`.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

PS Abs

PS Max

PS Min

PS Saturation

PS Sign

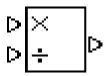
Purpose

Compute simple division of two input physical signals

Library

Physical Signals/Functions

Description



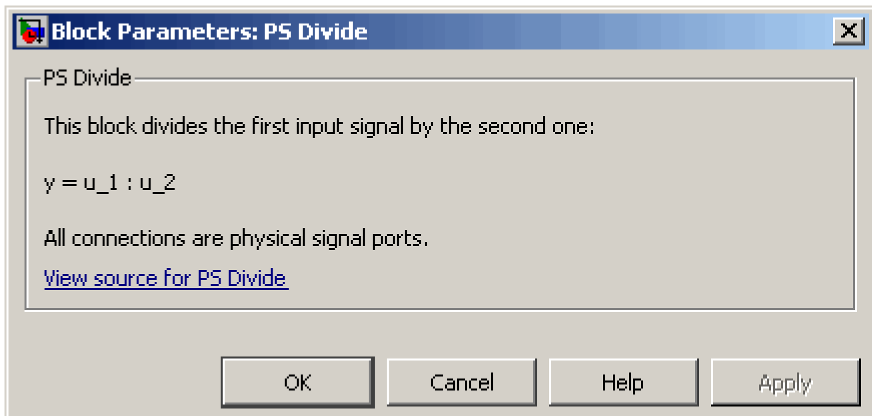
The PS Divide block divides one physical signal input by another and outputs the difference:

$$y = u_1 \div u_2$$

where

u_1	Physical signal at the first input port (marked with the x sign)
u_2	Physical signal at the second input port (marked with the ÷ sign)
y	Physical signal at the output port

Dialog Box and Parameters



The PS Divide block has no parameters.

Ports

The block has two physical signal input ports and one physical signal output port.

See Also

PS Add

PS Gain

PS Math Function

PS Product

PS Subtract

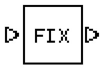
Purpose

Round input physical signal toward zero

Library

Physical Signals/Nonlinear Operators

Description



The PS Fix block rounds the input physical signal toward zero, that is, for a positive signal returns the nearest integer smaller than or equal to the input value, and for a negative signal returns the nearest integer larger than or equal to the input value:

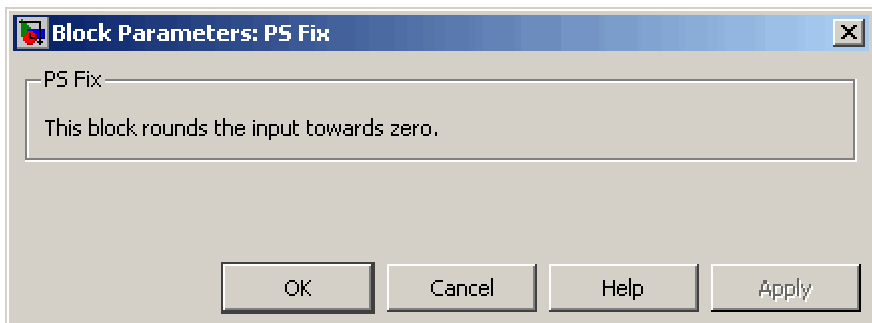
$$y = fix(u)$$

where

u	Physical signal at the input port
y	Physical signal at the output port

Both the input and the output are physical signals.

Dialog Box and Parameters



The PS Fix block has no parameters.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

`fix`

PS Ceil

PS Floor

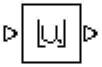
Purpose

Output the largest integer smaller than or equal to input physical signal

Library

Physical Signals/Nonlinear Operators

Description



The PS Floor block rounds the input physical signal toward negative infinity, that is, to the nearest integer smaller than or equal to the input value:

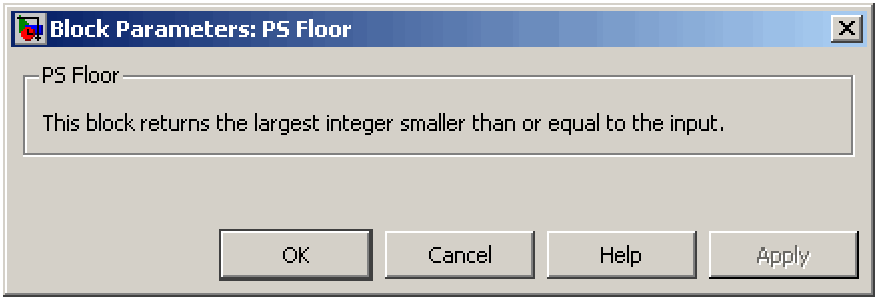
$$y = floor(u)$$

where

u	Physical signal at the input port
y	Physical signal at the output port

Both the input and the output are physical signals.

Dialog Box and Parameters



The PS Floor block has no parameters.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

`floor`

PS Ceil

PS Fix

PS Gain

Purpose

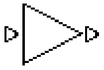
Multiply input physical signal by constant

Library

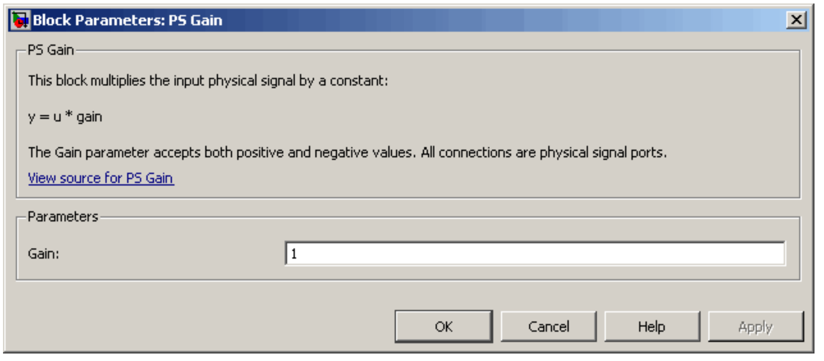
Physical Signals/Functions

Description

The PS Gain block multiplies the input physical signal by a constant value (gain). You specify the value of the gain as the **Gain** parameter.



Dialog Box and Parameters



Gain

The multiplication coefficient. You can specify both positive and negative values.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

PS Add

PS Divide

PS Math Function

PS Product

PS Subtract

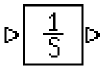
Purpose

Integrate physical signal

Library

Physical Signals/Linear Operators

Description



The PS Integrator block outputs the integral of its input at the current time step. The following equation represents the output of the block:

$$y(t) = \int_{t_0}^{t} u(t)dt + y_0$$

where

u	Physical signal at the input port
y_0	Initial condition
y	Physical signal at the output port
t	Time

The PS Integrator block is a dynamic system with one state, its output. The PS Integrator block's input is the state's time derivative:

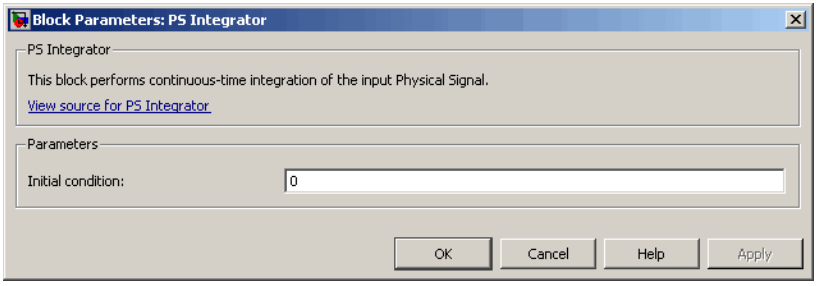
$$x = y(t)$$

$$x_0 = y_0$$

$$\dot{x} = u(t)$$

The solver computes the output of the PS Integrator block at the current time step, using the current input value and the value of the state at the previous time step. To support this computational model, the PS Integrator block saves its output at the current time step for use by the solver to compute its output at the next time step. The block also provides the solver with an initial condition for use in computing the block's initial state at the beginning of a simulation run. The default value of the initial condition is 0. You can specify another value for the initial condition as a parameter on the block dialog box.

Dialog Box and Parameters



Initial Condition

Specify the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `0`.

Ports

The block has one physical signal input port and one physical signal output port.

PS Lookup Table (1D)

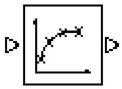
Purpose

Approximate one-dimensional function using specified lookup method

Library

Physical Signals/Lookup Tables

Description



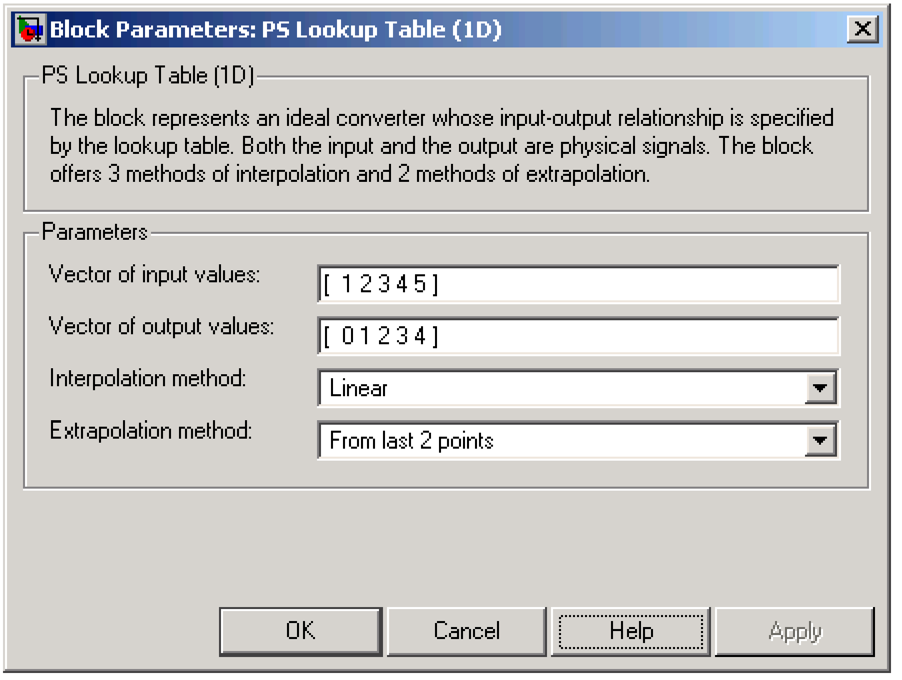
The PS Lookup Table (1D) block computes an approximation to some function `y=f(x)` given data vectors `x` and `y`. Both the input and the output are physical signals.

Note To map two physical signal inputs to an output, use the PS Lookup Table (2-D) block.

The length of the `x` and `y` data vectors provided to this block must match. Also, the `x` data vector must be *strictly monotonically increasing* (i.e., the value of the next element in the vector is greater than the value of the preceding element).

You define the lookup table by specifying the **Vector of input values** parameter as a 1-by-`n` vector and the **Vector of output values** parameter as a 1-by-`n` vector. The block generates output based on the input values using the selected interpolation and extrapolation methods. You have a choice of three interpolation methods and two extrapolation methods.

Dialog Box and Parameters



Vector of input values

Specify the vector of input values as a tabulated 1-by-`n` array. The input values vector must be strictly monotonically increasing. The values can be non-uniformly spaced.

Vector of output values

Specify the vector of output values as a tabulated 1-by-`n` array. The output values vector must be the same size as the input values vector.

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` — Uses a linear function.

- `Cubic` — Uses the Piecewise Cubic Hermite Interpolation Polinomial (PCHIP). For more information, see [1] and the `pchip` MATLAB® function.
- `Spline` — Uses the cubic spline interpolation algorithm described in [2].

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:

- `From last 2 points` — Extrapolates using the linear method (regardless of the interpolation method specified), based on the last two output values at the appropriate end of the range. That is, the block uses the first and second specified output values if the input value is below the specified range, and the two last specified output values if the input value is above the specified range.
- `From last point` — Uses the last specified output value at the appropriate end of the range. That is, the block uses the last specified output value for all input values greater than the last specified input argument, and the first specified output value for all input values less than the first specified input argument.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Interpolation method**
- **Extrapolation method**

All other block parameters are available for modification.

Ports

The block has one physical signal input port and one physical signal output port.

References

[1] D. Kahaner, Cleve Moler, Stephen Nash, *Numerical Methods and Software*, Prentice Hall, 1988

[2] W.H. Press, B.P. Flannery, S.A. Teulkolsky, W.T. Wetterling, *Numerical Recipes in C: The Art of Scientific Computing*, Cambridge University Press, 1992

See Also

PS Lookup Table (2D)

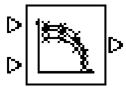
Purpose

Approximate two-dimensional function using specified lookup method

Library

Physical Signals/Lookup Tables

Description

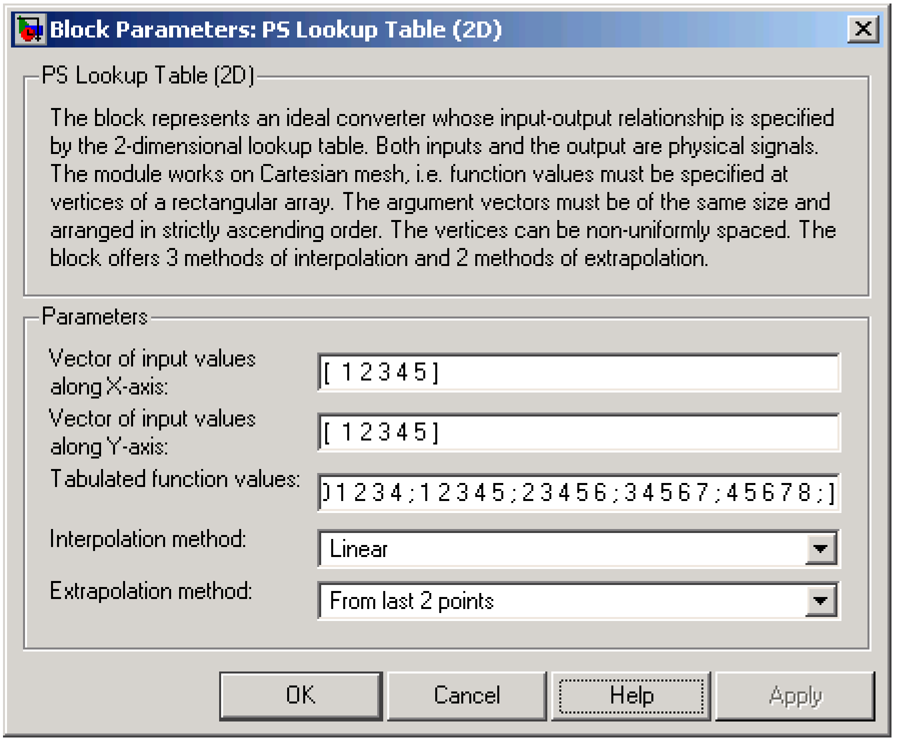


The PS Lookup Table (2D) block computes an approximation to some function `z=f(x,y)` given the `x`, `y`, `z` data points. The two inputs and the output are physical signals.

The `x` and `y` data vectors must be *strictly monotonically increasing* (i.e., the value of the next element in the vector is greater than the value of the preceding element). The matrix size of the tabulated function values must match the dimensions defined by the input vectors.

You define the lookup table by specifying the **Vector of input values along X-axis** parameter as a 1-by-`m` vector of `x` data points, the **Vector of input values along Y-axis** parameter as a 1-by-`n` vector of `y` data points, and the **Tabulated function values** as an `m`-by-`n` matrix of `z` data points. The block works on Cartesian mesh, i.e., function values must be specified at vertices of a rectangular array. The block generates output based on the input grid lookup using the selected interpolation and extrapolation methods. You have a choice of three interpolation methods and two extrapolation methods.

Dialog Box and Parameters



Vector of input values along X-axis

Specify the vector of input values along the *x*-axis as a tabulated 1-by-m array. The input values vector must be strictly monotonically increasing. The values can be non-uniformly spaced.

Vector of input values along Y-axis

Specify the vector of input values along the *y*-axis as a tabulated 1-by-n array. The input values vector must be strictly monotonically increasing. The values can be non-uniformly spaced.

Tabulated function values

Specify the output values as a tabulated `m`-by-`n` matrix, defining the function values at the input grid vertices. The matrix size must match the dimensions defined by the input vectors.

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` — Uses a bilinear interpolation algorithm, which is an extension of linear interpolation for functions in two variables. The method performs linear interpolation first in *x*-direction and then in *y*-direction.
- `Cubic` — Uses the bicubic interpolation algorithm described in [1].
- `Spline` — Uses the bicubic spline interpolation algorithm described in [1].

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:

- `From last 2 points` — Extrapolates using the linear method (regardless of the interpolation method specified) based on the last two output values at the appropriate grid location, similar to PS Lookup Table (1D) block.
- `From last point` — Uses the last specified output value at the appropriate grid location, similar to PS Lookup Table (1D) block..

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameters:

- **Interpolation method**

- **Extrapolation method**

All other block parameters are available for modification.

Ports

The block has two physical signal input ports and one physical signal output port.

References

[1] W.H.Press, B.P.Flannery, S.A.Teulkolsky, W.T.Wetterling, *Numerical Recipes in C: The Art of Scientific Computing*, Cambridge University Press, 1992

See Also

PS Lookup Table (1D)

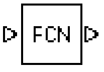
Purpose

Apply mathematical function to input physical signal

Library

Physical Signals/Functions

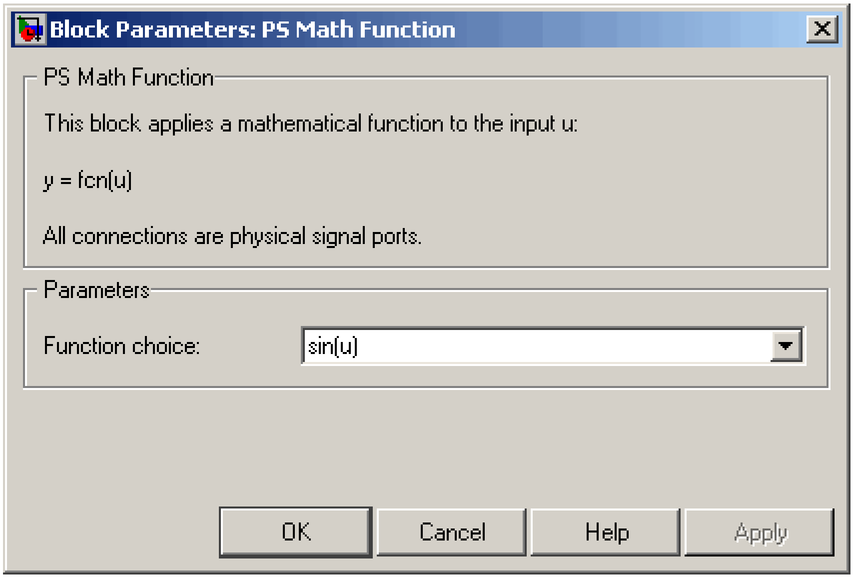
Description



The PS Math Function block applies a mathematical function to the input physical signal, u. The block output is the result of the operation of the function on the input. You can select one of the following functions from the **Function choice** parameter list.

Function	Description	Mathematical Expression
`sin(u)`	Sinus	$\sin(u)$
`cos(u)`	Cosinus	$\cos(u)$
`exp(u)`	Exponential	e^u
`log(u)`	Natural logarithm	$\ln(u)$
`10^u`	Power of base 10	10^u
`log10(u)`	Common (base 10) logarithm	$\log(u)$
`u^2`	Power 2	u^2
`sqrt(u)`	Square root	$u^{0.5}$
`1/u`	Reciprocal	$1/u$

Dialog Box and Parameters



Function choice

Select the function to perform. The block output is the result of the operation of the function on the input.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

PS Add

PS Divide

PS Gain

PS Product

PS Subtract

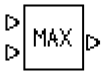
Purpose

Output maximum of two input physical signals

Library

Physical Signals/Nonlinear Operators

Description



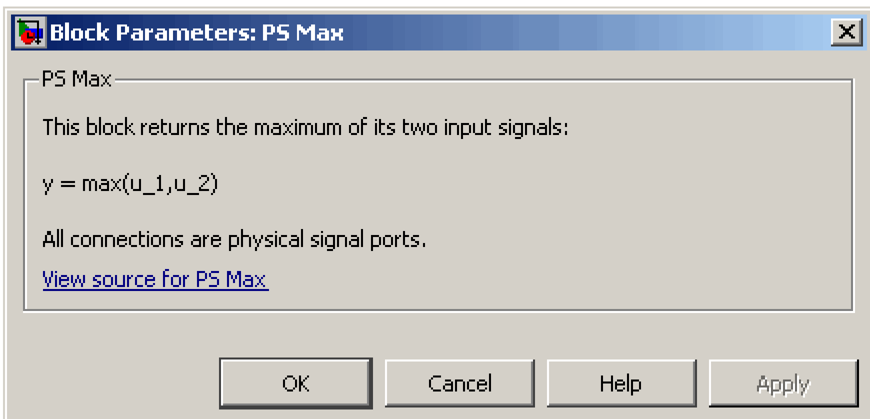
The PS Max block outputs the maximum of its two input physical signals:

$$y = \max(u_1, u_2)$$

where

u_1	Physical signal at the first input port
u_2	Physical signal at the second input port
y	Physical signal at the output port

Dialog Box and Parameters



The PS Max block has no parameters.

Ports

The block has two physical signal input ports and one physical signal output port.

See Also

PS Abs

PS Dead Zone

PS Min

PS Saturation

PS Sign

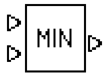
Purpose

Output minimum of two input physical signals

Library

Physical Signals/Nonlinear Operators

Description



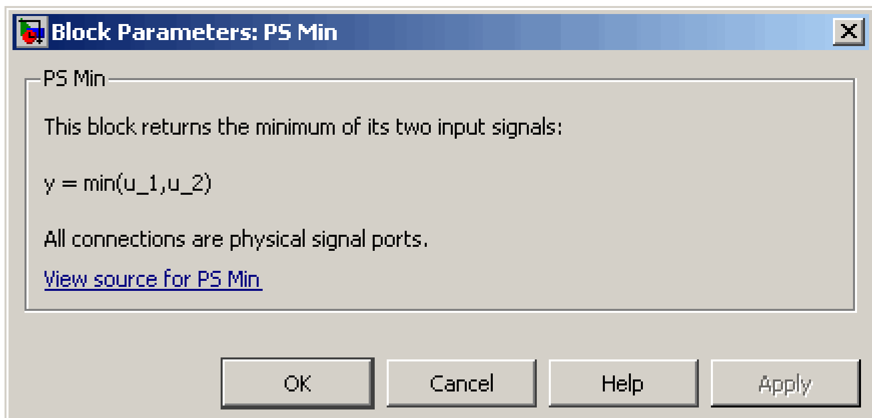
The PS Min block outputs the minimum of its two input physical signals:

$$y = \min(u_1, u_2)$$

where

u_1	Physical signal at the first input port
u_2	Physical signal at the second input port
y	Physical signal at the output port

Dialog Box and Parameters



The PS Min block has no parameters.

Ports

The block has two physical signal input ports and one physical signal output port.

See Also

PS Abs

PS Dead Zone

PS Max

PS Saturation

PS Sign

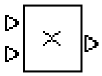
Purpose

Multiply two physical signal inputs

Library

Physical Signals/Functions

Description



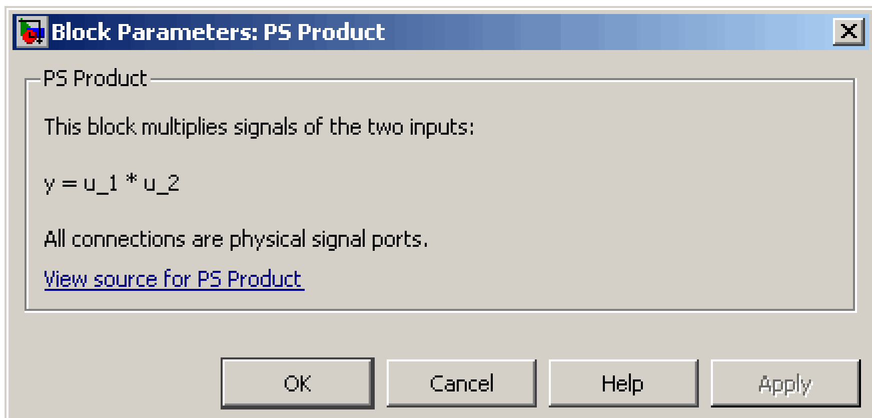
The PS Product block outputs the product of two input physical signals:

$$y = u_1 \cdot u_2$$

where

u_1	Physical signal at the first input port
u_2	Physical signal at the second input port
y	Physical signal at the output port

Dialog Box and Parameters



The PS Product block has no parameters.

Ports

The block has two physical signal input ports and one physical signal output port.

See Also

PS Add

PS Divide

PS Gain

PS Math Function

PS Subtract

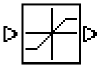
Purpose

Limit range of physical signal

Library

Physical Signals/Nonlinear Operators

Description

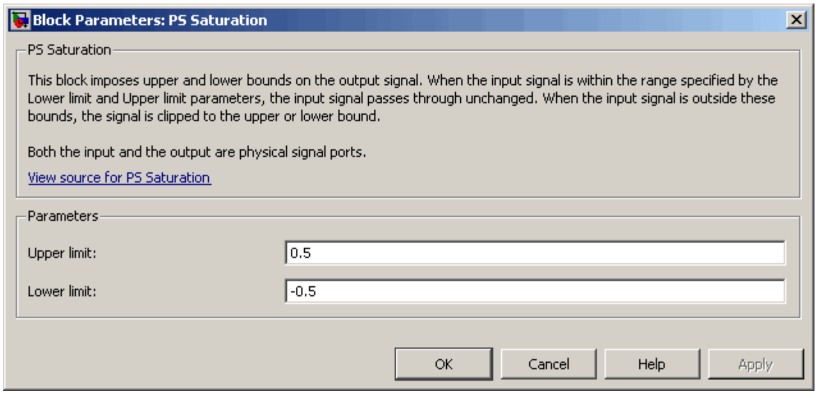


The PS Saturation block imposes upper and lower bounds on a physical signal. When the input signal is within the range specified by the **Lower limit** and **Upper limit** parameters, the input signal passes through unchanged. When the input signal is outside these bounds, the signal is clipped to the upper or lower bound.

When the **Lower limit** and **Upper limit** parameters are set to the same value, the block outputs that value.

Both the input and the output are physical signals.

Dialog Box and Parameters



Upper limit
The upper bound on the input signal. When the input signal to the Saturation block is above this value, the output of the block is clipped to this value. The default is `0.5`.

Lower limit
The lower bound on the input signal. When the input signal to the Saturation block is below this value, the output of the block is clipped to this value. The default is `-0.5`.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

PS Abs

PS Dead Zone

PS Max

PS Min

PS Sign

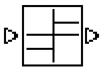
Purpose

Output sign of input physical signal

Library

Physical Signals/Nonlinear Operators

Description

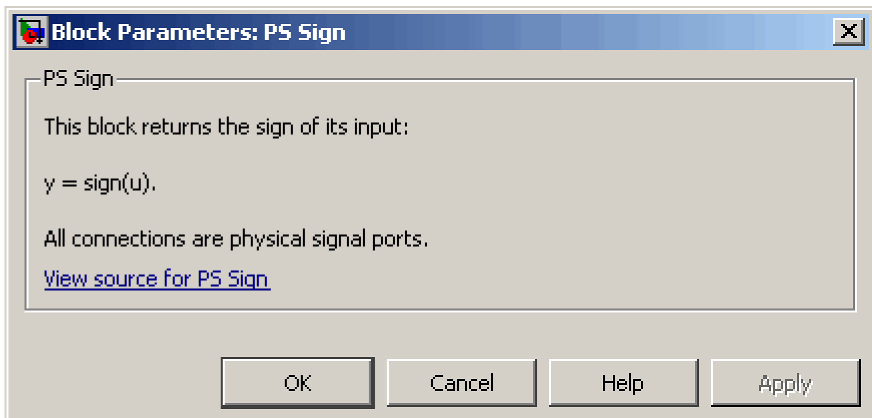


The PS Sign block returns the sign of the input physical signal:

- The output is 1 when the input is greater than zero.
- The output is 0 when the input is equal to zero.
- The output is –1 when the input is less than zero.

Both the input and the output are physical signals.

Dialog Box and Parameters



The PS Sign block has no parameters.

Ports

The block has one physical signal input port and one physical signal output port.

See Also

PS Abs

PS Dead Zone

PS Max

PS Min

PS Saturation

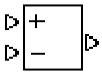
Purpose

Compute simple subtraction of two input physical signals

Library

Physical Signals/Functions

Description



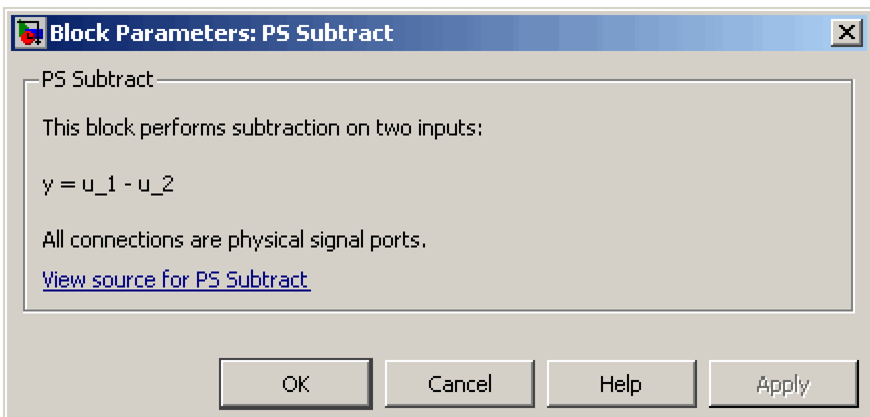
The PS Subtract block subtracts one physical signal input from another and outputs the difference:

$$y = u_1 - u_2$$

where

u_1	Physical signal at the first input port (marked with the plus sign)
u_2	Physical signal at the second input port (marked with the minus sign)
y	Physical signal at the output port

Dialog Box and Parameters



The PS Subtract block has no parameters.

Ports

The block has two physical signal input ports and one physical signal output port.

See Also

PS Add

PS Divide

PS Gain

PS Math Function

PS Product

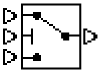
Purpose

Simulate single-pole double-throw switch controlled by external physical signal

Library

Physical Signals/Nonlinear Operators

Description

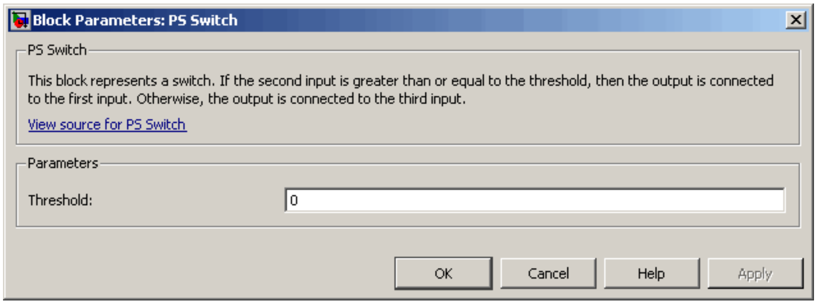


The PS Switch block compares the value of the physical signal presented at the second (middle) input port to the threshold value:

- If the control input value is greater than or equal to the threshold, the output is connected to the first input. This is the default connection shown in the block icon.
- If the control input value is less than the threshold, the output is connected to the third input.

The second (middle) input port is the control port and it never connects to the output. All the inputs and the output are physical signals.

Dialog Box and Parameters



Threshold

The threshold value for opening and closing the switch. If the control physical signal, presented at the second (middle) input port, is greater than or equal to this value, then the output is connected to the first input. Otherwise, the output is connected to the third input. The default value is `0`.

Ports

The block has three physical signal input ports and one physical signal output port.

See Also

Switch

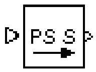
Purpose

Convert physical signal into Simulink output signal

Library

Utilities

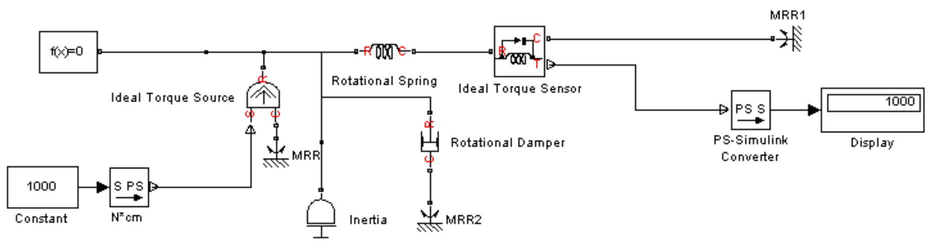
Description



The PS-Simulink Converter block converts a physical signal into a Simulink output signal. Use this block to connect outputs of a Physical Network diagram to Simulink scopes or other Simulink blocks.

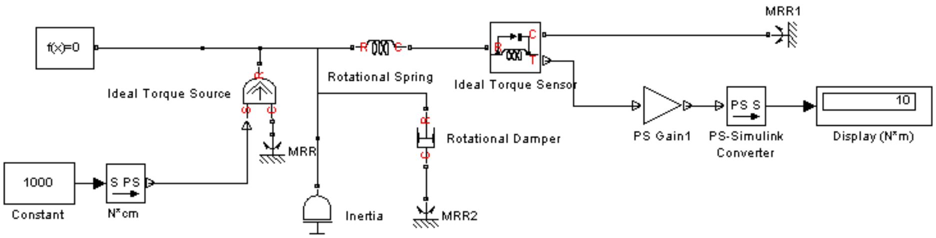
The **Output signal unit** parameter lets you specify the desired units for the output signal. These units must be commensurate with the units of the input physical signal coming into the block. The Simulink output signal is unitless, but if you specify a desired output unit, the block applies a gain equal to the conversion factor before outputting the Simulink signal. For example, if the input physical signal coming into the block is displacement, in meters, and you set **Output signal unit** to `mm`, the block multiplies the value of the input signal by 10e3 before outputting it.

In the diagram below, the input signal for the PS-Simulink Converter block is torque in N*m, and if you do not specify the output signal unit, the Display block shows the value of 10. If you change the **Output signal unit** parameter value in the PS-Simulink Converter block to `N*cm`, the torque value in the Display block changes to 1000, as shown in the diagram.



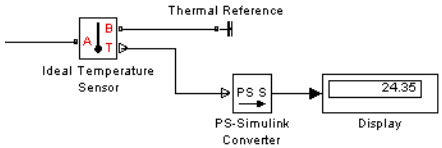
Note Currently, physical units are not propagated through the blocks in the Physical Signals library, such as PS Add, PS Gain, and so on. If your diagram contains a Physical Signals block before a PS-Simulink Converter block, the unit specification in the PS-Simulink Converter block is ignored.

In the following example, the PS-Simulink Converter block is installed after the PS Gain1 block. The display reading will remain the same regardless of the **Output signal unit** parameter setting in the PS-Simulink Converter block.

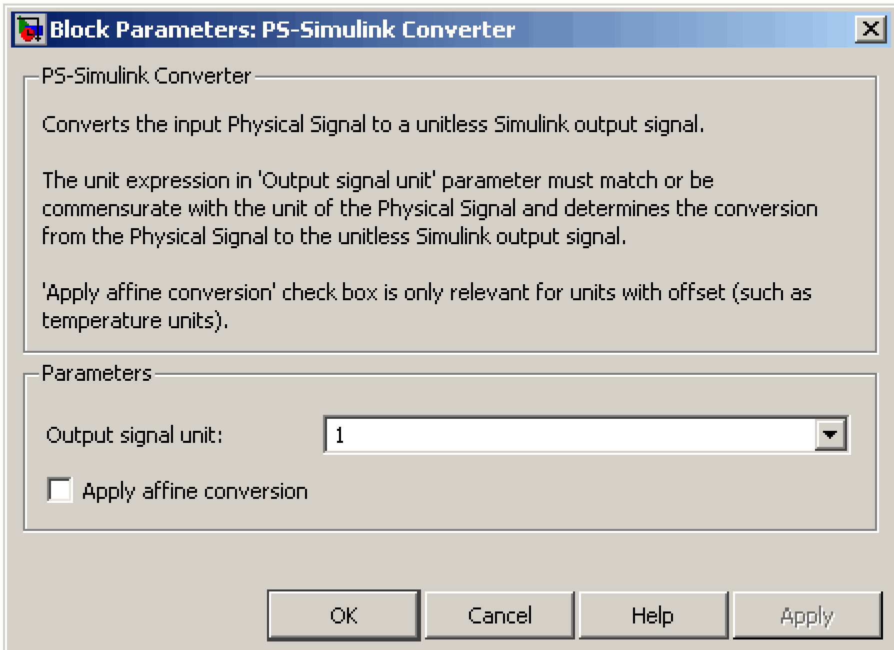


When the output signal is related to thermodynamic variables and contains units of temperature, you must decide whether affine conversion needs to be applied. For more information, see "When to Apply Affine Conversion". Usually, if the output signal represents a relative temperature, that is, a change in temperature, you need to apply linear conversion, $\Delta T_{new} = L * \Delta T_{old}$ (the default method). However, if the output signal represents an absolute temperature, you need to apply affine conversion, $T_{new} = L * T_{old} + O$.

In the following diagram, the Display block shows the room temperature. If you want to display it in degrees Celsius, open the PS-Simulink Converter block, type `C` in the **Output signal unit** field, and select the **Apply affine conversion** check box. The display reading is 24.35. However, if you leave the **Apply affine conversion** check box clear, the Display block would show 297.5.



Dialog Box and Parameters



Output signal unit

Specify the desired units for the output signal. These units must be commensurate with the units of the input physical signal coming into the block. The system compares the units you specified with the actual units of the input physical signal and applies a gain equal to the conversion factor before outputting the Simulink signal. You can select a unit from the drop-down list, or type the desired unit name, such as `rpm`, or a valid expression, such as `rad/s`. For more information and a list of unit abbreviations, see “Working with Physical Units”. The default value is `1`, which means that the unit is not specified. If you do not specify a unit, or if the unit matches the actual units of the input physical signal, no gain is applied.

Apply affine conversion
This check box is applicable only for units that can be converted either with or without an affine offset, such as thermal units. For more information, see “Thermal Unit Conversions”.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify any of the block parameters.

Ports

The block has a physical signal input port, located on its left side, and a Simulink output port, located on its right side (in the block default orientation).

See Also

Simulink-PS Converter

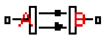
Purpose

Simulate heat transfer by radiation

Library

Thermal Elements

Description



The Radiative Heat Transfer block represents a heat transfer by radiation between two surfaces in such a way that the energy of emitting body is completely absorbed by a receiving body. The transfer is governed by the Stefan-Boltzmann law and is described with the following equation:

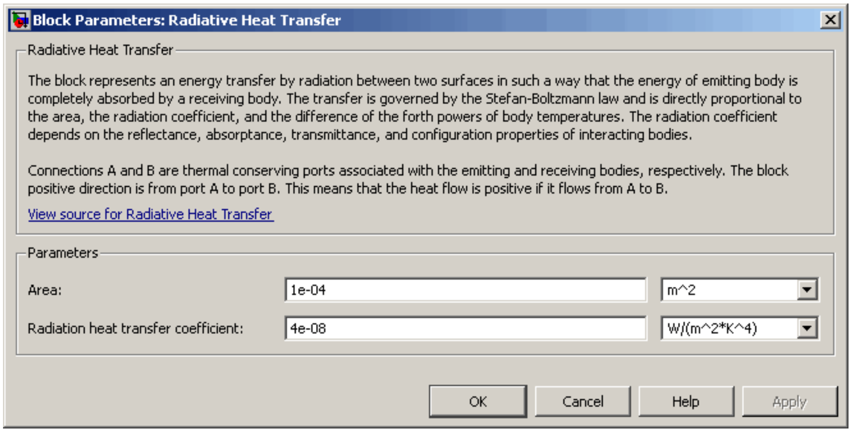
$$Q = k \bullet A \bullet (T_A^4 - T_B^4)$$

where

Q	Heat flow
k	Radiation heat transfer coefficient
A	Surface area
T_A, T_B	Temperatures of the bodies

Connections A and B are thermal conserving ports associated with the emitting and receiving bodies, respectively. The block positive direction is from port A to port B. This means that the heat flow is positive if it flows from A to B.

Dialog Box and Parameters



Area

Surface area of heat transfer. The default value is `0.0001` m^2.

Radiation heat transfer coefficient

Heat transfer coefficient according to the Stefan-Boltzmann law. The default value is `4e-8` W/m^2/K^4.

Ports

The block has the following ports:

A

Thermal conserving port associated with body A.

B

Thermal conserving port associated with body B.

See Also

Conductive Heat Transfer

Convective Heat Transfer

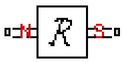
Purpose

Simulate magnetic reluctance

Library

Magnetic Elements

Description



The Reluctance block models a magnetic reluctance, that is, a component that resists flux flow. The ratio of the magnetomotive force (mmf) across the component to the resulting flux that flows through the component is constant, and the ratio value is defined as the reluctance. Reluctance depends on the geometry of the section being modeled.

The block is based on the following equations:

$$\mathtt{F} = \Phi \cdot \Re$$

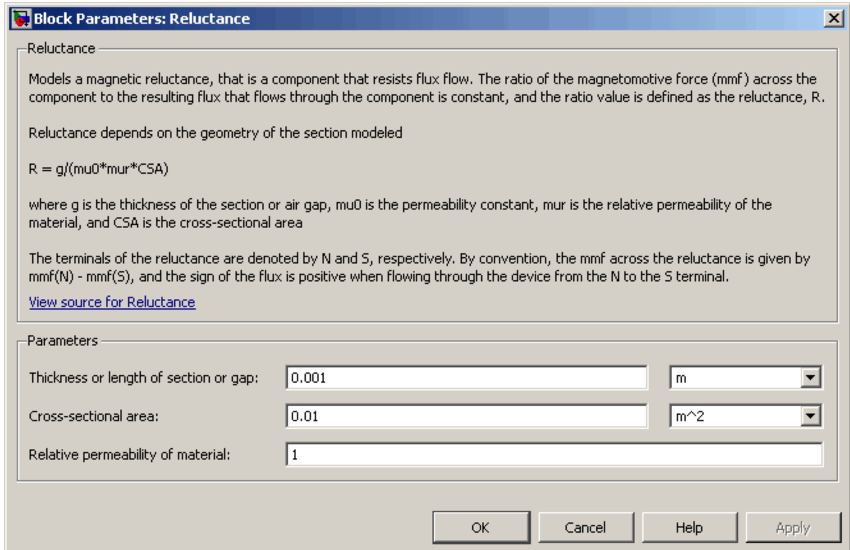
$$\Re = \frac{g}{\mu_0 \cdot \mu_r \cdot A}$$

where

$\mathtt{F}$	Magnetomotive force (mmf) across the component
Φ	Flux through the component
$\Re$	Reluctance
g	Thickness of the section being modeled, or length of air gap
μ_0	Permeability constant
μ_r	Relative permeability of the material
A	Cross-sectional area of the section being modeled

Connections N and S are magnetic conserving ports. The mmf across the reluctance is given by $\mathtt{F}(N) - \mathtt{F}(S)$, and the sign of the flux is positive when flowing through the device from N to S.

Dialog Box and Parameters



Thickness or length of section or gap
: Thickness of the section being modeled, or length of air gap. The default value is `0.001` m.

Cross-sectional area
: Area of the section being modeled. The default value is `0.01` m^2.

Relative permeability of material
: Relative permeability of the section material. The default value is `1`.

Ports

The block has the following ports:

`N`
: Magnetic conserving port associated with the block North terminal.

`S`
: Magnetic conserving port associated with the block South terminal.

See Also

Variable Reluctance

Reluctance Force Actuator

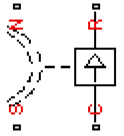
Purpose

Simulate magnetomotive device based on reluctance force

Library

Magnetic Elements

Description



The Reluctance Force Actuator block models a generic magnetomotive device based on reluctance force.

The block is based on the following equations:

$$F = -0.5 \cdot \Phi^2 \cdot \frac{d\Re}{dx}$$

$$\Re(x) = \frac{x}{\mu_0 \cdot \mu_r \cdot A}$$

$$u = dx$$

where

F	Reluctance force
Φ	Flux in the magnetic circuit
$\Re$	Reluctance
x	Thickness or length of the air gap
μ_0	Permeability constant
μ_r	Relative permeability of the material
A	Cross-sectional area of the section being modeled
u	Velocity

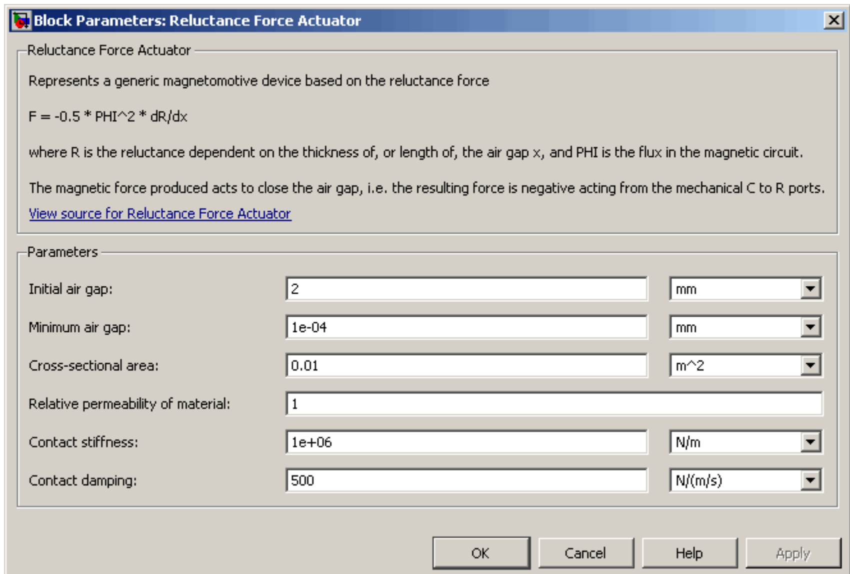
Connections N and S are magnetic conserving ports, and connections C and R are mechanical translational conserving ports. The magnetic force produced by the actuator acts to close the gap, therefore the resulting force is negative when it acts from C to R.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The current excitation in the system is constant.
- Only axial reluctance is modeled.

Dialog Box and Parameters



Initial air gap

Thickness or length of air gap at the beginning of simulation. The default value is `2` mm.

Minimum air gap

Minimal value of air gap, with the reluctance force acting to close the air gap. The parameter value has to be greater than 0. The default value is `1e-4` mm.

Cross-sectional area

Area of the section being modeled. The default value is `0.01` m^2.

Relative permeability of material
Relative permeability of the section material. The default value is `1`.

Contact stiffness
Stiffness that models the hard stop at the minimum air gap position. The default value is `10e6` N/m.

Contact damping
Damping that models the hard stop at the minimum air gap position. The default value is 500 N/(m/s).

Ports

The block has the following ports:

`N`
Magnetic conserving port associated with the block North terminal.

`S`
Magnetic conserving port associated with the block South terminal.

`R`
Mechanical translational conserving port associated with the rod.

`C`
Mechanical translational conserving port associated with the case.

See Also

Reluctance

Variable Reluctance

Resistor

Purpose

Simulate linear resistor in electrical systems

Library

Electrical Elements

Description

The Resistor block models a linear resistor, described with the following equation:

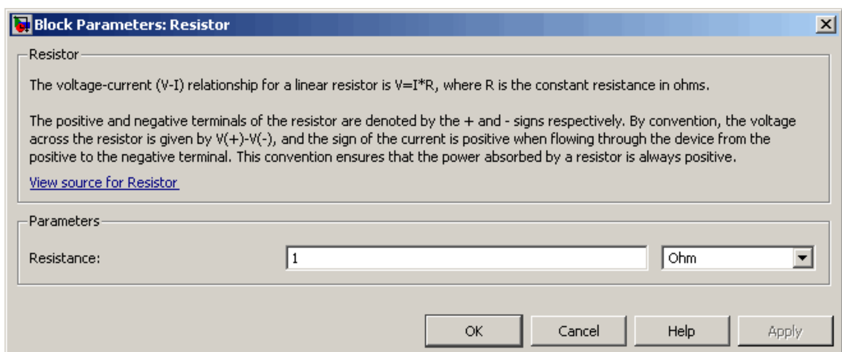
$$V = I \cdot R$$

where

V	Voltage
I	Current
R	Resistance

Connections + and – are conserving electrical ports corresponding to the positive and negative terminals of the resistor, respectively. By convention, the voltage across the resistor is given by $V(+) - V(-)$, and the sign of the current is positive when flowing through the device from the positive to the negative terminal. This convention ensures that the power absorbed by a resistor is always positive.

Dialog Box and Parameters



Resistance

Resistance, in ohms. The default value is 1 Ω.

Ports

The block has the following ports:

+
: Electrical conserving port associated with the resistor positive terminal.

-
: Electrical conserving port associated with the resistor negative terminal.

See Also

Variable Resistor

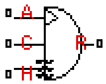
Purpose

Simulate rotational pneumatic piston chamber based on ideal gas law

Library

Pneumatic Elements

Description



The Rotary Pneumatic Piston Chamber block models a pneumatic rotary piston chamber based on the ideal gas law and assuming constant specific heats. Use this model as a building block for pneumatic rotational actuators. The piston can generate torque in one direction only, and the direction is set by the **Chamber orientation** parameter.

The continuity equation for the network representation of the piston chamber is

$$G = \frac{V_0 + D \bullet \theta}{RT}\left(\frac{dp}{dt} - \frac{p}{T}\frac{dT}{dt}\right) + \frac{D}{RT} \bullet p \bullet \frac{d\theta}{dt}$$

where

G	Mass flow rate at input port
V_0	Initial chamber volume
D	Piston displacement (volume per unit angle)
Θ	Piston angle
p	Absolute pressure in the chamber
R	Specific gas constant
T	Absolute gas temperature
t	Time

The energy equation is

$$q = \frac{c_v}{R}(V_0 + D \bullet \theta)\frac{dp}{dt} + \frac{c_p \bullet D}{R}p\frac{d\theta}{dt} - q_w$$

where

q	Heat flow due to gas inflow in the chamber (through the pneumatic port)
q_w	Heat flow through the chamber walls (through the thermal port)
c_v	Specific heat at constant volume
c_p	Specific heat at constant pressure

The torque equation is

$$\tau = p \bullet D$$

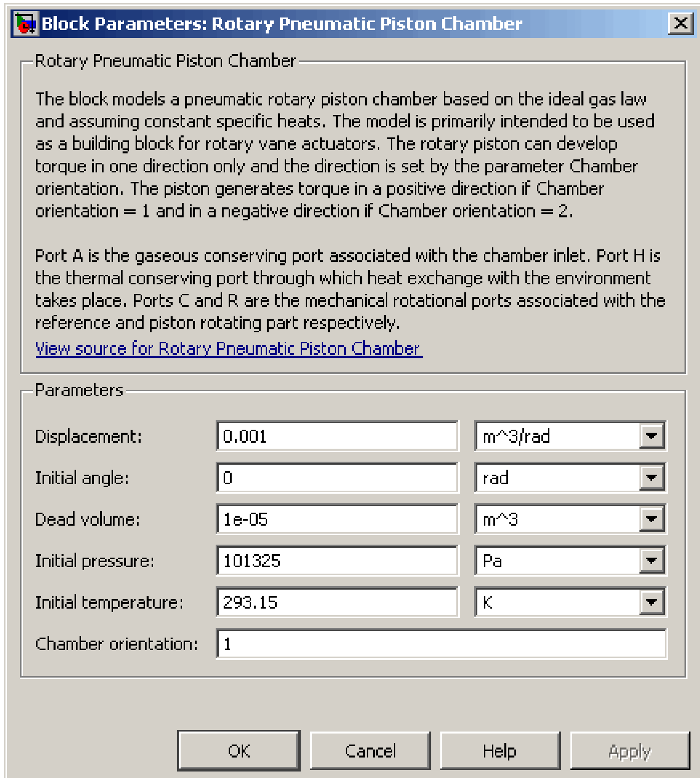
Port A is the pneumatic conserving port associated with the chamber inlet. Port H is a thermal conserving port through which heat exchange with the environment takes place. Ports C and R are mechanical rotational conserving ports associated with the piston case and rod, respectively. The gas flow and the heat flow are considered positive if they flow into the chamber.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The gas is ideal.
- Specific heats at constant pressure and constant volume, c_p and c_v, are constant.

Dialog Box and Parameters



Displacement
Specify the effective piston displacement, as volume per unit angle. The default value is `.001` m^3/rad.

Initial angle
Specify the initial piston angle. The default value is `0`.

Dead volume
Specify the volume of gas in the chamber at zero piston position. The default value is `1e-5` m^3.

Initial pressure
: Specify the initial pressure in the chamber. This parameter specifies the initial condition for use in computing the initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `101235` Pa.

Initial temperature
: Specify the initial temperature of the gas in the chamber. This parameter specifies the initial condition for use in computing the initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `293.15` K.

Chamber orientation
: Specify the direction of torque generation. The piston generates torque in a positive direction if this parameter is set to `1` (the default). If you set this parameter to `2`, the piston generates torque in a negative direction.

Ports

The block has the following ports:

`A`
: Pneumatic conserving port associated with the chamber inlet.

`H`
: Thermal conserving port through which heat exchange with the environment takes place.

`R`
: Mechanical rotational conserving port associated with the piston (rod).

`C`
: Mechanical rotational conserving port associated with the reference (case).

See Also

Constant Volume Pneumatic Chamber

Pneumatic Piston Chamber

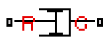
Purpose

Simulate viscous damper in mechanical rotational systems

Library

Mechanical Rotational Elements

Description



The Rotational Damper block represents an ideal mechanical rotational viscous damper described with the following equations:

$$T = D \cdot \omega$$

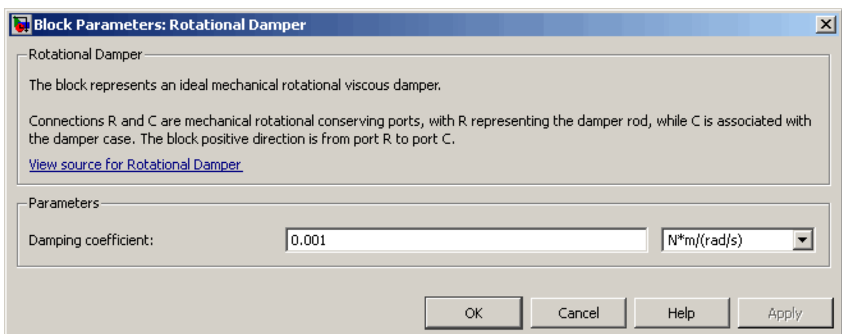
$$\omega = \omega_R - \omega_C$$

where

T	Torque transmitted through the damper
D	Damping (viscous friction) coefficient
ω	Relative angular velocity
ω_R,ω_C	Absolute angular velocities of terminals R and C, respectively

The block positive direction is from port R to port C. This means that the torque is positive if it acts in the direction from R to C.

Dialog Box and Parameters



Damping coefficient

Damping coefficient, defined by viscose friction. The default value is `0.001` N*m/(rad/s).

Ports

The block has the following ports:

`R`
: Mechanical rotational conserving port.

`C`
: Mechanical rotational conserving port.

See Also

Rotational Friction

Rotational Hard Stop

Rotational Spring

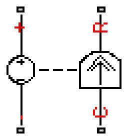
Purpose

Provide interface between electrical and mechanical rotational domains

Library

Electrical Elements

Description



The Rotational Electromechanical Converter block provides an interface between the electrical and mechanical rotational domains. It converts electrical energy into mechanical energy in the form of rotational motion, and vice versa. The converter is described with the following equations:

$$T = K \cdot I$$

$$V = K \cdot \omega$$

where

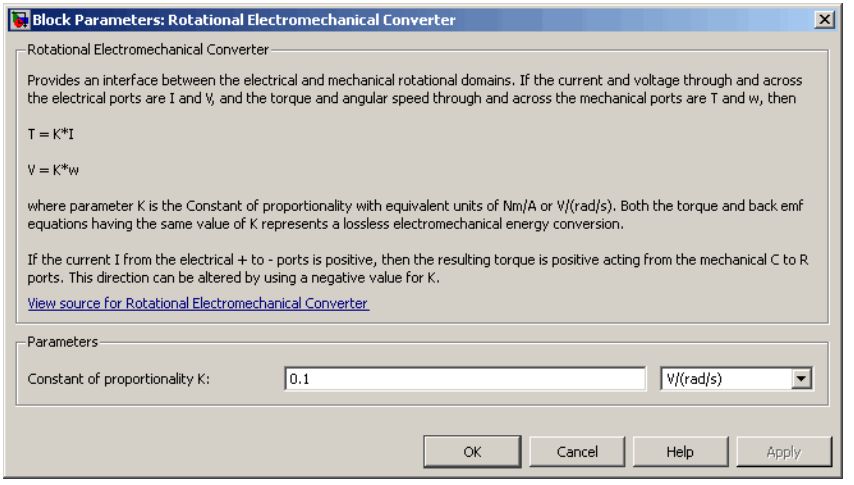
V	Voltage across the electrical ports of the converter
I	Current through the electrical ports of the converter
T	Torque
ω	Angular speed
K	Constant of proportionality

The Rotational Electromechanical Converter block represents a lossless electromechanical energy conversion, therefore the same constant of proportionality is used in both equations.

Connections + and – are conserving electrical ports corresponding to the positive and negative terminals of the converter, respectively. Connections C and R are conserving mechanical rotational ports. If the current flowing from the positive to the negative terminal is positive, then the resulting torque is positive acting from port C to port R. This direction can be altered by using a negative value for K.

Rotational Electromechanical Converter

Dialog Box and Parameters



Constant of proportionality K

Constant of proportionality for electromechanical conversions. The default value is `0.1` V/(rad/s).

Ports

The block has the following ports:

`+`

Electrical conserving port associated with the converter positive terminal.

`-`

Electrical conserving port associated with the converter negative terminal.

`C`

Mechanical rotational conserving port.

`R`

Mechanical rotational conserving port.

See Also

Translational Electromechanical Converter

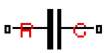
Purpose

Simulate friction in contact between rotating bodies

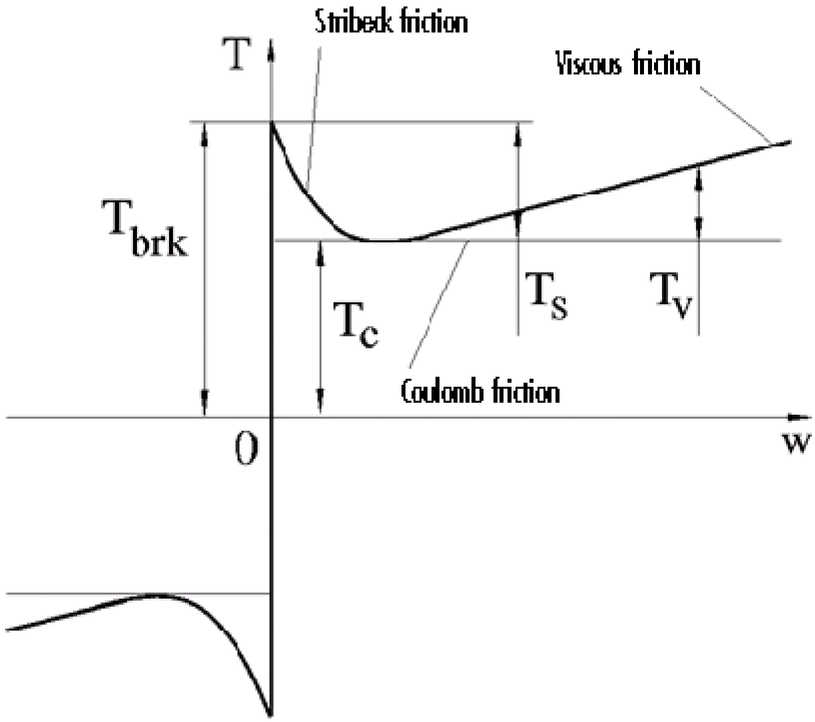
Library

Mechanical Rotational Elements

Description



The Rotational Friction block represents friction in contact between rotating bodies. The friction torque is simulated as a function of relative velocity and is assumed to be the sum of Stribeck, Coulomb, and viscous components, as shown in the following figure.



The Stribeck friction, T_S, is the negatively sloped characteristics taking place at low velocities (see [1]). The Coulomb friction, T_C, results in a constant torque at any velocity. The viscous friction, T_V, opposes motion with the torque directly proportional to the relative velocity. The sum of the Coulomb and Stribeck frictions at the vicinity of zero velocity is often referred to as the breakaway friction, T_{brk}. The friction is approximated with the following equations:

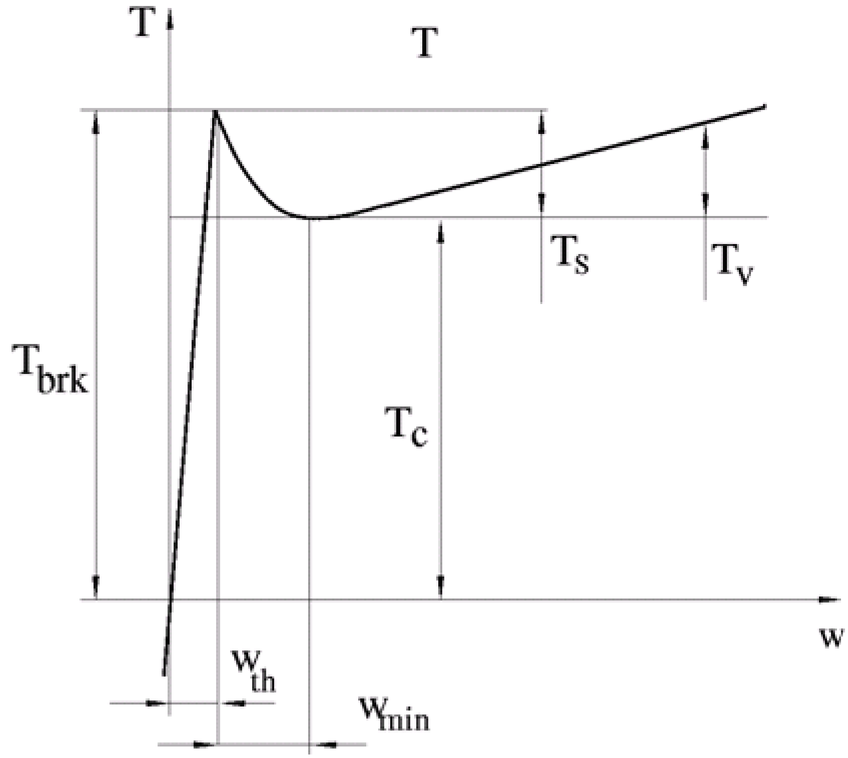
$$T = \left(T_C + (T_{brk} - T_C)\cdot \exp(-c_v \,|\, \omega \,|)\right) sign(\omega) + f\omega$$

$$\omega = \omega_R - \omega_C$$

where

T	Friction torque
T_C	Coulomb friction torque
T_{brk}	Breakaway friction torque
c_v	Coefficient
ω	Relative velocity
ω_R,ω_C	Absolute angular velocities of terminals R and C, respectively
f	Viscous friction coefficient

The approximation above is too idealistic and has a substantial drawback. The characteristic is discontinuous at $\omega = 0$, which creates considerable computational problems. It has been proven that the discontinuous friction model is a nonphysical simplification in the sense that the mechanical contact with distributed mass and compliance cannot exhibit an instantaneous change in torque (see [1]). There are numerous models of friction without discontinuity. The Rotational Friction block implements one of the simplest versions of continuous friction models. The friction torque-relative velocity characteristic of this approximation is shown in the following figure.



The discontinuity is eliminated by introducing a very small, but finite, region in the zero velocity vicinity, within which friction torque is assumed to be linearly proportional to velocity, with the proportionality coefficient T_{brk}/ω_{th}, where ω_{th} is the velocity threshold. It has been proven experimentally that the velocity threshold in the range between 10^{-3} and 10^{-5} rad/s is a good compromise between the accuracy and computational robustness and effectiveness. Notice that friction torque computed with this approximation does not actually stop relative motion when an acting torque drops below breakaway friction level. The bodies will creep relative to each other at a very small velocity proportional to acting torque.

As a result of introducing the velocity threshold, the block equations are slightly modified:

- If $|\omega| >= \omega_{th}$,

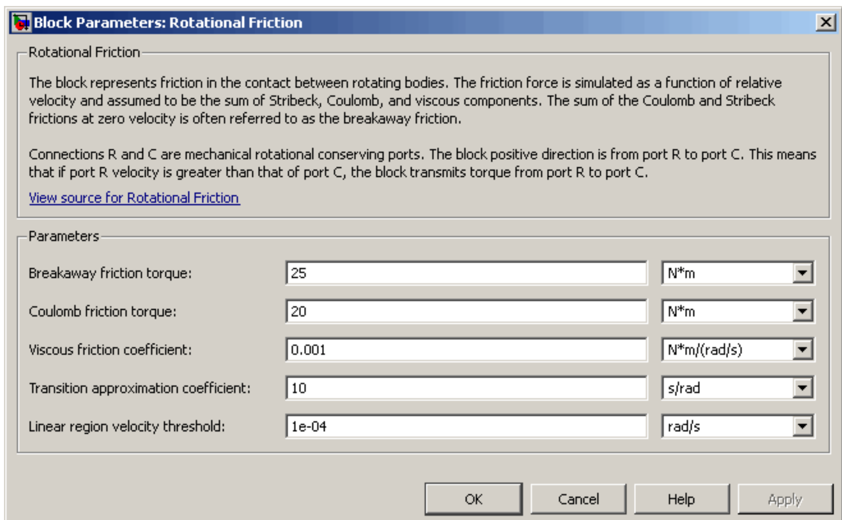
$$T = \left(T_C + (T_{brk} - T_C) \bullet \exp(-c_v\,|\omega|)\right) sign(\omega) + f\omega$$

- If $|\omega| < \omega_{th}$,

$$T = \omega \frac{\left(f\omega_{th} + \left(T_C + (T_{brk} - T_C) \bullet \exp(-c_v \omega_{th})\right)\right)}{\omega_{th}}$$

The block positive direction is from port R to port C. This means that if the port R velocity is greater than that of port C, the block transmits torque from R to C.

Dialog Box and Parameters



Breakaway friction torque

Breakaway friction torque, which is the sum of the Coulomb and the static frictions. It must be greater than or equal to the Coulomb friction torque value. The default value is 25 N*m.

Coulomb friction torque

Coulomb friction torque, which is the friction that opposes rotation with a constant torque at any velocity. The default value is 20 N*m.

Viscous friction coefficient

Proportionality coefficient between the friction torque and the relative angular velocity. The parameter value must be greater than or equal to zero. The default value is 0.001 N*m/(rad/s).

Transition approximation coefficient

The parameter sets the value of coefficient c_v, which is used for the approximation of the transition between the static and the Coulomb frictions. Its value is assigned based on the following considerations: the static friction component reaches approximately 95% of its steady-state value at velocity $3/c_v$, and 98% at velocity $4/c_v$, which makes it possible to develop an approximate relationship $c_v \sim= 4/\omega_{min}$, where ω_{min} is the relative velocity at which friction torque has its minimum value. By default, c_v is set to 10 rad/s, which corresponds to a minimum friction at velocity of about 0.4 s/rad.

Linear region velocity threshold

The parameter sets the small vicinity near zero velocity, within which friction torque is considered to be linearly proportional to the relative velocity. The MathWorks recommends that you use values in the range between 1e-5 and 1e-3 rad/s. The default value is 1e-4 rad/s.

Ports

The block has the following ports:

R

Mechanical rotational conserving port.

`C`

Mechanical rotational conserving port.

Examples

The Mechanical Rotational System with Stick-Slip Motion demo (`ssc_rot_system_stick_slip`) illustrates the use of the Rotational Friction block in mechanical systems. The friction element is installed between the load and the velocity source, and there is a difference between the breakaway and the Coulomb frictions. As a result, stick-slip motion is developed in the regions of constant velocities.

References

[1] B. Armstrong, C.C. de Wit, *Friction Modeling and Compensation*, The Control Handbook, CRC Press, 1995

See Also

Rotational Damper

Rotational Hard Stop

Rotational Spring

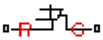
Purpose

Simulate double-sided rotational hard stop

Library

Mechanical Rotational Elements

Description



The Rotational Hard Stop block represents a double-sided mechanical rotational hard stop that restricts motion of a body between upper and lower bounds. Both ports of the block are of mechanical rotational type. The impact interaction between the slider and the stops is assumed to be elastic. The stop is implemented as a spring that comes into contact with the slider as the gap is cleared. The spring opposes slider penetration into the stop with the force linearly proportional to this penetration. To account for energy dissipation and nonelastic effects, the damping is introduced as a block parameter, thus making it possible to account for energy loss.

The hard stop is described with the following equations:

$$T = \begin{cases} K_p \cdot \delta + D_p(\omega_R - \omega_C) & \text{for } \delta >= g_p \\ 0 & \text{for } g_n < \delta < g_p \\ K_n \cdot \delta + D_n(\omega_R - \omega_C) & \text{for } \delta <= g_n \end{cases}$$

$$\delta = \varphi_R - \varphi_C$$

$$\omega_R = \frac{d\varphi_R}{dt}$$

$$\omega_C = \frac{d\varphi_C}{dt}$$

where

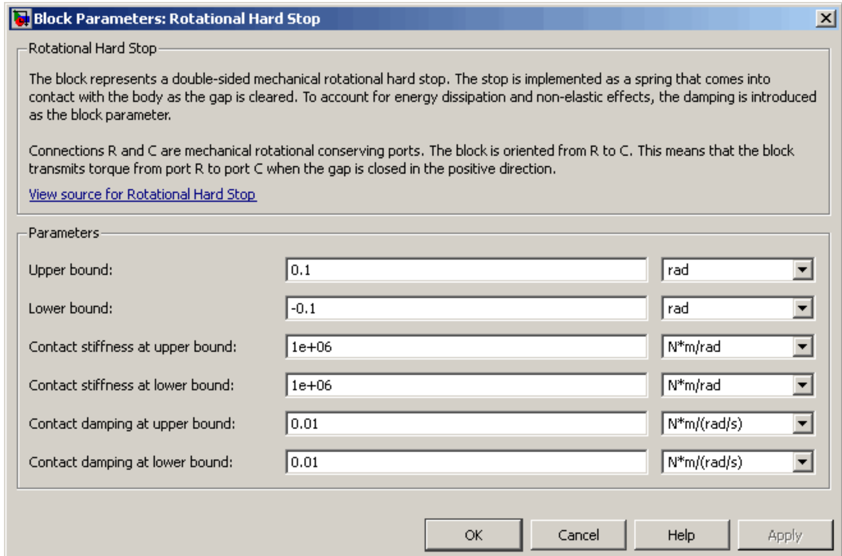
T	Interaction torque between the slider and the case
	Relative angular displacement between the slider and the case

g_p	Gap between the slider and the case in positive direction
g_n	Gap between the slider and the case in negative direction
ω_R, ω_C	Absolute angular velocities of terminals R and C, respectively
φ_R, φ_C	Absolute angular displacements of terminals R and C, respectively
K_p	Contact stiffness at positive restriction
K_n	Contact stiffness at negative restriction
D_p	Damping coefficient at positive restriction
D_n	Damping coefficient at negative restriction
t	Time

The equations are derived with respect to the local coordinate system whose axis is directed clockwise from port R to port C. The terms "positive" and "negative" in the variable descriptions refer to this coordinate system, and the gap in negative direction must be specified with negative value. If the local coordinate system is not aligned with the globally assigned positive direction, the gaps interchange their values with respective sign adjustment.

The block is oriented from R to C. This means that the block transmits torque from port R to port C when the gap in positive direction is cleared up.

Dialog Box and Parameters



Upper bound
: Gap between the slider and the upper bound. The direction is specified with respect to the local coordinate system, with the slider located in the origin. A positive value of the parameter specifies the gap between the slider and the upper bound. A negative value sets the slider as penetrating into the upper bound. The default value is `0.1` rad.

Lower bound
: Gap between the slider and the lower bound. The direction is specified with respect to the local coordinate system, with the slider located in the origin. A negative value of the parameter specifies the gap between the slider and the lower bound. A positive value sets the slider as penetrating into the lower bound. The default value is `-0.1` rad.

Contact stiffness at upper bound
: The parameter specifies the elastic property of colliding bodies when the slider hits the upper bound. The greater the value of

the parameter, the less the bodies penetrate into each other, the more rigid the impact becomes. Lesser value of the parameter makes contact softer, but generally improves convergence and computational efficiency. The default value is `1e6` N*m/rad.

Contact stiffness at lower bound

The parameter specifies the elastic property of colliding bodies when the slider hits the lower bound. The greater the value of the parameter, the less the bodies penetrate into each other, the more rigid the impact becomes. Lesser value of the parameter makes contact softer, but generally improves convergence and computational efficiency. The default value is `1e6` N*m/rad.

Contact damping at upper bound

The parameter specifies dissipating property of colliding bodies when the slider hits the upper bound. At zero damping, the impact is close to an absolutely elastic one. The greater the value of the parameter, the more energy dissipates during an interaction. Keep in mind that damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. For computational efficiency and convergence reasons, The MathWorks recommends that you assign a nonzero value to this parameter. The default value is 0.01 N*m*s/rad.

Contact damping at lower bound

The parameter specifies dissipating property of colliding bodies when the slider hits the lower bound. At zero damping, the impact is close to an absolutely elastic one. The greater the value of the parameter, the more energy dissipates during an interaction. Keep in mind that damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. For computational efficiency and convergence reasons, The MathWorks recommends that you assign a nonzero value to this parameter. The default value is 0.01 N*m*s/rad.

Ports

The block has the following ports:

R
: Mechanical rotational conserving port associated with the slider that travels between stops installed on the case.

C
: Mechanical rotational conserving port associated with the case.

See Also

Rotational Damper

Rotational Friction

Rotational Spring

Rotational Hydro-Mechanical Converter

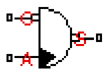
Purpose

Simulate ideal hydro-mechanical transducer as building block for rotary actuators

Library

Hydraulic Elements

Description



The Rotational Hydro-Mechanical Converter block models an ideal transducer that converts hydraulic energy into mechanical energy, in the form of rotational motion of the converter shaft, and vice versa. Physically, the converter represents the main component of a single-acting rotary vane actuator. Using this block as a basic element, you can build a large variety of rotary actuators by adding application-specific effects, such as fluid compressibility, leakage, friction, hard stops, and so on.

The converter is simulated according to the following equations:

$$q = D(\omega_S - \omega_C)\bullet or$$

$$T = D\bullet p\bullet or$$

where

q	Flow rate to the converter chamber
D	Converter displacement, or fluid volume needed to rotate the shaft per angle unit
ω_S	Converter shaft angular velocity
ω_C	Converter case angular velocity
F	Torque on the shaft
p	Gauge pressure of fluid in the converter chamber
or	Converter orientation with respect to the globally assigned positive direction. If pressure applied at port A generates torque in positive direction, *or* equals 1. If pressure applied at port A generates torque in negative direction, *or* equals –1.

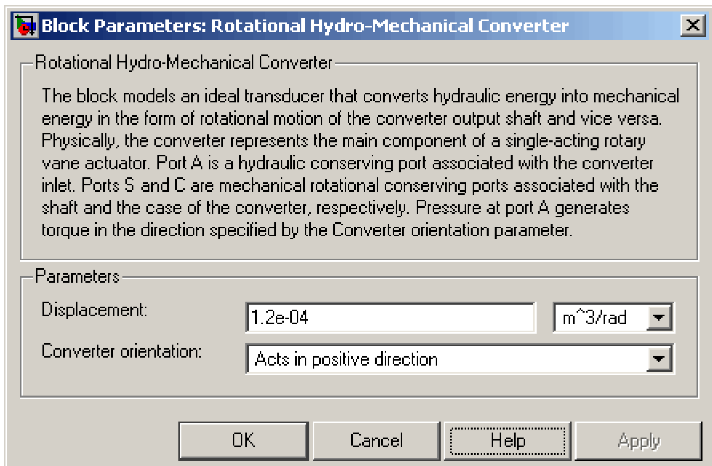
Port A is a hydraulic conserving port associated with the converter inlet. Ports S and C are mechanical rotational conserving ports associated with the shaft and the case of the converter, respectively. Pressure at port A generates torque in the direction specified by the **Converter orientation** parameter.

Basic Assumptions and Limitations

The model is based on the following assumption:

- The block simulates an ideal converter, with only the transduction property considered. No inertia, friction, leakage, or other effects are taken into account.

Dialog Box and Parameters



Displacement

Effective converter displacement. The default value is `1.2e-4` m^3/rad.

Converter orientation

Specifies converter orientation with respect to the globally assigned positive direction. The converter can be installed in two different ways, depending upon whether it generates torque in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port A generates torque in negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Converter orientation**

All other block parameters are available for modification.

Ports

The block has the following ports:

`A`
: Hydraulic conserving port associated with the converter inlet.

`S`
: Mechanical rotational conserving port associated with the shaft of the converter.

`C`
: Mechanical rotational conserving port associated with the case of the converter.

See Also

Translational Hydro-Mechanical Converter

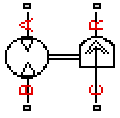
Purpose

Provide interface between pneumatic and mechanical rotational domains

Library

Pneumatic Elements

Description



The Rotational Pneumatic-Mechanical Converter block provides an interface between the pneumatic and the mechanical rotational domains. Use it as a building block for modeling pneumatic pumps and motors.

The pneumatic flow rate and mechanical rotation are related by the following equations:

$$Q = D \cdot \omega$$

$$T = \begin{cases} D \cdot (p_A - p_B) \cdot \eta & \text{for } (p_A - p_B) \cdot \omega >= 0 \\ D \cdot (p_A - p_B) / \eta & \text{for } (p_A - p_B) \cdot \omega < 0 \end{cases}$$

where

Q	Volumetric flow rate flowing from port A to port B
p_A	Pressure at port A
p_B	Pressure at port B
ω	Shaft angular rotational speed
T	Mechanical torque
D	Volumetric displacement per unit rotation
η	Converter efficiency

The torque equation depends on the direction of power flow, and is always such that the conversion results in some thermal losses.

From considering energy flow, the heat flow out (q_o) of the converter must equate to the heat flow in (q_i) minus mechanical work done. Therefore, the heat equations are:

$$q_i = |G| \cdot c_p \cdot T_i$$

$$q_o = \begin{cases} q_i - D \cdot (p_A - p_B) \cdot \omega \cdot \eta & \text{for } (p_A - p_B) \cdot \omega >= 0 \\ q_i - D \cdot (p_A - p_B) \cdot \omega / \eta & \text{for } (p_A - p_B) \cdot \omega < 0 \end{cases}$$

where G is the mass flow rate.

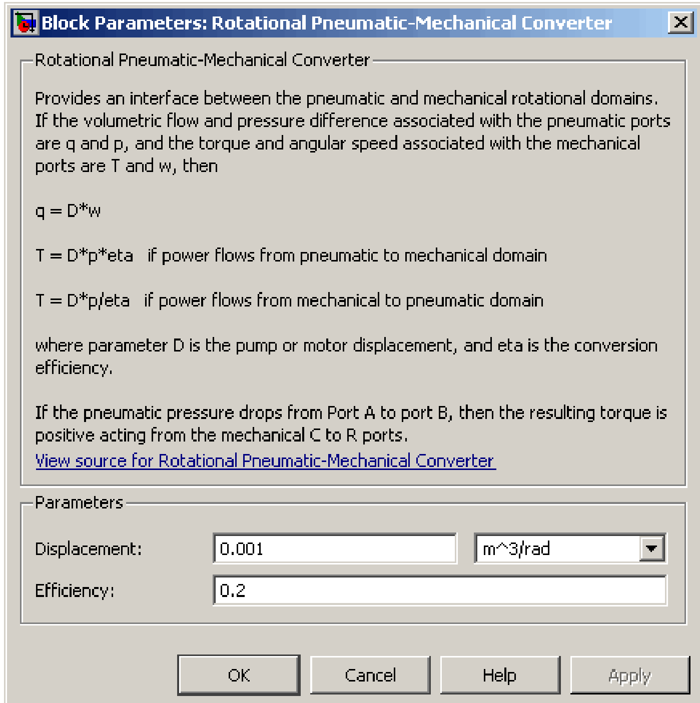
If the pneumatic pressure drops from port A to port B, then the resulting torque is positive acting from the mechanical port C to port R.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- Conversion efficiency is constant, that is, it does not depend on torque or speed.
- Gas flow rate is linearly dependent of pump speed.
- The process is adiabatic, that is, there is no heat transfer with the environment.
- Gravitational effects can be neglected.

Dialog Box and Parameters



Displacement

Specify the effective piston displacement, as volume per unit angle. The default value is `.001` m^3/rad.

Efficiency

Specify the converter efficiency. The default value is `0.2`.

Ports

The block has the following ports:

A

Pneumatic conserving port associated with the converter inlet.

B

Pneumatic conserving port associated with the converter outlet.

R
: Mechanical rotational conserving port associated with the piston (rod).

C
: Mechanical rotational conserving port associated with the reference (case).

See Also

Rotary Pneumatic Piston Chamber

Rotational Spring

Purpose

Simulate ideal spring in mechanical rotational systems

Library

Mechanical Rotational Elements

Description

The Rotational Spring block represents an ideal mechanical rotational linear spring, described with the following equations:

$$T = K \cdot \varphi$$

$$\varphi = \varphi_{init} + \varphi_R - \varphi_C$$

$$\omega = \frac{d\varphi}{dt}$$

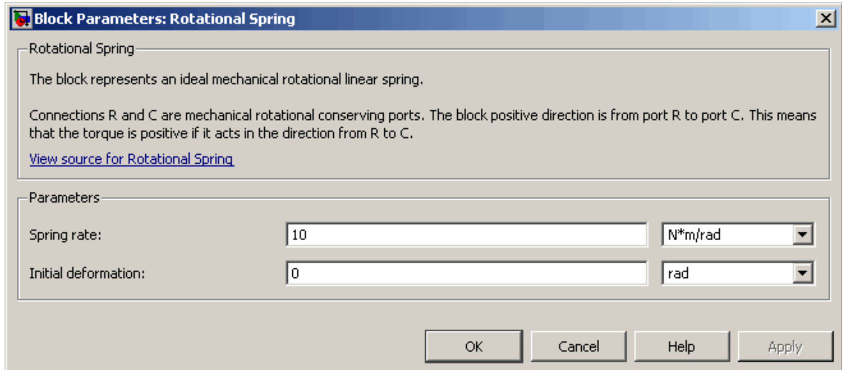
where

T	Torque transmitted through the spring
K	Spring rate
φ	Relative displacement angle (spring deformation)
φ_{init}	Spring preliminary winding (spring offset)
φ_{R},φ_{C}	Absolute angular displacements of terminals R and C, respectively
ω	Relative angular velocity
t	Time

The block positive direction is from port R to port C. This means that the torque is positive if it acts in the direction from R to C.

Rotational Spring

Dialog Box and Parameters



Spring rate

Spring rate. The default value is `10` N*m/rad.

Initial deformation

Spring initial deformation, or offset, in angular units. The deformation is determined as $\varphi = \varphi_{init} + \varphi_R - \varphi_C$, where φ_{init} is the initial deformation, and φ_R,$\varphi_C$are the absolute angular displacements of terminals R and C in the globally assigned positive direction. The spring can be initially compressed ($\varphi_{init} > 0$) or stretched ($\varphi_{init} < 0$). This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `0`.

Ports

The block has the following ports:

`R`

Mechanical rotational conserving port.

`C`

Mechanical rotational conserving port.

See Also

Rotational Damper

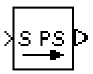
Rotational Friction

Rotational Hard Stop

Purpose Convert Simulink input signal into physical signal

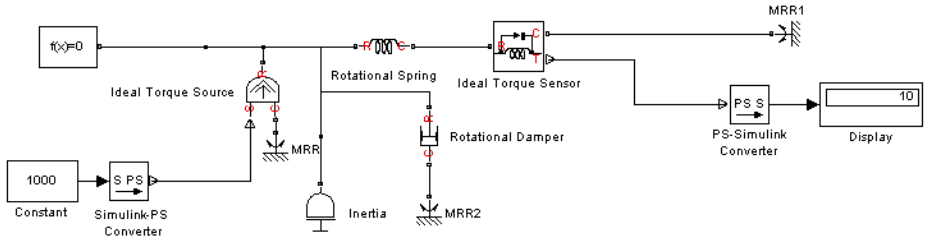
Library Utilities

Description The Simulink-PS Converter block converts the input Simulink signal into a physical signal. Use this block to connect Simulink sources or other Simulink blocks to the inputs of a Physical Network diagram.



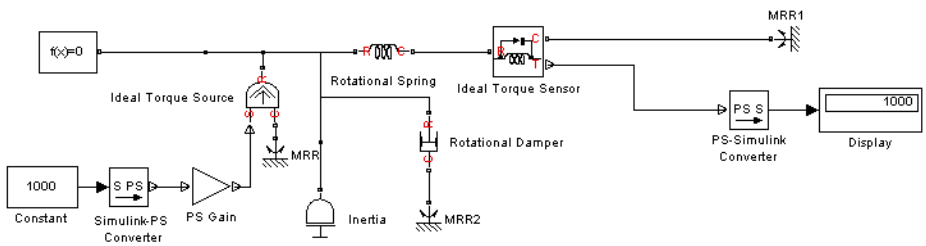
You specify the desired units as the **Input signal unit** parameter. If you leave the block unitless, with the **Input signal unit** parameter set to `1`, then the physical signal units are inferred from the destination block. The default destination block units are meter-kilogram-second or MKS (SI). If you specify different units, commensurate with the expected default units of the destination block input, then the unit manager attaches these units to the input Simulink signal value and performs the necessary unit conversion when providing the signal to the destination block.

In the diagram below, the Ideal Torque Source block expects a torque signal, in N*m, on its S port. The Constant source block provides the value for this input signal. If you left the Simulink-PS Converter block unitless, the Ideal Torque Source block would generate torque of 1000 N*m. The parameters of other blocks in this example are chosen so that the output value of the Ideal Torque Sensor block is equal to the torque generated by the Ideal Torque Source block, and therefore the Display block would show the value of 1000. If you change the **Input signal unit** parameter value in the Simulink-PS Converter block to `N*cm`, the unit manager performs the conversion and the Ideal Torque Source block generates torque of 10 N*m; the torque value in the Display block changes to 10, as shown in the diagram.



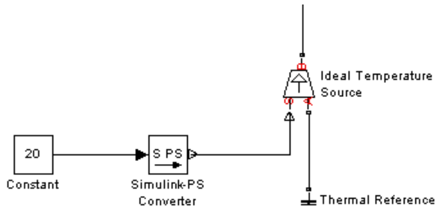
Note Currently, physical units are not propagated through the blocks in the Physical Signals library, such as PS Add, PS Gain, and so on. If your diagram contains a Physical Signals block after a Simulink-PS Converter block, the unit specification in the Simulink-PS Converter block does not propagate to the rest of the network.

In the following example, the PS Gain block is installed after the Simulink-PS Converter block. It stops the unit propagation to the rest of the physical network, and the Ideal Torque Source block will generate torque of 1000 N*m regardless of the **Input signal unit** parameter setting in the Simulink-PS Converter block.



When the input signal is related to thermodynamic variables and contains units of temperature, you must decide whether affine conversion needs to be applied. For more information, see "When to Apply Affine Conversion". Usually, if the input signal represents a relative temperature, that is, a change in temperature, you need to apply linear conversion, $\Delta T_{new} = L * \Delta T_{old}$ (the default method). However, if the input signal represents an absolute temperature, you need to apply affine conversion, $T_{new} = L * T_{old} + O$.

For example, in the Simulink-PS Converter block shown in the following diagram, if you type `C` in the **Input signal unit** field and select the **Apply affine conversion** check box, the temperature generated by the Ideal Temperature Source block is equal to 293.15 K. However, if you leave the **Apply affine conversion** check box clear, the output of the Ideal Temperature Source block is 20 K.

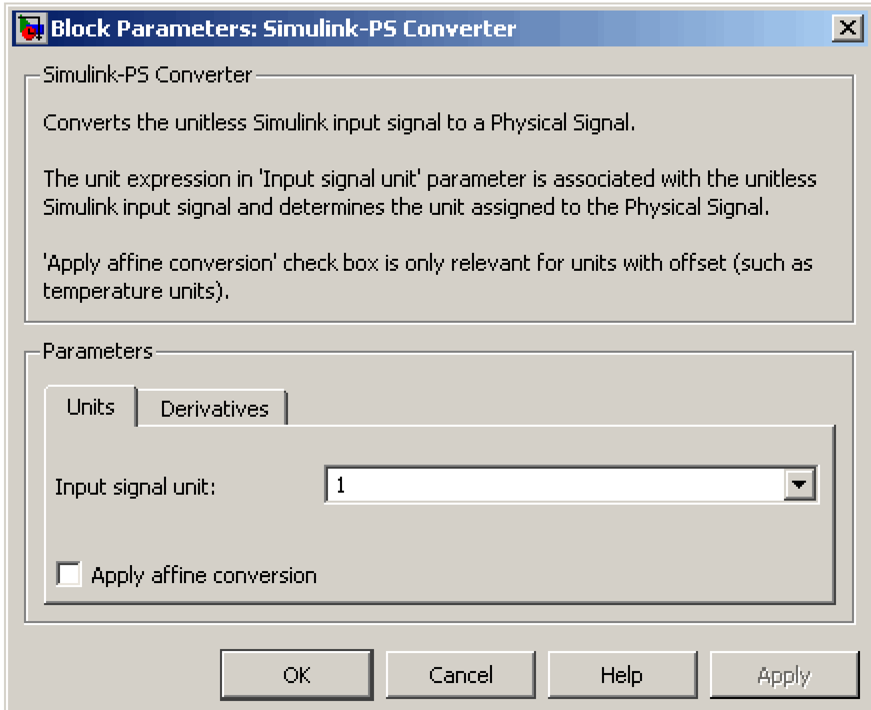


Dialog Box and Parameters

The block dialog box contains two tabs:

- "Units" on page 2-259
- "Derivatives" on page 2-260

Units



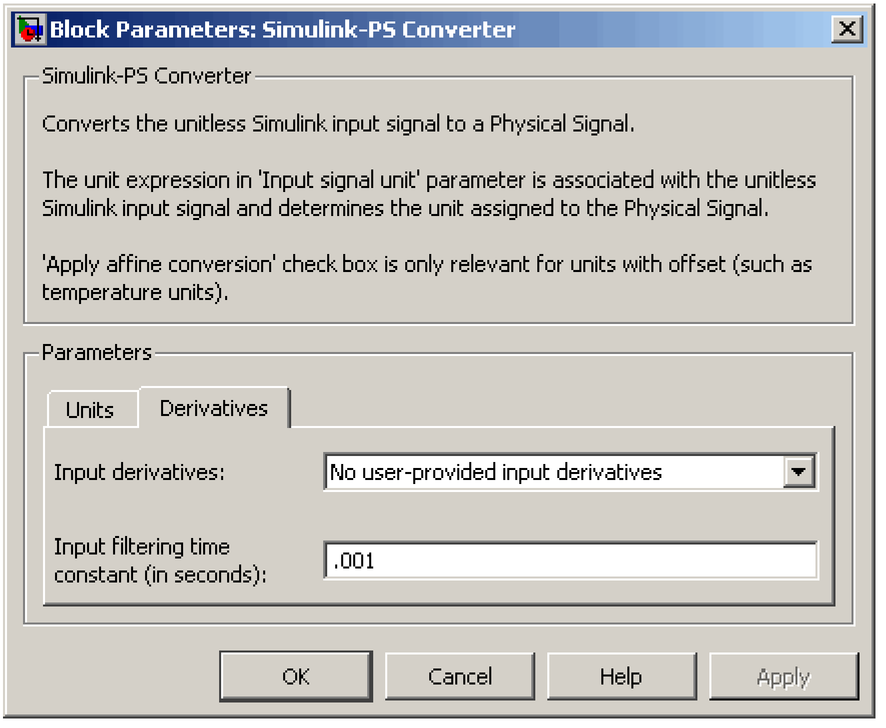
Input signal unit

Units to be assigned to the physical signal. These units must be commensurate with the expected default units of the destination block input. You can select a unit from the drop-down list, or type the desired unit name, such as `rpm`, or a valid expression, such as `rad/s`. For more information and a list of unit abbreviations, see "Working with Physical Units". The default value is `1`, which means that the units of the physical signal at the block output match the expected default units of the destination block input.

Apply affine conversion

This check box is applicable only for units that can be converted either with or without an affine offset, such as thermal units. For more information, see "Thermal Unit Conversions".

Derivatives



Input derivatives

This parameter is applicable only when you use an explicit solver for your model. You can select between two ways of providing time derivatives of the input signals:

- `No user-input provided derivatives` — Provide input derivatives by filtering the input through a low-pass filter.

The derivative of the filtered input is then computed by the simulation engine. This is the default method. If you use it, set the appropriate **Input filtering time constant** parameter value, as described below.

Because input filtering can appreciably change the input signal and drastically affect simulation results if the time constant is too large, a warning is issued when input filtering is used. The warning indicates which Simulink-PS Converter blocks have their input signals filtered. This warning can be turned off (or changed to an error) by changing the preferences on the **Simscape** pane of the Configuration Parameters dialog box.

- `First derivative of input user-provided` — Provide first derivative of the input signal as an additional input signal to the Simulink-PS Converter block. If you select this option, input filtering is turned off and an additional Simulink input port appears on the Simulink-PS Converter block, to let you connect the signal providing input derivatives.

Input filtering time constant (in seconds)

This parameter is applicable only if the **Input derivatives** parameter is set to `No user-input provided derivatives`. It specifies the filter time constant, which controls the filtering of the input signal. The filtered input follows the true input but is smoothed, with a lag on the order of the time constant chosen. You should set the time constant to a value no larger than the smallest time interval of interest in the system. The trade-off in choosing a very small time constant is that the filtered input signal will be closer to the true input signal, at the cost of increasing the stiffness of the system and slowing down the simulation. The default value is `.001` s.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify any of the block parameters, with the following exception: if the **Input derivatives** parameter has been set to `No user-input provided` `derivatives` prior to entering Restricted mode, you can change the value of the **Input filtering time constant** parameter.

Ports

The block has one or two Simulink input ports, depending on the **Input derivatives** parameter value, located on its left side, and a physical signal output port, located on its right side (in the block default orientation).

See Also

PS-Simulink Converter

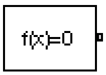
Purpose

Represent Physical Networks environment and solver configuration

Library

Utilities

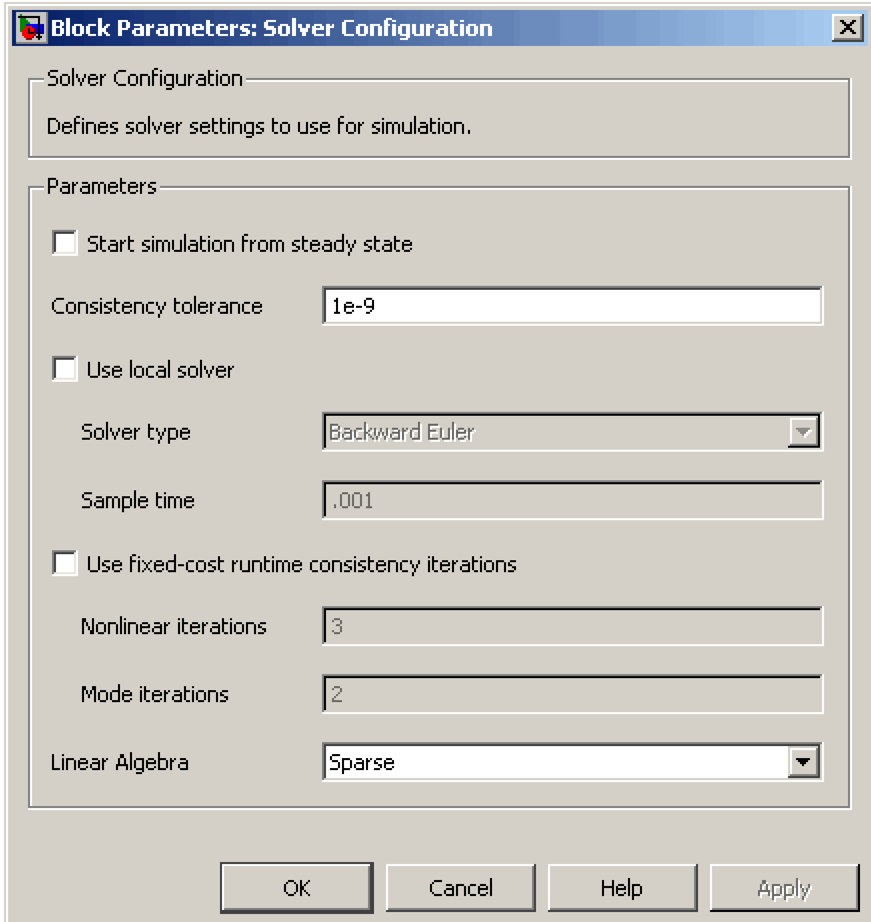
Description



Each physical device represented by a connected Simscape block diagram requires global environment information for simulation. The Solver Configuration block specifies this global information and provides parameters for the solver that your model needs before you can begin simulation.

Each topologically distinct Simscape block diagram requires exactly one Solver Configuration block to be connected to it.

Dialog Box and Parameters



Start simulation from steady state

When this box is selected, the solver attempts to find the steady state that would result if the inputs to the system were held constant for a sufficiently large time, starting from the initial state obtained from the initial conditions computation. For more information , see "Computing Initial Conditions". Simulation then starts from this steady state.

Note Using the **Initial state** option on the **Data Import/Export** pane of the Configuration Parameters dialog box overrides the **Start simulation from steady state** option.

Consistency Tolerance

This parameter affects the nonlinear solver used for computing initial conditions and for transient initialization. It determines how accurately the algebraic constraints are to be satisfied at the beginning of simulation and after every discrete event (for example, a discontinuity resulting from a valve opening, a hard stop hitting the stop, and so on). Decreasing the parameter value (that is, tighter tolerance) results in a more reliable time simulation. Increase the parameter value (that is, relax the tolerance) if solving for initial conditions failed to converge, or to reduce the computation time. The default value is `1e-9`, which is applicable to most cases.

Use local solver

Lets you use a sample-based local solver with a sample time specified by the **Sample time** parameter, described below. In sample-based simulation, all the Physical Network states, otherwise represented as continuous, become discrete states. The solver updates the states once per time step. This option is especially useful for code generation, or hardware-in-the-loop (HIL) simulations.

This option makes it possible to perform simulations with a predictable (and typically nearly-fixed) run time per unit of simulated time. In order to achieve this fixed-cost behavior, select **Use fixed-cost runtime consistency iterations** as well as **Use local solver**. Also, the fixed-cost behavior is only obtained if you use a fixed step solver for the entire model, by using the **Solver options** parameters on the **Solver** pane of the Configuration Parameters dialog box. In the typical case of a model with no continuous states outside the Physical Networks parts, select `Fixed-step` under **Type** and `discrete (no continuous states)` under **Solver**. Otherwise, the software may automatically change the solver for a model with no continuous states to either Fixed-Step Discrete or Variable-Step Discrete, depending on whether the solver type choice in Configuration Parameters is `Fixed-step` or `Variable-step`, and will issue a warning when making the change. Note that Variable-Step Discrete solver may take additional steps beyond the ones specified by the **Sample Time** parameter, and is therefore not a good choice for fixed-cost simulation.

Note If you use a local solver, simultaneous use of Simulink or Simulink® Control Design™ linearization tools is not recommended.

Solver type

Select the solver type used for updating the states: `Backward Euler` or `Trapezoidal Rule`. The **Use local solver** check box must be selected. `Backward Euler` is stable and has good (first-order) local accuracy, but typically gives a computed solution which has numerical damping compared to the true solution. `Trapezoidal Rule` has better (second order) local accuracy and does not suffer from numerical damping, but is only marginally stable, so that fast dynamics that are damped quickly in the actual system may be damped only slowly in the `Trapezoidal Rule` simulation. `Trapezoidal Rule` is slightly less efficient. The default is `Backward Euler` because it is more robust to increasing the time step for stiff systems, which are typically encountered in physical modeling.

Sample time

Specify the sample time for the local solver. The **Use local solver** check box must be selected. The sample time must be positive. The default is `.001` s.

The trade-off in choosing a sample time is simulation speed versus accuracy, stability, and robustness. A larger sample time will result in faster simulations (less real time per unit of simulated time), but also a less accurate and less robust simulation. If simulation fails or results look unphysical, try a smaller sample time. Models with friction or hard stops are particularly difficult for the sample-based solver, and may not work at all or may require a very small choice of sample time. Also, for `Trapezoidal Rule`, ringing becomes more of a problem as the sample time is increased.

It is possible to perform multirate simulations using the local solver option. This means having more than one Solver Configuration block in the model, with different sample times (or having a sample-based Simulink block in the model with a different sample time from the Solver Configuration block). To avoid Simulink errors in sample time propagation, The MathWorks recommends that you select the **Automatically handle rate transition for data transfer** check box on the **Solver** pane of the Configuration Parameters dialog box.

Use fixed-cost runtime consistency iterations

Lets you perform transient initialization at a fixed computational cost for real-time simulation. If you select this check box, you can specify the maximum number of nonlinear and mode iterations for transient initialization. If the system does not converge upon reaching these numbers, it ignores the failure and goes to the next step. If you clear the check box, the system uses a more robust and time-consuming algorithm, and errors out if it fails to reach convergence at the time of transient initialization.

Nonlinear Iterations

Specify the maximum number of Newton iterations at the time of transient initialization. The **Use fixed-cost runtime consistency iterations** check box must be selected. The default number is `3`.

Mode Iterations

Specify the maximum number of mode iterations at the time of transient initialization. The **Use fixed-cost runtime consistency iterations** check box must be selected. The default number is `2`. Only one major mode update per step is performed when using local solvers, therefore this parameter is not available if the **Use local solver** check box is selected.

Linear Algebra

Specifies how the solver treats matrices. The parameter can have one of two values: `Sparse` or `Full`. The default value of the parameter is `Sparse`.

This parameter affects the simulation speed, depending on the number of states. For smaller systems, `Full` provides faster results. For larger systems, `Sparse` is typically faster.

If you use a local solver, this parameter value is propagated to code generated from your model. If you do not use a local solver, generated code treats this parameter value as `Full`, regardless of your setting.

Ports

The block has one conserving port. You can add this block anywhere on a physical network circuit by creating a branching point and connecting it to the only port of the Solver Configuration block.

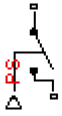
Purpose

Simulate switch controlled by external physical signal

Library

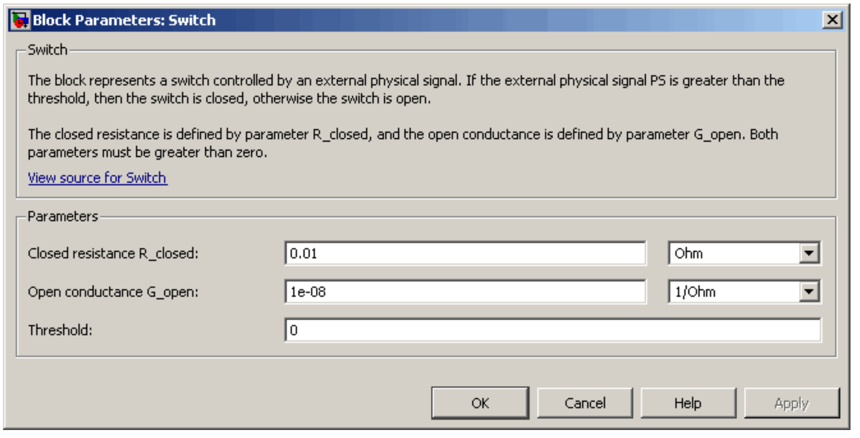
Electrical Elements

Description



The Switch block models a switch controlled by an external physical signal. If the external physical signal PS is greater than the value specified in the **Threshold** parameter, then the switch is closed, otherwise the switch is open.

Dialog Box and Parameters



Closed resistance R_closed

The resistance of the switch when it is closed. The parameter value must be greater than zero. The default value is `0.01` Ω.

Open conductance G_open

The conductance of the switch when it is open. The parameter value must be greater than zero. The default value is `1e-8` 1/Ω.

Threshold

The threshold value for opening and closing the switch. If the external physical signal PS is greater than this value, then the switch is closed, otherwise the switch is open. The default value is 0.

Ports

The block has two electrical conserving ports and one physical signal port PS.

See Also

PS Switch

Purpose

Simulate mass in thermal systems

Library

Thermal Elements

Description

The Thermal Mass block represents a thermal mass, which reflects the ability of a material or a combination of materials to store internal energy. The property is characterized by mass of the material and its specific heat. The thermal mass is described with the following equation:

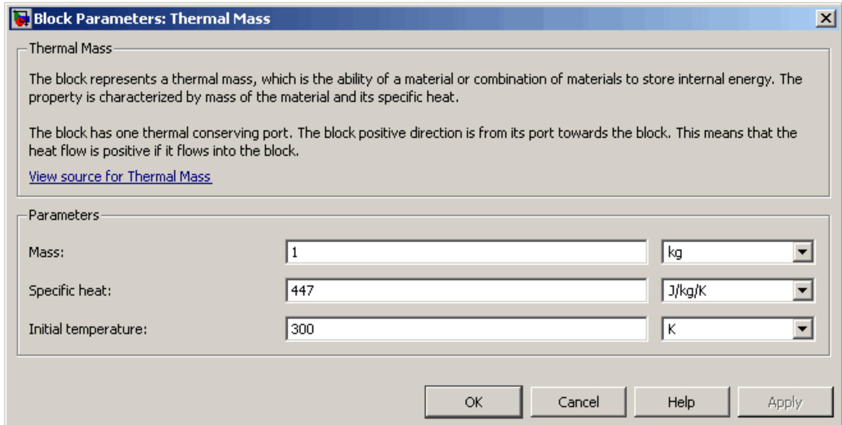
$$Q = c \bullet m \frac{dT}{dt}$$

where

Q	Heat flow
c	Specific heat of mass material
m	Mass
T	Temperature
t	Time

The block has one thermal conserving port. The block positive direction is from its port towards the block. This means that the heat flow is positive if it flows into the block.

Dialog Box and Parameters



Mass

Mass. The default value is 1 kg.

Specific heat

Specific heat of the material. The default value is 447 J/kg/K.

Initial temperature

Initial temperature of the mass. This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is 300 K.

Ports

The block has one thermal conserving port, associated with the mass connection to the system.

See Also

Mass

Purpose

Simulate reference for thermal ports

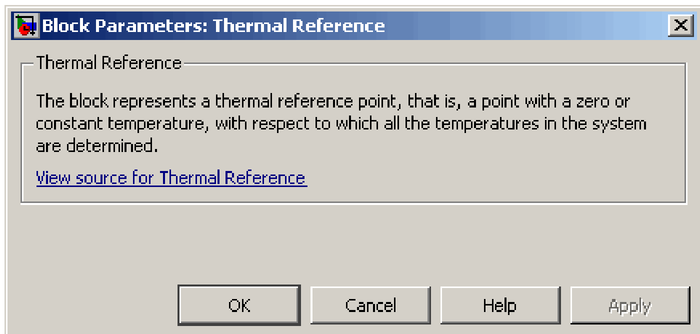
Library

Thermal Elements

Description

The Thermal Reference block represents a thermal reference point, that is, a point with an absolute zero temperature, with respect to which all the temperatures in the system are determined.

Dialog Box and Parameters



The Thermal Reference block has no parameters.

Ports

The block has one thermal conserving port.

See Also

Electrical Reference

Hydraulic Reference

Mechanical Rotational Reference

Mechanical Translational Reference

Translational Damper

Purpose

Simulate viscous damper in mechanical translational systems

Library

Mechanical Translational Elements

Description

The Translational Damper block represents an ideal mechanical translational viscous damper, described with the following equations:

$$F = Dv$$

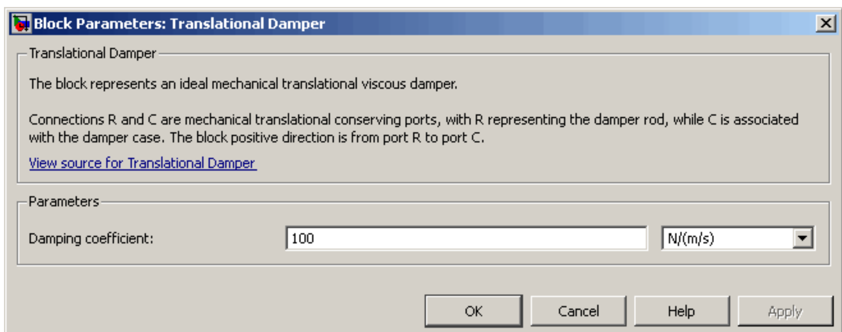
$$v = v_R - v_C$$

where

F	Force transmitted through the damper
D	Damping (viscous friction) coefficient
v	Relative velocity
v_R, v_C	Absolute velocities of terminals R and C, respectively

The block positive direction is from port R to port C. This means that the force is positive if it acts in the direction from R to C.

Dialog Box and Parameters



Damping coefficient

Damping coefficient, defined by viscose friction. The default value is 100 N/(m/s).

Ports

The block has the following ports:

`R`
: Mechanical translational conserving port associated with the damper rod.

`C`
: Mechanical translational conserving port associated with the damper case.

See Also

Translational Friction

Translational Hard Stop

Translational Spring

Translational Electromechanical Converter

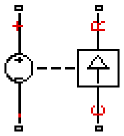
Purpose

Provide interface between electrical and mechanical translational domains

Library

Electrical Elements

Description



The Translational Electromechanical Converter block provides an interface between the electrical and mechanical translational domains. It converts electrical energy into mechanical energy in the form of translational motion, and vice versa. The converter is described with the following equations:

$$F = K \cdot I$$

$$V = K \cdot U$$

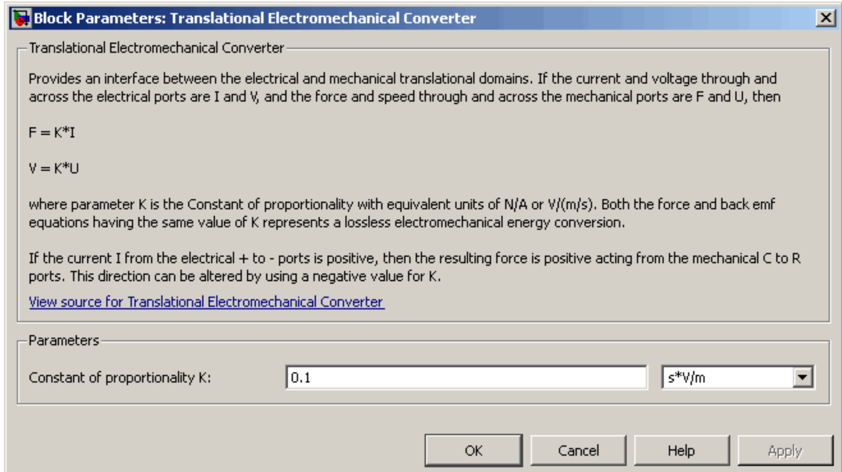
where

V	Voltage across the electrical ports of the converter
I	Current through the electrical ports of the converter
F	Force
U	Speed
K	Constant of proportionality

The Translational Electromechanical Converter block represents a lossless electromechanical energy conversion, therefore the same constant of proportionality is used in both equations.

Connections + and – are conserving electrical ports corresponding to the positive and negative terminals of the converter, respectively. Connections C and R are conserving mechanical translational ports. If the current flowing from the positive to the negative terminal is positive, then the resulting force is positive acting from port C to port R. This direction can be altered by using a negative value for K.

Dialog Box and Parameters



Constant of proportionality K

Constant of proportionality for electromechanical conversions. The default value is `0.1` V/(m/s).

Ports

The block has the following ports:

`+`

Electrical conserving port associated with the converter positive terminal.

`-`

Electrical conserving port associated with the converter negative terminal.

`C`

Mechanical translational conserving port.

`R`

Mechanical translational conserving port.

See Also

Rotational Electromechanical Converter

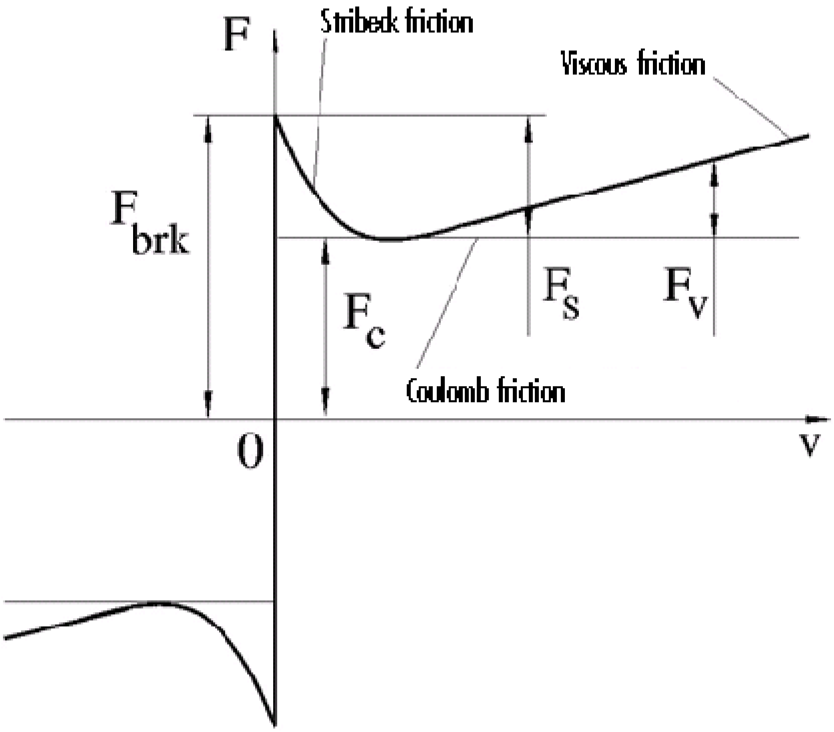
Translational Friction

Purpose Simulate friction in contact between moving bodies

Library Mechanical Translational Elements

Description

The Translational Friction block represents friction in contact between moving bodies. The friction force is simulated as a function of relative velocity and is assumed to be the sum of Stribeck, Coulomb, and viscous components, as shown in the following figure.



The Stribeck friction, F_S, is the negatively sloped characteristics taking place at low velocities (see [1]). The Coulomb friction, F_C, results in a constant force at any velocity. The viscous friction, F_V, opposes motion with the force directly proportional to the relative velocity. The sum of the Coulomb and Stribeck frictions at the vicinity of zero velocity is often referred to as the breakaway friction, F_{brk}. The friction is approximated with the following equations:

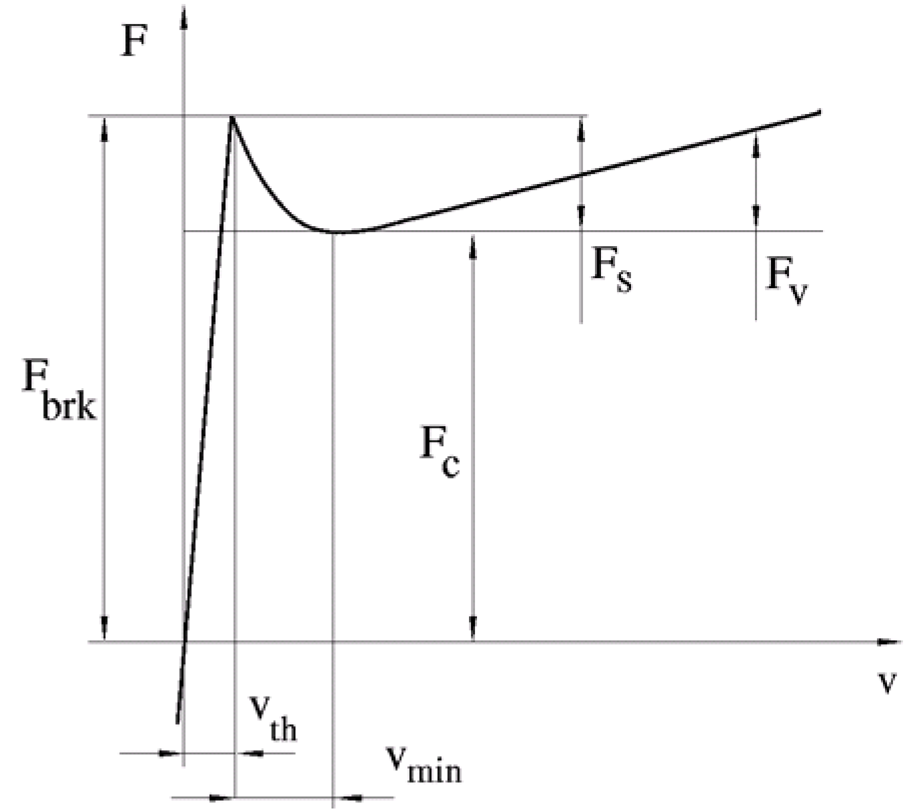
$$F = \left(F_C + (F_{brk} - F_C) \cdot \exp(-c_v \mid v \mid)\right) sign(v) + fv$$

$$v = v_R - v_C$$

where

F	Friction force
F_C	Coulomb friction
F_{brk}	Breakaway friction
c_v	Coefficient
v	Relative velocity
$v_{R,} v_C$	Absolute velocities of terminals R and C, respectively
f	Viscous friction coefficient

The approximation above is too idealistic and has a substantial drawback. The characteristic is discontinuous at $v = 0$, which creates considerable computational problems. It has been proven that the discontinuous friction model is a nonphysical simplification in the sense that the mechanical contact with distributed mass and compliance cannot exhibit an instantaneous change in force (see [1]). There are numerous models of friction without discontinuity. The Translational Friction block implements one of the simplest versions of continuous friction models. The friction force-relative velocity characteristic of this approximation is shown in the following figure.



The discontinuity is eliminated by introducing a very small, but finite, region in the zero velocity vicinity, within which friction force is assumed to be linearly proportional to velocity, with the proportionality coefficient F_{brk}/v_{th}, where v_{th} is the velocity threshold. It has been proven experimentally that the velocity threshold in the range between 10^{-4} and 10^{-6} m/s is a good compromise between the accuracy and computational robustness and effectiveness. Notice that friction force computed with this approximation does not actually stop relative motion when an acting force drops below breakaway friction level. The bodies will creep relative to each other at a very small velocity proportional to acting force.

As a result of introducing the velocity threshold, the block equations are slightly modified:

- If $|v| >= v_{th}$,

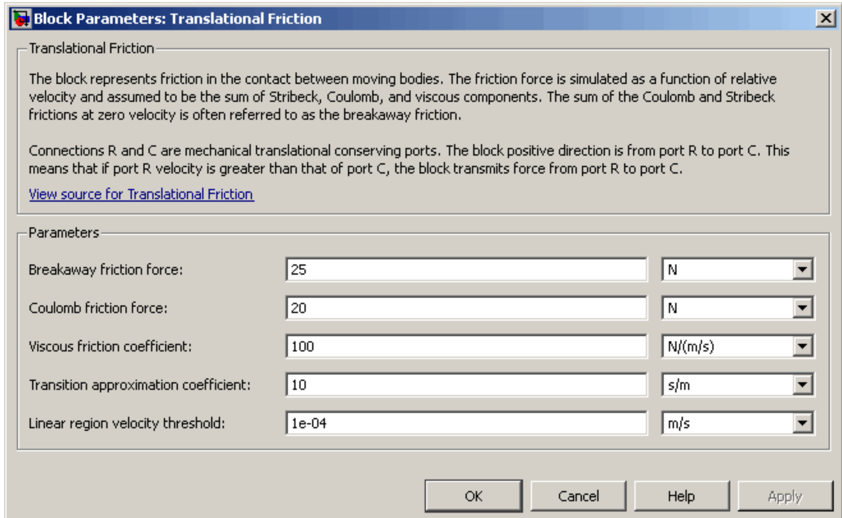
$$F = \left(F_C + (F_{brk} - F_C) \cdot \exp(-c_v |v|)\right) sign(v) + fv$$

- If $|v| < v_{th}$,

$$F = v \frac{\left(fv_{th} + \left(F_C + (F_{brk} - F_C) \cdot \exp(-c_v v_{th})\right)\right)}{v_{th}}$$

The block positive direction is from port R to port C. This means that if the port R velocity is greater than that of port C, the block transmits force from R to C.

Dialog Box and Parameters



Breakaway friction force

Breakaway friction force, which is the sum of the Coulomb and the static frictions. It must be greater than or equal to the Coulomb friction force value. The default value is 25 N.

Coulomb friction force

Coulomb friction force, which is the friction that opposes motion with a constant force at any velocity. The default value is 20 N.

Viscous friction coefficient

Proportionality coefficient between the friction force and the relative velocity. The parameter value must be greater than or equal to zero. The default value is 100 N/(m/s).

Transition approximation coefficient

The parameter sets the value of coefficient c_v, which is used for the approximation of the transition between the static and the Coulomb frictions. Its value is assigned based on the following considerations: the static friction component reaches approximately 95% of its steady-state value at velocity $3/c_v$, and 98% at velocity $4/c_v$, which makes it possible to develop an approximate relationship c_v ~= 4/v_{min}, where v_{min} is the relative velocity at which friction force has its minimum value. By default, c_v is set to 10 s/m, which corresponds to a minimum friction at velocity of about 0.4 m/s.

Linear region velocity threshold
The parameter sets the small vicinity near zero velocity, within which friction force is considered to be linearly proportional to the relative velocity. The MathWorks recommends that you use values in the range between 1e-6 and 1e-4 m/s. The default value is 1e-4 m/s.

Ports

The block has the following ports:

R
Mechanical translational conserving port.

C
Mechanical translational conserving port.

References

[1] B. Armstrong, C.C. de Wit, *Friction Modeling and Compensation*, The Control Handbook, CRC Press, 1995

See Also

Translational Damper

Translational Hard Stop

Translational Spring

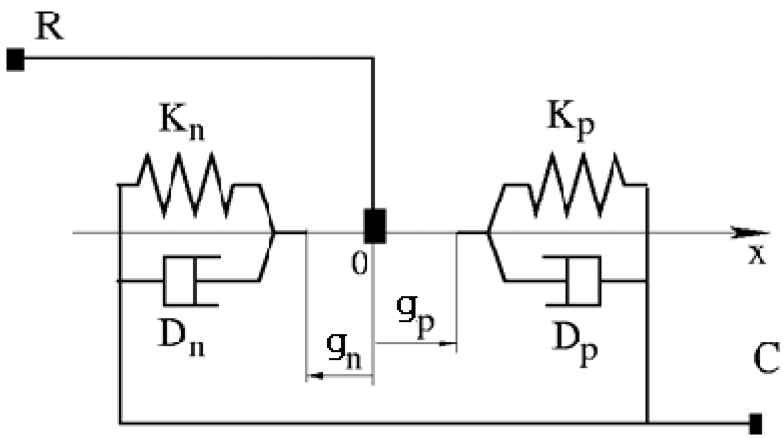
Translational Hard Stop

Purpose Simulate double-sided translational hard stop

Library Mechanical Translational Elements

Description

The Translational Hard Stop block represents a double-sided mechanical translational hard stop that restricts motion of a body between upper and lower bounds. Both ports of the block are of mechanical translational type. The impact interaction between the slider and the stops is assumed to be elastic. This means that the stop is represented as a spring that comes into contact with the slider as the gap is cleared and opposes slider penetration into the stop with the force linearly proportional to this penetration. To account for energy dissipation and nonelastic effects, the damping is introduced as the block's parameter, thus making it possible to account for energy loss. The following schematic shows the idealization of the mechanical translational hard stop adopted in the block:



The hard stop is described with the following equations:

$$F = \begin{cases} K_p \bullet \delta + D_p (v_R - v_C) & \text{for } \delta >= g_p \\ 0 & \text{for } g_n < \delta < g_p \\ K_n \bullet \delta + D_n (v_R - v_C) & \text{for } \delta <= g_n \end{cases}$$

$$\delta = x_R - x_C$$

$$v_R = \frac{dx_R}{dt}$$

$$v_C = \frac{dx_C}{dt}$$

where

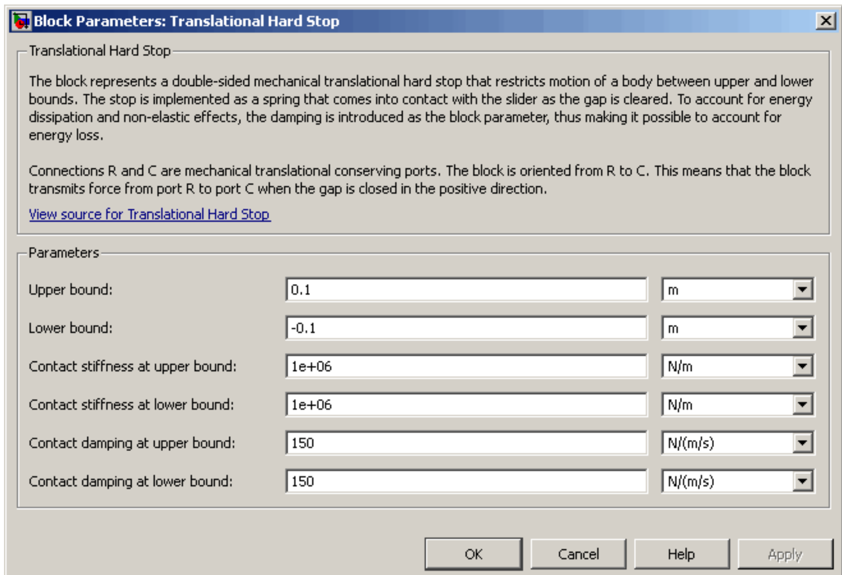
F	Interaction force between the slider and the case
δ	Relative displacement between the slider and the case
g_p	Gap between the slider and the case in positive direction
g_n	Gap between the slider and the case in negative direction
v_R, v_C	Absolute velocities of terminals R and C, respectively
x_R, x_C	Absolute displacements of terminals R and C, respectively
K_p	Contact stiffness at positive restriction
K_n	Contact stiffness at negative restriction
D_p	Damping coefficient at positive restriction
D_n	Damping coefficient at negative restriction
t	Time

The equations are derived with respect to the local coordinate system whose axis is directed from port R to port C. The terms “positive” and “negative” in the variable descriptions refer to this coordinate system, and the gap in negative direction must be specified with negative value.

If the local coordinate system is not aligned with the globally assigned positive direction, the gaps interchange their values with respective sign adjustment.

The block is oriented from R to C. This means that the block transmits force from port R to port C when the gap in positive direction is cleared up.

Dialog Box and Parameters



Upper bound

Gap between the slider and the upper bound. The direction is specified with respect to the local coordinate system, with the slider located in the origin. A positive value of the parameter specifies the gap between the slider and the upper bound. A negative value sets the slider as penetrating into the upper bound. The default value is `0.005` m.

Lower bound

Gap between the slider and the lower bound. The direction is specified with respect to the local coordinate system, with the slider located in the origin. A negative value of the parameter specifies the gap between the slider and the lower bound. A positive value sets the slider as penetrating into the lower bound. The default value is `-0.005` m.

Contact stiffness at upper bound

The parameter specifies the elastic property of colliding bodies when the slider hits the upper bound. The greater the value of the parameter, the less the bodies penetrate into each other, the more rigid the impact becomes. Lesser value of the parameter makes contact softer, but generally improves convergence and computational efficiency. The default value is `10e6` N/m.

Contact stiffness at lower bound

The parameter specifies the elastic property of colliding bodies when the slider hits the lower bound. The greater the value of the parameter, the less the bodies penetrate into each other, the more rigid the impact becomes. Lesser value of the parameter makes contact softer, but generally improves convergence and computational efficiency. The default value is `10e6` N/m.

Contact damping at upper bound

The parameter specifies dissipating property of colliding bodies when the slider hits the upper bound. At zero damping, the impact is close to an absolutely elastic one. The greater the value of the parameter, the more energy dissipates during an interaction. Keep in mind that damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. For computational efficiency and convergence reasons, The MathWorks recommends that you assign a nonzero value to this parameter. The default value is 150 N*s/m.

Contact damping at lower bound

The parameter specifies dissipating property of colliding bodies when the slider hits the lower bound. At zero damping, the impact is close to an absolutely elastic one. The greater the value of the parameter, the more energy dissipates during an interaction. Keep in mind that damping affects slider motion as long as the slider is in contact with the stop, including the period when slider is pulled back from the contact. For computational efficiency and convergence reasons, The MathWorks recommends that you assign a nonzero value to this parameter. The default value is 150 N*s/m.

Ports

The block has the following ports:

`R`
: Mechanical translational conserving port associated with the slider that travels between stops installed on the case.

`C`
: Mechanical translational conserving port associated with the case.

Examples

The Mechanical System with Translational Hard Stop demo (`ssc_mechanical_system_translational_hardstop`) illustrates the use of the Translational Hard Stop block in mechanical systems. Two masses are interacting through a hard stop. The mass on the left is driven by an ideal velocity source. Plotting the displacement of the second mass against the displacement of the first mass produces a typical hysteresis curve.

See Also

Translational Damper

Translational Friction

Translational Spring

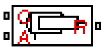
Purpose

Simulate single chamber of hydraulic cylinder as building block for various cylinder models

Library

Hydraulic Elements

Description



The Translational Hydro-Mechanical Converter block models an ideal transducer that converts hydraulic energy into mechanical energy in the form of translational motion of the converter output member. Using this block as a basic element, you can build a large variety of hydraulic cylinder models by adding application-specific effects, such as fluid compressibility, leakage, friction, hard stops, and so on.

The converter is simulated according to the following equations:

$$q = A(v_R - v_C) \bullet or$$

$$F = A \bullet p \bullet or$$

where

q	Flow rate due to fluid compressibility
A	Effective piston area
v_R	Converter rod velocity
v_C	Converter case velocity
F	Force developed by the converter
p	Gauge pressure of fluid in the converter chamber
or	Converter orientation with respect to the globally assigned positive direction. If pressure applied at port A exerts force in positive direction, *or* equals 1. If pressure applied at port A exerts force in negative direction, *or* equals –1.

Port A is a hydraulic conserving port associated with the converter inlet. Ports R and C are translational mechanical conserving ports associated with the rod and the case of the converter, respectively.

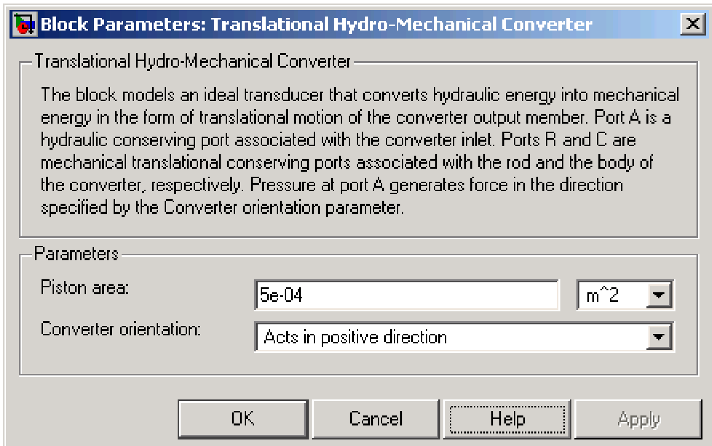
Translational Hydro-Mechanical Converter

Basic Assumptions and Limitations

The model is based on the following assumption:

- The block simulates an ideal converter, with only the transduction property considered. No inertia, friction, leakage, or other effects are taken into account.

Dialog Box and Parameters



Piston area

Effective piston area. The default value is `5e-4` m^2.

Converter orientation

Specifies converter orientation with respect to the globally assigned positive direction. The converter can be installed in two different ways, depending upon whether it exerts force in the positive or in the negative direction when pressure is applied at its inlet. If pressure applied at port A exerts force in negative direction, set the parameter to `Acts in negative direction`. The default value is `Acts in positive direction`.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Converter orientation**

All other block parameters are available for modification.

Ports

The block has the following ports:

A
: Hydraulic conserving port associated with the converter inlet.

R
: Mechanical translational conserving port associated with the rod of the converter.

C
: Mechanical translational conserving port associated with the case of the converter.

See Also

Rotational Hydro-Mechanical Converter

Translational Spring

Purpose

Simulate ideal spring in mechanical translational systems

Library

Mechanical Translational Elements

Description

The Translational Spring block represents an ideal mechanical linear spring, described with the following equations:

$$F = Kx$$

$$x = x_{init} + x_R - x_C$$

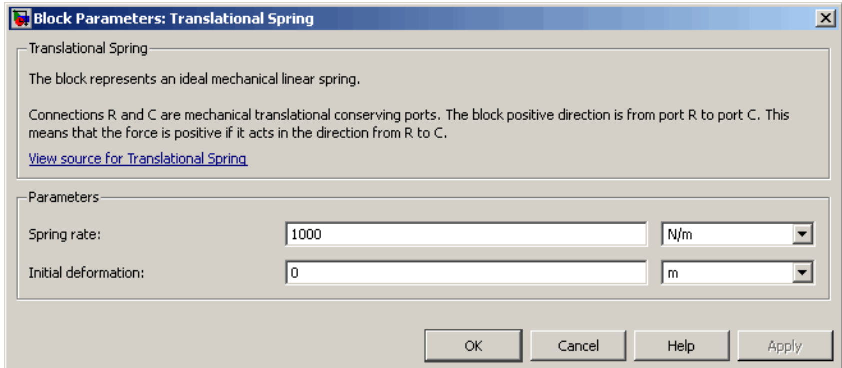
$$v = \frac{dx}{dt}$$

where

F	Force transmitted through the spring
K	Spring rate
x	Relative displacement (spring deformation)
x_{init}	Spring initial displacement (spring offset)
x_R, x_C	Absolute displacements of terminals R and C, respectively
v	Relative velocity
t	Time

The block positive direction is from port R to port C. This means that the force is positive if it acts in the direction from R to C.

Dialog Box and Parameters



Spring rate

Spring rate. The default value is 1000 N/m.

Initial deformation

Spring initial deformation, or offset, in length units. The deformation is determined as $x = x_{init} + x_R - x_C$, where x_{init} is the initial deformation, and x_R, x_C are the absolute displacements of terminals R and C in the globally assigned positive direction. The spring can be initially compressed ($x_{init} > 0$) or stretched ($x_{init} < 0$). This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is 0.

Ports

The block has the following ports:

R

Mechanical translational conserving port.

C

Mechanical translational conserving port.

See Also

Translational Damper

Translational Friction

Translational Hard Stop

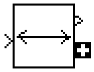
Purpose

Create two-way connector port for subsystem

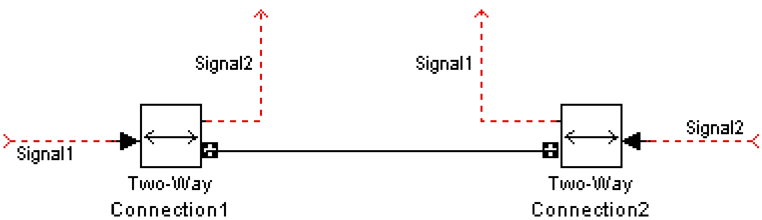
Library

Utilities

Description



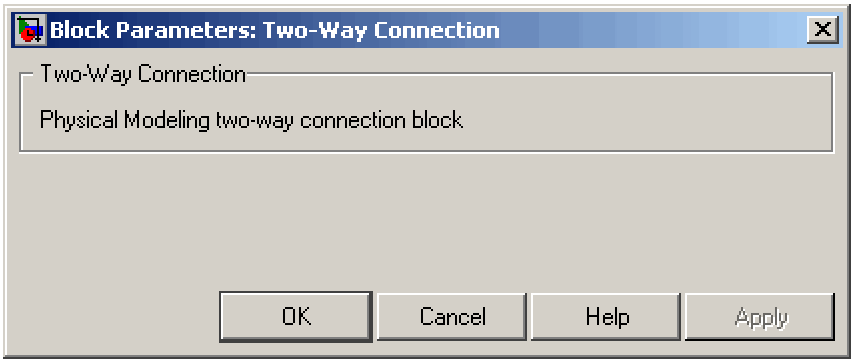
The Two-Way Connection block has a two-way connector port, which transports Simulink signals both ways. You connect this port to another two-way connector port. The schematic below illustrates how the two-way connection works. It carries the signal `Signal1` from the input port of the first Two-Way Connection block to the output port of the second Two-Way Connection block, and at the same time carries the signal `Signal2` from the input port of the second Two-Way Connection block to the output port of the first Two-Way Connection block.



The Two-Way Connection block supports invariant model architecture for top-down or bottom-up design. It lets you build subsystems as Simulink models, based on signals, and then connect them as if they are physical systems. Place the Two-Way Connection blocks inside the subsystem and connect them to the Connection Port blocks. Then the ports on the subsystem boundary appear as two-way connector ports ⊞.

Note Two-way connection blocks cannot be connected across nonvirtual subsystems.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has a Simulink input port, a Simulink output port, and a two-way connector port.

See Also

In the Using Simulink documentation, see “Working with Block Masks”.

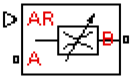
Purpose

Simulate hydraulic variable orifice created by cylindrical spool and sleeve

Library

Hydraulic Elements

Description



The Variable Area Hydraulic Orifice block models a variable orifice created by a cylindrical sharp-edged spool and a variable-area slot in a sleeve. The area of the orifice is expected to be computed outside the block and imported via the AR physical signal connection. The minimum orifice area value is 1e-12 m^2. If the input signal falls below this level (for example, turns negative), the area is saturated to this value. The flow rate through the orifice is proportional to the orifice area and the pressure differential across the orifice.

The flow rate is determined according to the following equations:

$$q = \begin{cases} C_D \cdot A\sqrt{\frac{2}{\rho}|p|} \cdot sign(p) & \text{for } Re >= Re_{cr} \\ 2C_{DL} \cdot A\frac{D_H}{\nu \cdot \rho}p & \text{for } Re < Re_{cr} \end{cases}$$

$$p = p_A - p_B$$

$$\mathrm{Re} = \frac{q \cdot D_H}{A \cdot \nu}$$

$$C_{DL} = \left(\frac{C_D}{\sqrt{\mathrm{Re}_{cr}}}\right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

q	Flow rate
p	Pressure differential
p_A, p_B	Gauge pressures at the block terminals
C_D	Flow discharge coefficient
A	Orifice passage area, provided through the signal port
D_H	Orifice hydraulic diameter
ρ	Fluid density
ν	Fluid kinematic viscosity

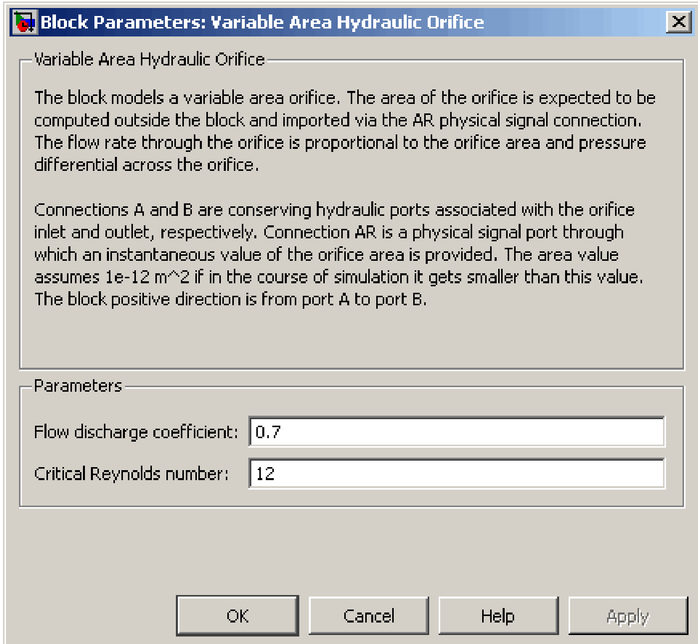
The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B and the pressure differential is determined as $p = p_A - p_B$.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- Fluid inertia is not taken into account.
- The transition between laminar and turbulent regimes is assumed to be sharp and taking place exactly at $Re=Re_{cr}$.

Dialog Box and Parameters



Flow discharge coefficient

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is `0.7`.

Critical Reynolds number

The maximum Reynolds number for laminar flow. The transition from laminar to turbulent regime is supposed to take place when the Reynolds number reaches this value. The value of the parameter depends on orifice geometrical profile, and the recommendations on the parameter value can be found in hydraulic textbooks. The default value is `12`, which corresponds to a round orifice in thin material with sharp edges.

Global Parameters

Fluid density

The parameter is determined by the type of working fluid selected for the system under design. Use the Custom Hydraulic Fluid block, or the Hydraulic Fluid block available with SimHydraulics block libraries, to specify the fluid properties.

Fluid kinematic viscosity

The parameter is determined by the type of working fluid selected for the system under design. Use the Custom Hydraulic Fluid block, or the Hydraulic Fluid block available with SimHydraulics block libraries, to specify the fluid properties.

Ports

The block has the following ports:

A

Hydraulic conserving port associated with the orifice inlet.

B

Hydraulic conserving port associated with the orifice outlet.

AR

Physical signal port that provides the value of the orifice area.

See Also

Constant Area Hydraulic Orifice

Variable Area Pneumatic Orifice

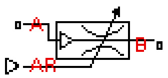
Purpose

Simulate variable orifice in pneumatic systems

Library

Pneumatic Elements

Description



The Variable Area Pneumatic Orifice block models the flow rate of an ideal gas through a sharp-edged variable-area orifice. The area of the orifice is expected to be computed outside the block and imported via the AR physical signal connection. The **Minimum area** parameter specifies the minimum orifice area value. If the input signal falls below this level (for example, turns negative), the area is saturated to this value.

The flow rate through the orifice is proportional to the orifice area and the pressure differential across the orifice.

$$G = C_d \bullet A \bullet p_i \sqrt{\frac{2\gamma}{\gamma - 1} \bullet \frac{1}{RT_i} \left[\left(\frac{p_o}{p_i} \right)^{\frac{2}{\gamma}} - \left(\frac{p_o}{p_i} \right)^{\frac{\gamma+1}{\gamma}} \right]}$$

where

G	Mass flow rate
C_d	Discharge coefficient, to account for effective loss of area due to orifice shape
A	Orifice cross-sectional area
p_i, p_o	Absolute pressures at the orifice inlet and outlet, respectively. The inlet and outlet change depending on flow direction. For positive flow ($G > 0$), $p_i = p_A$, otherwise $p_i = p_B$.
γ	The ratio of specific heats at constant pressure and constant volume, c_p / c_v
R	Specific gas constant
T	Absolute gas temperature

The choked flow occurs at the critical pressure ratio defined by

$$\beta_{cr} = \frac{p_o}{p_i} = \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

after which the flow rate depends on the inlet pressure only and is computed with the expression

$$G = C_d \bullet A \bullet p_i \sqrt{\frac{\gamma}{RT_i} \bullet \beta_{cr}^{\frac{\gamma+1}{\gamma}}}$$

The square root relationship has infinite gradient at zero flow, which can present numerical solver difficulties. Therefore, for very small pressure differences, defined by $p_o / p_i > 0.999$, the flow equation is replaced by a linear flow-pressure relationship

$$G = kC_d \bullet A \bullet T_i^{-0.5} (p_i - p_o)$$

where k is a constant such that the flow predicted for p_o / p_i is the same as that predicted by the original flow equation for $p_o / p_i = 0.999$.

The heat flow out of the orifice is assumed equal to the heat flow into the orifice, based on the following considerations:

- The orifice is square-edged or sharp-edged, and as such is characterized by an abrupt change of the downstream area. This means that practically all the dynamic pressure is lost in the expansion.
- The lost energy appears in the form of internal energy that rises the output temperature and makes it very close to the inlet temperature.

Therefore, $q_i = q_o$, where q_i and q_o are the input and output heat flows, respectively.

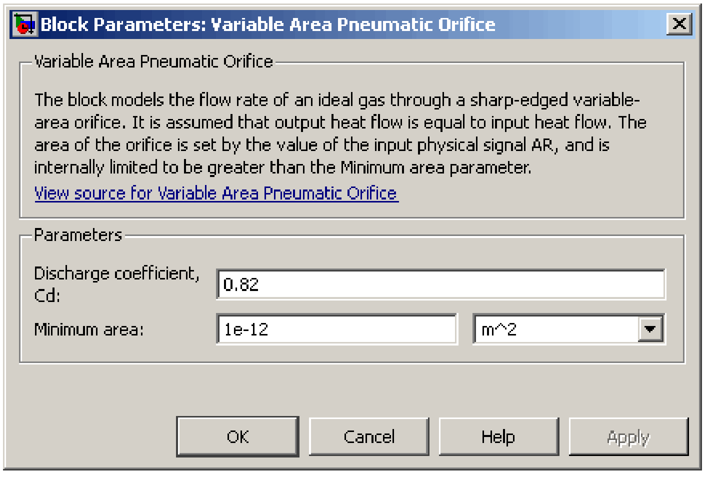
The block positive direction is from port A to port B. This means that the flow rate is positive if it flows from A to B.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- The gas is ideal.
- Specific heats at constant pressure and constant volume, c_p and c_v, are constant.
- The process is adiabatic, that is, there is no heat transfer with the environment.
- Gravitational effects can be neglected.
- The orifice adds no net heat to the flow.

Dialog Box and Parameters



Discharge coefficient, Cd

Semi-empirical parameter for orifice capacity characterization. Its value depends on the geometrical properties of the orifice, and usually is provided in textbooks or manufacturer data sheets. The default value is `0.82`.

Minimum area

Specifies the minimum orifice area value. If the input signal falls below this level (for example, turns negative), the area is saturated to this value. The default value is `1e-12` m^2.

Ports

The block has the following ports:

A

Pneumatic conserving port associated with the orifice inlet for positive flow.

B

Pneumatic conserving port associated with the orifice outlet for positive flow.

AR

Physical signal port that provides the value of the orifice area.

See Also

Constant Area Pneumatic Orifice

Constant Area Pneumatic Orifice (ISO 6358)

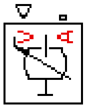
Purpose

Simulate hydraulic capacity of variable volume with compressible fluid

Library

Hydraulic Elements

Description



The Variable Hydraulic Chamber block models fluid compressibility in variable volume chambers. The fluid is considered to be a mixture of liquid and a small amount of entrained, nondissolved gas. Use this block together with the Translational Hydro-Mechanical Converter block.

Note The Variable Hydraulic Chamber block takes into account only the flow rate caused by fluid compressibility. The fluid volume consumed to create piston velocity is accounted for in the Translational Hydro-Mechanical Converter block.

The chamber is simulated according to the following equations:

$$q = \frac{V_0 + V}{E} \cdot \frac{dp}{dt}$$

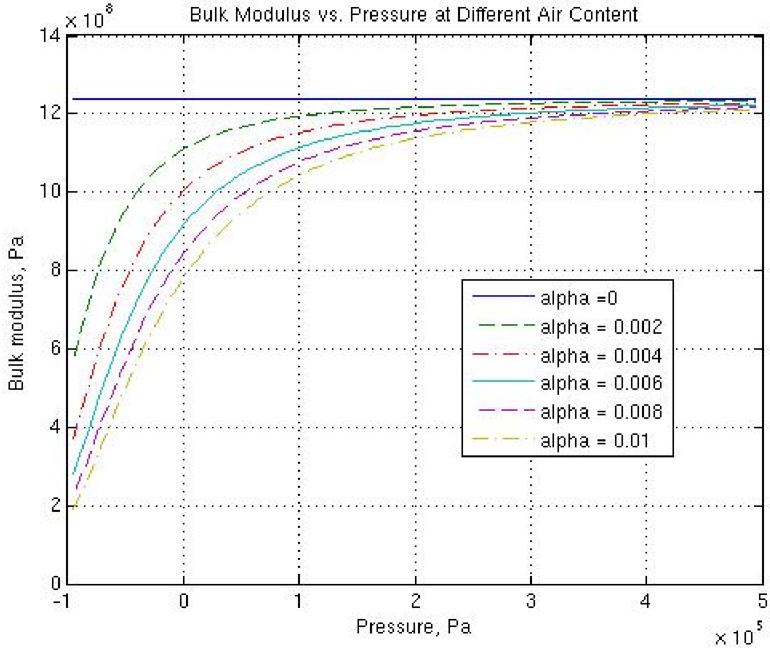
$$E = E_l \frac{1 + \alpha\left(\frac{p_a}{p_a + p}\right)^{1/n}}{1 + \alpha \frac{p_a^{1/n}}{n \cdot (p_a + p)^{\frac{n+1}{n}}} E_l}$$

where

q	Flow rate due to fluid compressibility
V_0	Initial volume of fluid in the chamber
V	Chamber volume change, provided through port V
E	Fluid bulk modulus

E_1	Pure liquid bulk modulus
p	Gauge pressure of fluid in the chamber
p_α	Atmospheric pressure
α	Relative gas content at atmospheric pressure, $\alpha = V_G/V_L$
V_G	Gas volume at atmospheric pressure
V_L	Volume of liquid
n	Gas-specific heat ratio

The main objective of representing fluid as a mixture of liquid and gas is to introduce an approximate model of cavitation, which takes place in a chamber if pressure drops below fluid vapor saturation level. As it is seen in the graph below, the bulk modulus of a mixture decreases at $p \to p_a$, thus considerably slowing down further pressure change. At high pressure, $p >> p_a$, a small amount of nondissolved gas has practically no effect on the system behavior.



Cavitation is an inherently thermodynamic process, requiring consideration of multiple-phase fluids, heat transfers, etc., and as such cannot be accurately simulated with Simscape software. But the simplified version implemented in the block is good enough to signal if pressure falls below dangerous level, and to prevent computation failure that normally occurs at negative pressures.

Port A is a hydraulic conserving port associated with the chamber inlet. Port V is a physical signal port that provides the chamber volume variation.

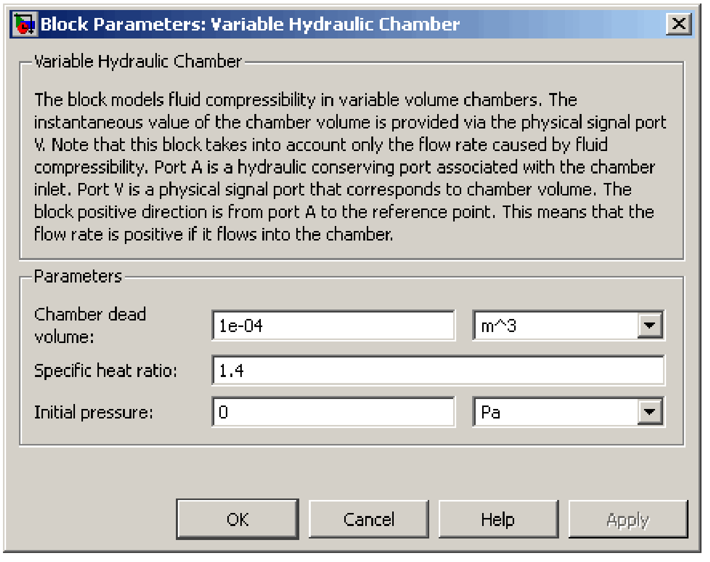
The block positive direction is from port A to the reference point. This means that the flow rate is positive if it flows into the chamber.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- Fluid density remains constant.
- Chamber volume can not be less that the dead volume.
- Fluid fills the entire chamber volume.

Dialog Box and Parameters



Chamber dead volume

Minimal volume of fluid in the chamber. The default value is `1e-4` m^3.

Specific heat ratio

Gas-specific heat ratio. The default value is `1.4`.

Initial pressure

Initial pressure in the chamber. This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `0`.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Chamber orientation**

All other block parameters are available for modification.

Global Parameters

Fluid bulk modulus
The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Nondissolved gas ratio
Nondissolved gas relative content determined as a ratio of gas volume to the liquid volume. The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Ports

The block has the following ports:

A
Hydraulic conserving port associated with the chamber inlet.

V
Physical signal port that provides the chamber volume variation.

See Also

Constant Volume Hydraulic Chamber

Hydraulic Piston Chamber

Variable Reluctance

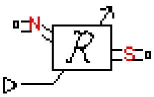
Purpose

Simulate variable reluctance

Library

Magnetic Elements

Description



The Variable Reluctance block models a variable reluctance, that is, a component that resists flux flow. The ratio of the magnetomotive force (mmf) across the component to the resulting flux that flows through the component is defined as the reluctance, and is dependent on the value of the input physical signal.

The block is based on the following equations:

$$\mathtt{F} = \Phi \cdot \Re$$

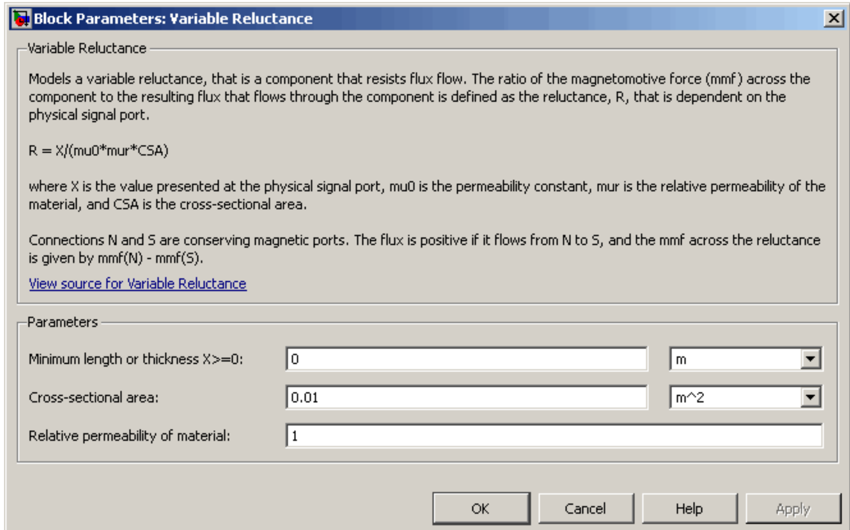
$$\Re = \frac{X}{\mu_0 \cdot \mu_r \cdot A}$$

where

$\mathtt{F}$	Magnetomotive force (mmf) across the component
Φ	Flux through the component
$\Re$	Reluctance
X	Value presented at the physical signal port
μ_0	Permeability constant
μ_r	Relative permeability of the material
A	Cross-sectional area of the section being modeled

Connections N and S are magnetic conserving ports. The mmf across the reluctance is given by $\mathtt{F}(N) - \mathtt{F}(S)$, and the sign of the flux is positive when flowing through the device from N to S.

Dialog Box and Parameters



Minimum length or thickness X>=0
: The minimum value of length of air gap or thickness of section. If the input signal falls below this level (for example, turns negative), this minimum value is used. The parameter value must be nonnegative. The default value is `0`.

Cross-sectional area
: Area of the section being modeled. The default value is `0.01` m^2.

Relative permeability of material
: Relative permeability of the section material. The default value is `1`.

Ports

The block has the following ports:

`N`
: Magnetic conserving port associated with the block North terminal.

S

Magnetic conserving port associated with the block South terminal.

The block also has one physical signal input port that provides the value of the length of air gap or thickness of section.

See Also

Reluctance

Purpose

Simulate linear variable resistor in electrical systems

Library

Electrical Elements

Description

The Variable Resistor block models a linear variable resistor, described with the following equation:

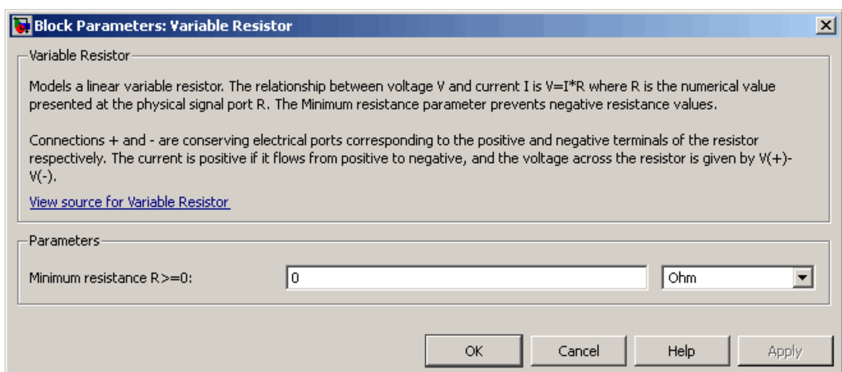
$$V = I \cdot R$$

where

V	Voltage
I	Current
R	Resistance, i.e., the value presented at the control port

Connections + and – are conserving electrical ports corresponding to the positive and negative terminals of the resistor, respectively. P is a physical signal input port that controls the resistance value. The current is positive if it flows from positive to negative, and the voltage across the resistor is equal to the difference between the voltage at the positive and the negative terminal, $V(+) - V(–)$.

Dialog Box and Parameters



Minimum resistance R>=0
The minimum resistance value. If the input signal falls below this level (for example, turns negative), this minimum resistance value is used. The parameter value must be nonnegative. The default value is 0.

Ports

The block has the following ports:

+
: Electrical conserving port associated with the resistor positive terminal.

-
: Electrical conserving port associated with the resistor negative terminal.

P
: Physical signal input port that provides the resistance value.

See Also

Resistor

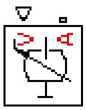
Purpose

Simulate hydraulic capacity of variable volume with compressible fluid

Library

None (kept for compatibility purposes only)

Description



Note The Variable Volume Chamber block has been deprecated and removed from the library as of Version 3.0 (R2008b). Documentation is kept for compatibility reasons. If you use this block in your older models, it will still work. However, support may be discontinued in a future version. It is recommended that you replace this block with the Hydraulic Piston Chamber block.

The Variable Volume Chamber block models fluid compressibility in variable volume chambers, such as hydraulic cylinder cavities. The fluid is considered to be a mixture of liquid and a small amount of entrained, nondissolved gas. Use this block together with the Translational Hydro-Mechanical Converter block.

Note The Variable Volume Chamber block takes into account only the flow rate caused by fluid compressibility. The fluid volume consumed to create piston velocity is accounted for in the Translational Hydro-Mechanical Converter block.

The chamber is simulated according to the following equations:

$$q = \frac{V_0 + A \bullet x \bullet or}{E} \bullet \frac{dp}{dt}$$

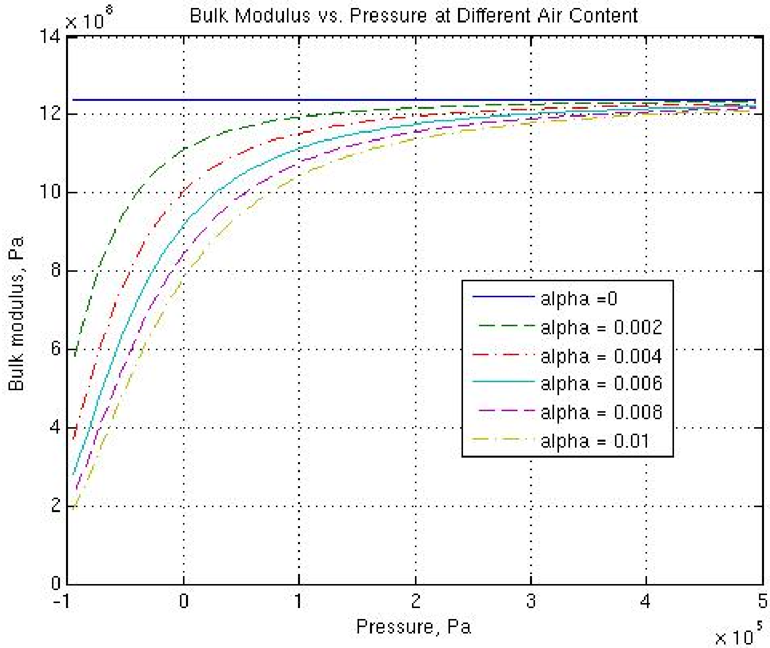
$$E = E_l \frac{1 + \alpha \left(\frac{p_a}{p_a + p} \right)^{1/n}}{1 + \alpha \frac{p_a^{1/n}}{n \bullet (p_a + p)^{\frac{n+1}{n}}} E_l}$$

where

q	Flow rate due to fluid compressibility
V_0	Initial volume of fluid in the chamber
A	Effective piston area
x	Piston displacement from initial position
or	Chamber orientation with respect to the globally assigned positive direction. If displacement in positive direction increases the volume of the chamber, or equals 1. If displacement in positive direction decreases the volume of the chamber, or equals –1.
E	Fluid bulk modulus
E_1	Pure liquid bulk modulus
p	Gauge pressure of fluid in the chamber
p_α	Atmospheric pressure
α	Relative gas content at atmospheric pressure, $\alpha = V_G/V_L$
V_G	Gas volume at atmospheric pressure
V_L	Volume of liquid
n	Gas-specific heat ratio

The main objective of representing fluid as a mixture of liquid and gas is to introduce an approximate model of cavitation, which takes place in a chamber if pressure drops below fluid vapor saturation level. As it is seen in the graph below, the bulk modulus of a mixture decreases at $p \rightarrow p_a$, thus considerably slowing down further pressure change.

At high pressure, $p >> p_a$, a small amount of nondissolved gas has practically no effect on the system behavior.



Cavitation is an inherently thermodynamic process, requiring consideration of multiple-phase fluids, heat transfers, etc., and as such cannot be accurately simulated with Simscape software. But the simplified version implemented in the block is good enough to signal if pressure falls below dangerous level, and to prevent computation failure that normally occurs at negative pressures.

If it is known that cavitation is unlikely in the system under design, you can set the relative gas content in the fluid properties to zero, thus increasing the speed of computations.

Port A is a hydraulic conserving port associated with the chamber inlet. Port P is a physical signal port that controls piston displacement.

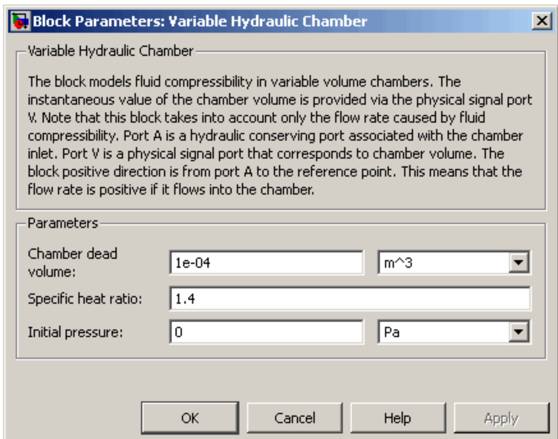
The block positive direction is from port A to the reference point. This means that the flow rate is positive if it flows into the chamber.

Basic Assumptions and Limitations

The model is based on the following assumptions:

- Fluid density remains constant.
- Fluid fills the entire chamber volume.

Dialog Box and Parameters



Piston area

Effective piston area. The default value is `5e-4` m^2.

Chamber orientation

Specifies chamber orientation with respect to the globally assigned positive direction. The chamber can be installed in two different ways, depending upon whether the piston motion in the positive direction increases or decreases the volume of the chamber. If piston motion in the positive direction decreases the chamber volume, set the parameter to `Decreases at positive`. The default value is `Increases at positive`.

Chamber dead volume
Volume of fluid in the chamber at initial piston position. The default value is `1e-4` m^3.

Specific heat ratio
Gas-specific heat ratio. The default value is `1.4`.

Initial pressure
Initial pressure in the chamber. This parameter specifies the initial condition for use in computing the block's initial state at the beginning of a simulation run. For more information, see "Computing Initial Conditions". The default value is `0`.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Chamber orientation**

All other block parameters are available for modification.

Global Parameters

Fluid bulk modulus
The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Nondissolved gas ratio
Nondissolved gas relative content determined as a ratio of gas volume to the liquid volume. The parameter is determined by the type of working fluid selected for the system under design. Use the Hydraulic Fluid block or the Custom Hydraulic Fluid block to specify the fluid properties.

Ports

The block has the following ports:

A
Hydraulic conserving port associated with the chamber inlet.

P

Physical signal port that controls piston displacement.

See Also

Constant Volume Hydraulic Chamber

Hydraulic Piston Chamber

Translational Hydro-Mechanical Converter

Variable Hydraulic Chamber

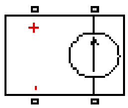
Purpose

Simulate linear voltage-controlled current source

Library

Electrical Sources

Description



The Voltage-Controlled Current Source block models a linear voltage-controlled current source, described with the following equation:

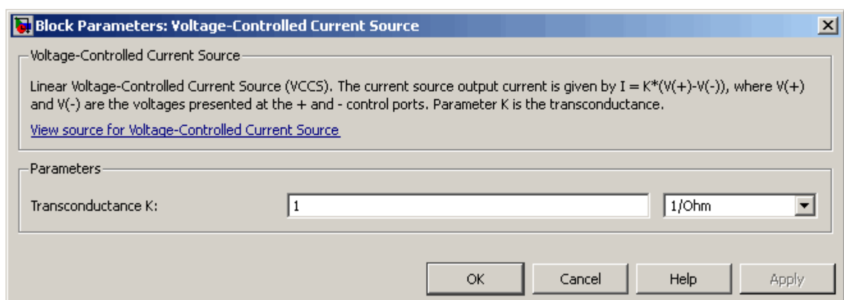
$$I = K \bullet (V(+) - V(-))$$

where

I	Current
K	Transconductance
V(+),V(-)	Voltages presented at the + and – control ports

To use the block, connect the + and – ports on the left side of the block (the control ports) to the control voltage source. The two ports on the right side of the block (the output ports) generate the output current. The arrow indicates the positive direction of the current flow.

Dialog Box and Parameters



Transconductance K

Transconductance, or the change in output current divided by the change in input voltage that causes it. The default value is 1 1/Ω.

Ports

The block has four electrical conserving ports. Connections + and – on the left side of the block are the control ports. The other two ports are the electrical terminals that provide the output current. The arrow indicates the positive direction of the current flow.

See Also

Current-Controlled Current Source

Current-Controlled Voltage Source

Voltage-Controlled Voltage Source

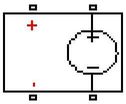
Purpose

Simulate linear voltage-controlled voltage source

Library

Electrical Sources

Description



The Voltage-Controlled Voltage Source block models a linear voltage-controlled voltage source, described with the following equation:

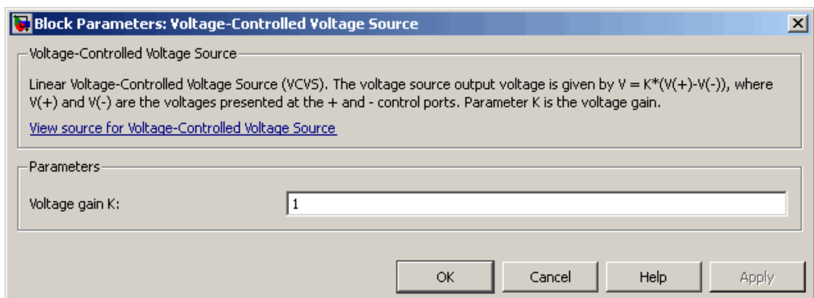
$$V = K \cdot (V(+) - V(-))$$

where

`V`	Output voltage
`K`	Voltage gain
`V(+),V(-)`	Voltages presented at the + and – control ports

To use the block, connect the + and – ports on the left side of the block (the control ports) to the control voltage source. The two ports on the right side of the block (the output ports) generate the output voltage. Polarity is indicated by the + and – signs.

Dialog Box and Parameters



Voltage gain K

The change in the output voltage divided by the change in the control voltage that causes it. The default value is 1.

Ports

The block has four electrical conserving ports. Connections + and – on the left side of the block are the control ports. The other two ports are the electrical terminals that provide the output voltage. Polarity is indicated by the + and – signs.

See Also

Current-Controlled Current Source

Current-Controlled Voltage Source

Voltage-Controlled Current Source

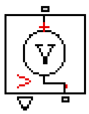
Purpose

Simulate voltage sensor in electrical systems

Library

Electrical Sensors

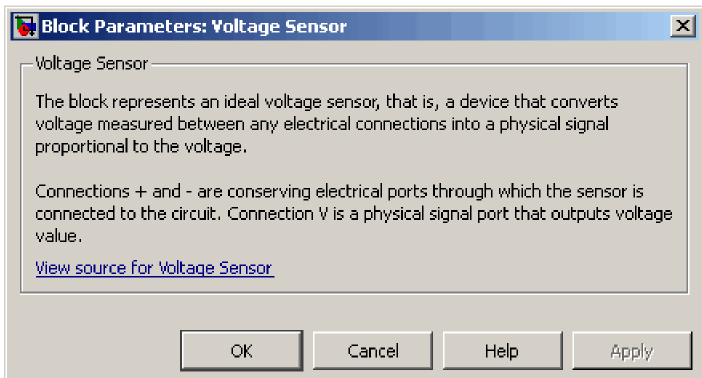
Description



The Voltage Sensor block represents an ideal voltage sensor, that is, a device that converts voltage measured between two points of an electrical circuit into a physical signal proportional to the voltage.

Connections + and – are electrical conserving ports through which the sensor is connected to the circuit. Connection V is a physical signal port that outputs the measurement result.

Dialog Box and Parameters



The block has no parameters.

Ports

The block has the following ports:

+

Electrical conserving port associated with the sensor positive terminal.

-

Electrical conserving port associated with the sensor negative terminal.

V

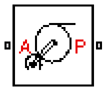
Physical signal output port for voltage.

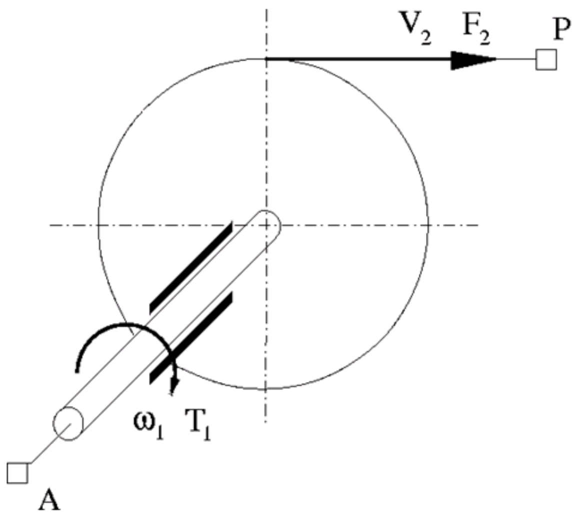
See Also Current Sensor

Purpose Simulate wheel and axle mechanism in mechanical systems

Library Mechanisms

Description The Wheel and Axle block represents a wheel and axle mechanism shown in the following schematic.





The wheel and the axle have the same axis, and the axis is assumed to be rigidly connected to the frame, thus making this mechanism an ideal converter of mechanical rotational into mechanical translational motion. The mechanism has two connections: a mechanical rotational port A, which corresponds to the axle, and a mechanical translational port P, which corresponds to the wheel periphery. The mechanism is described with the following equations:

$$T = r \cdot F \cdot or$$

$$v = r \cdot \omega \cdot or$$

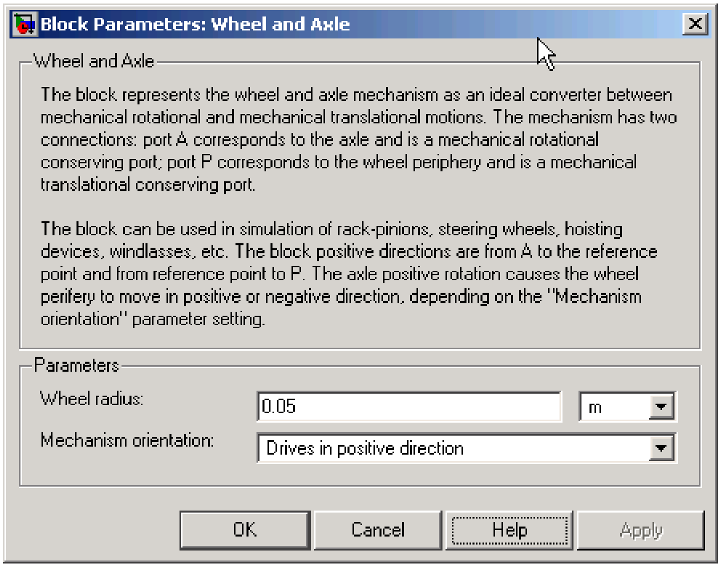
where

T	Torque on the axle
F	Force on the wheel periphery
ω	Angular velocity
v	Linear velocity on the wheel periphery
r	Wheel radius
or	Mechanism orientation indicator. The variable assumes +1 value if axle rotation in the globally assigned positive direction is converted into translational motion in positive direction, and –1 if positive rotation results in translational motion in negative direction.

The block can be used in simulation of rack-pinions, steering wheels, hoisting devices, windlasses, and so on.

The block positive directions are from A to the reference point and from the reference point to P.

Dialog Box and Parameters



Wheel radius
Radius of the wheel. The default value is `0.05` m.

Mechanism orientation
The parameter can be set to one of two options: `Drives in positive direction` or `Drives in negative direction`. The value `Drives in positive direction` specifies a mechanism where axle rotation in the globally assigned positive direction is converted into translational motion in positive direction. The value `Drives in negative direction` specifies a mechanism where axle rotation in the globally assigned positive direction is converted into translational motion in negative direction. The default value is `Drives in positive direction`.

Restricted Parameters

When your model is in Restricted editing mode, you cannot modify the following parameter:

- **Mechanism orientation**

All other block parameters are available for modification.

Ports

The block has the following ports:

A
: Mechanical rotational conserving port associated with the axle.

P
: Mechanical translational conserving port associated with the wheel periphery.

Examples

The Simple Mechanical System demo (`ssc_simple_mechanical_system`) illustrates the use of the Wheel and Axle block in mechanical systems.

See Also

Gear Box

Function Reference

pm_adddimension	Add new dimension to unit registry
pm_addunit	Add new unit to unit registry
pm_getdimensions	Get information about all dimensions in unit registry
pm_getunits	Get information about all units in unit registry
print	Print complete logging tree of node object
simscape.dependency.file	Check dependencies for single file
simscape.dependency.lib	Check dependencies for library package
simscape.dependency.model	Check dependencies for model
simscape.logging.Node	Represent hierarchy tree for simulation data
simscape.logging.Series	Represent time-values series for simulation data
sl_postprocess	Make postprocessing customizations when building custom block library
ssc_build	Build custom library from collection of Simscape files
ssc_clean	Clean all derived files generated by library build process
ssc_mirror	Create protected mirror of library of Simscape files

`ssc_new`	Create new Simscape model populated by required and commonly-used blocks
`ssc_protect`	Generate Simscape protected files from source files
`ssc_reserved`	List reserved words
`time`	Extract time vector from simulation series
`values`	Extract values vector from simulation series

Purpose

Add new dimension to unit registry

Syntax

```
pm_adddimension(dimension, unitname)
```

Description

`pm_adddimension(dimension, unitname)` adds a new dimension named `dimension` with a fundamental unit, `unitname`. `dimension` may be any string. `unitname` must be a valid unit name, that is, it must begin with a letter and contain only letters and numbers.

Examples

Add a new unit dimension, `length`, with a fundamental unit of meter, `m`:

```
pm_adddimension('length', 'm');
```

See Also

`pm_addunit`, `pm_getdimensions`, `pm_getunits`

pm_addunit

Purpose

Add new unit to unit registry

Syntax

```
pm_addunit(unitname, conversion, unitexpression)
```

Description

`pm_addunit(unitname, conversion, unitexpression)` introduces a new unit, `unitname`, defined as `conversion * unitexpression`.

The first argument, `unitname`, must be a valid unit name, that is, it must begin with a letter and contain only letters and numbers.

The second argument, `conversion`, may be either a positive real scalar or a 1x2 array. If this argument has two elements, then it is specifying an affine conversion, with the first element (a positive real number) being the linear conversion coefficient, and the second being the offset. For more information, see "Thermal Unit Conversions".

The third argument, `unitexpression`, must be a valid unit expression in terms of units already defined in the unit registry.

The following operators are supported in the unit mathematical expressions:

`*`	Multiplication
`/`	Division
`^`	Power
`+, -`	Plus, minus — for exponents only
`()`	Brackets to specify evaluation order

Examples

Add a new unit centimeter, `cm`, in terms of meter, `m`:

```
pm_addunit('cm', 0.01, 'm');
```

Add a new unit newton, `N`, in terms of kilograms, meters, and seconds:

```
pm_addunit('N', 1, 'kg*m/s^2');
```

Add a new unit Fahrenheit, `Fh`, in terms of Celsius:

```
pm_addunit('Fh', [5/9 -32*5/9], 'C');
```

See Also

`pm_adddimension`, `pm_getdimensions`, `pm_getunits`

pm_getdimensions

Purpose

Get information about all dimensions in unit registry

Syntax

```
[dimensions, units] = pm_getdimensions
```

Description

`[dimensions, units] = pm_getdimensions` returns all dimensions registered in the unit registry in a cell array , `dimensions`. Their corresponding units are returned in the `units` cell array.

Examples

List all dimensions currently defined in the registry:

```
pm_getdimensions

ans =

    'charge'
    'length'
    'mass'
    'mole'
    'temperature'
    'time'
```

See Also

`pm_adddimension`, `pm_addunit`, `pm_getunits`

Purpose

Get information about all units in unit registry

Syntax

```
[units, conversions, expressions] = pm_getunits
```

Description

`[units, conversions, expressions] = pm_getunits` returns all units in the registry in a cell array , `units`. Their corresponding conversions and base expressions are returned in `conversions` and `expressions`, respectively. For fundamental units, the conversion is `1.0` and the base expression is the unit itself.

Examples

List all units currently defined in the registry:

```
pm_getunits

ans =

    'm'
    'kg'
    's'
    'c'
    'K'
    'mol'
    'cm'
    'mm'
    'km'
    'um'
    'C'
    'Fh'
    'R'
    'in'
    'ft'
    'mi'
    'yd'
    'l'
    'gal'
    'g'
    'mg'
```

```
'lbm'
'oz'
'slug'
'N'
'lbf'
'dyn'
'lb'
'mN'
'min'
'hr'
'ms'
'us'
'ns'
'rad'
'deg'
'rev'
'mph'
'fpm'
'fps'
'rpm'
'Hz'
'kHz'
'MHz'
'GHz'
'J'
'Btu'
'eV'
'W'
'HP'
'V'
'A'
'F'
'H'
'Ohm'
'S'
'Wb'
'T'
```

```
'G'
'mV'
'kV'
'pA'
'nA'
'uA'
'mA'
'kA'
'pF'
'nF'
'uF'
'uH'
'mH'
'kOhm'
'MOhm'
'GOhm'
'nS'
'uS'
'mS'
'Pa'
'bar'
'psi'
'atm'
'lpm'
'gpm'
'Poise'
'cP'
'reyn'
'St'
'cSt'
'Newt'
```

See Also

pm_adddimension, pm_addunit, pm_getdimensions

simscape.dependency.file

Purpose

Check dependencies for single file

Syntax

```
[fn_list, missing] = simscape.dependency.file('fileName')
[fn_list, missing] = simscape.dependency.file('fileName',
   dependencyType)
[fn_list, missing] = simscape.dependency.file('fileName',
   dependencyType, isRecursive)
[fn_list, missing] = simscape.dependency.file('fileName',
   dependencyType, isRecursive, doTMWFile)
```

Description

`[fn_list, missing] = simscape.dependency.file('fileName')` returns two cell arrays of strings: full path names of existing dependency files, *`fn_list`*, and missing files, *`missing`*. These cell arrays list the existing and missing files that are needed for the specified Simscape file to build successfully, or to correctly visualize and execute in MATLAB.

`[fn_list, missing] = simscape.dependency.file('fileName', dependencyType)` returns dependency files of the specified type.

`[fn_list, missing] = simscape.dependency.file('fileName', dependencyType, isRecursive)` lets you specify whether analysis is recursive on the generated dependency files. By default, returns only the top-level dependency files.

`[fn_list, missing] = simscape.dependency.file('fileName', dependencyType, isRecursive, doTMWFile)` lets you specify whether to include files inside the MATLAB root folder (installation directory) in the analysis.

Input Arguments

`dependencyType`

Enumerated value of type `Simscape.DependencyType`, which specifies the type of returned files:

`All` (default)	All the dependency files
`Auxiliary`	Files that are not necessary to convert the file and use it in block diagrams, but are needed to visualize it correctly, for example, block icon images
`Core`	Files necessary to convert the file and use it in block diagrams, for example, a domain file referenced by the component file being analyzed
`Derived`	Internally generated files that are not necessary for sharing the component file being analyzed, but including them will avoid rebuilding the library on the same platform.
`Simulink`	Additional files that help visualize the block generated from the component file being analyzed. These files are not necessary for simulation.

These enumerated values have the following order: `Core`, `Derived`, `Auxiliary`, `Simulink`, `All`. The return is accumulative. This means that for a requested file type, all earlier file types are also returned. For example, if you specify *`dependencyType`* as `Simscape.DependencyType.Derived`, the analysis returns both Core and Derived files.

`doTMWFile`

Logical value that indicates whether the file analysis includes files inside the MATLAB root folder (installation directory):

`true` (default)

`false`

fileName

The name of the Simscape file (with path), or class method, for which the dependencies are checked. In case of multiple files with the same name, only the first file of the specified name on the MATLAB path is analyzed.

isRecursive

Logical value that indicates whether the analysis is recursive on the generated dependency files:

`true`
`false` (default)

See Also

`simscape.dependency.lib` | `simscape.dependency.model`

How To

- "Checking File and Model Dependencies"

Purpose

Check dependencies for library package

Syntax

```
[fn_list, missing] = simscape.dependency.lib('libName')
[fn_list, missing] = simscape.dependency.lib('libName',
   dependencyType)
[fn_list, missing] = simscape.dependency.lib('libName',
   dependencyType, 'mdlFileName')
[fn_list, missing] = simscape.dependency.lib('libName',
   dependencyType, 'mdlFileName', isRecursive)
[fn_list, missing] = simscape.dependency.lib('libName',
   dependencyType, 'mdlFileName', isRecursive, doTMWFile)
```

Description

`[fn_list, missing] = simscape.dependency.lib('libName')` returns two cell arrays of strings: full path names of existing dependency files, *fn_list*, and missing files, *missing*. These cell arrays list the existing and missing files that are needed for the specified Simscape library package to build successfully, or to correctly visualize and execute in MATLAB.

`[fn_list, missing] = simscape.dependency.lib('libName', dependencyType)` returns dependency files of the specified type.

`[fn_list, missing] = simscape.dependency.lib('libName', dependencyType, 'mdlFileName')` lets you specify the name of the library model. When not specified, or specified as an empty string (`''`), *libName*`_lib.mdl` is used.

`[fn_list, missing] = simscape.dependency.lib('libName', dependencyType, 'mdlFileName', isRecursive)` lets you specify whether analysis is recursive on the generated dependency files. By default, returns only the top-level dependency files.

`[fn_list, missing] = simscape.dependency.lib('libName', dependencyType, 'mdlFileName', isRecursive, doTMWFile)` lets you specify whether to include files inside the MATLAB root folder (installation directory) in the analysis.

If the package contains Simscape protected files, with the corresponding Simscape source files in the same folder, the analysis returns the names of protected files and then analyzes the source files for further dependencies. If the package contains Simscape protected files without the corresponding source files, the protected file names are returned without further analysis.

Input Arguments

dependencyType

Enumerated value of type `Simscape.DependencyType`, which specifies the type of returned files:

`All` (default)	All the dependency files
`Auxiliary`	Files that are not necessary to build the library, or run the models built from its blocks, but are needed to visualize it correctly, for example, block icon images or `lib.m` files.
`Core`	Files necessary to build the library or run the models built from its blocks, such as Simscape files or MATLAB files.
`Derived`	Internally generated files that are not necessary for sharing the library, but including them will avoid rebuilding the library on the same platform.
`Simulink`	Additional files that help visualize the blocks generated from the library components. These files are not necessary for simulation.

These enumerated values have the following order: `Core`, `Derived`, `Auxiliary`, `Simulink`, `All`. The return is accumulative.

This means that for a requested file type, all earlier file types are also returned. For example, if you specify `dependencyType` as `Simscape.DependencyType.Derived`, the analysis returns both Core and Derived files.

`doTMWFile`

Logical value that indicates whether the file analysis includes files inside the MATLAB root folder (installation directory):

`true` (default)
`false`

`isRecursive`

Logical value that indicates whether the analysis is recursive on the generated dependency files:

`true`
`false` (default)

`libName`

The name of a Simscape library package. The package folder name begins with a leading + character, whereas the argument to `simscape.dependency.lib` must omit the + character. You must run the command from the folder containing the top-level package, or from inside the package folder. In the latter case, you can omit the name of the library package if it is the only argument.

`mdlFileName`

The name of the library model (either without path, or with relative path, or with absolute path). The suffix `.mdl` is optional.

Default: *`libName`*`_lib.mdl`

See Also

`simscape.dependency.file` | `simscape.dependency.model`

How To

- "Checking File and Model Dependencies"

simscape.dependency.model

Purpose Check dependencies for model

Syntax

```
[fn_list, missing, reference2fnList,
   reference2missing] =
simscape.dependency.model('modelName')
```

Description

`[fn_list, missing, reference2fnList, reference2missing] = simscape.dependency.model('modelName')` checks dependencies for a model containing Simscape and Simulink blocks. *`modelName`* specifies the name of the model (either without path, or with relative path, or with absolute path). The suffix `.mdl` is optional.

You must open the model first.

This command returns dependency information regarding Simscape files and blocks only. To perform a complete dependencies check for a model, use the Simulink Manifest Tools. For more information, see "Model Dependencies" in the *Simulink User's Guide*.

If during the analysis this command encounters a Simscape file located inside the MATLAB root folder, it returns the file name without performing any further analysis on this file, because all the dependent files in this case are part of standard MathWorks installation.

Output Arguments

`fn_list`

A cell array of strings containing the full paths of all existing files referenced by the model *`modelName`*.

`missing`

A cell array of strings containing the names of all files that are referenced by the model *`modelName`* but cannot be found.

`reference2fnList`

A list of structures, each of which includes a field `'names'` as a list of file names causing the reference, and a field `'type'` as the reference type for each file. Two reference types are used:

`'Simscape component'` indicates reference from a model block. `'Simscape'` indicates reference from a file.

`reference2missing`

A list of structures, each of which includes a field `'names'` as a list of missing file names, and a field `'type'` as the reference type for each file. Two reference types are used: `'Simscape component'` indicates reference from a model block. `'Simscape'` indicates reference from a file.

See Also

`simscape.dependency.file` | `simscape.dependency.lib`

How To

- "Checking File and Model Dependencies"

simscape.logging.Node class

Purpose

Represent hierarchy tree for simulation data

Description

This class represents the hierarchy of nodes for logging simulation data in a model. The tree starts with the workspace variable, which represents simulation data for the whole model, and recursively creates nodes for each of the children. The children are defined depending on the type of the parent node:

- For the top-level simulation log workspace variable, the children are all the Simscape blocks (and subsystems containing Simscape blocks) in the top-level model diagram.
- For a subsystem or a structural block, the children are all the constituent Simscape blocks and subsystems.
- For a block, the children are all its physical ports, Through and Across variables, and all internal variables defined in the block's Simscape file.
- For a physical port, the children are all its Across variables.

Final nodes in this recursion correspond to all the variables logged for the model. Final nodes do not have children nodes, and contain the series data logged during simulation.

You cannot construct an object of this class. The object is constructed automatically during simulation, as part of the simulation log workspace variable, if you enable data logging for the model.

Properties

`id`

The string identifying the `Node` object. For the simulation log workspace variable, this is the name of the top-level block diagram. For blocks and subsystems, the `id` is constructed automatically as a valid MATLAB identifier based on the name of the block or subsystem. For other types, the `id` is the name of the corresponding port or variable.

`series`

For `Node` objects that do not have children nodes, and therefore correspond to the logged variables, the `series` property returns an object of the `simscape.logging.Series` class that contains the simulation series data for this variable. For nodes that do not represent variables, the `series` property is hidden. If you access the hidden `series` property for such node, the property returns an object of the `simscape.logging.Series` class representing an empty series (with zero points).

The other properties are dynamic, and represent all the children of the `Node` object.

Methods

`print`	Print complete logging tree of node object

Copy Semantics

Handle. To learn how handle classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

See Also

`simscape.logging.Series`

Tutorials

- "Data Logging Example"

How To

- "How to Log Simulation Data"

simscape.logging.Node.print

Purpose

Print complete logging tree of node object

Syntax

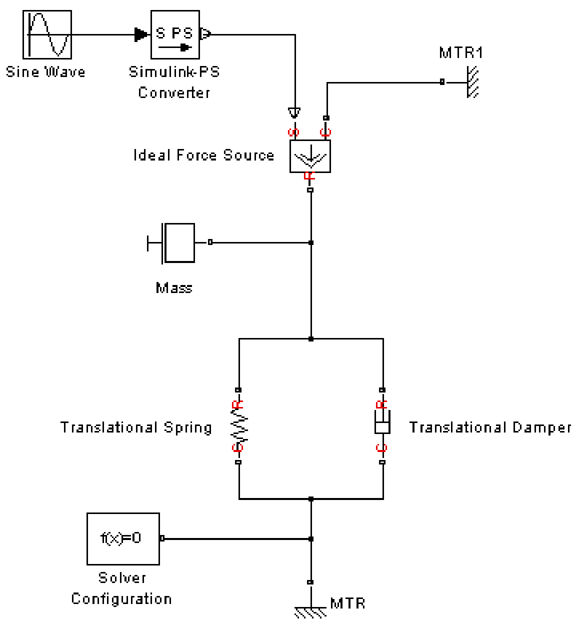
path_to_node.print

Description

path_to_node.print prints the complete logging tree starting with the specified node. *path_to_node* is a full identifier path to the node, starting with the workspace log variable name.

Examples

Consider the following model. The model name is simple_mech2, and data logging is enabled with the default workspace variable name, simlog.



Return the complete logging tree for the whole model:

```
simlog.print
     simple_mech2
```

```
+-Ideal_Force_Source
| +-C
| | +-v
| +-R
| | +-v
| +-S
| +-f
| +-v
+-MTR
| +-V
| | +-v
| +-f
+-MTR1
| +-V
| | +-v
| +-f
+-Mass
| +-M
| | +-v
| +-f
+-Simulink_PS_Converter
+-Translational_Damper
| +-C
| | +-v
| +-R
| | +-v
| +-f
| +-v
+-Translational_Spring
  +-C
  | +-v
  +-R
  | +-v
  +-f
  +-v
  +-x
```

Print the logging tree just for the Mass block:

```
simlog.Mass.print
     Mass
     +-M
     | +-v
     +-f
```

See Also

`simscape.logging.Node`

Tutorials

- "Data Logging Example"

simscape.logging.Series class

Purpose

Represent time-values series for simulation data

Description

This class represents simulation data for a variable in a model. The series is a representation containing time-value pairs for each simulation step. The size of the series is determined by the number of simulation steps. You can also limit the size by specifying the maximum number of logged steps when you set your data logging preferences.

You cannot construct an object of this class. The object is constructed automatically during simulation, as part of the simulation log workspace variable, if you enable data logging for the model.

Properties

`points`

Size or number of steps in the simulation series.

`dimension`

Dimension of variable represented by the series.

`unit`

The default unit associated with the values in the series.

Methods

`time`	Extract time vector from simulation series
`values`	Extract values vector from simulation series

Copy Semantics

Handle. To learn how handle classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

See Also

`simscape.logging.Node`

Tutorials

- "Data Logging Example"

How To

- "How to Log Simulation Data"

simscape.logging.Series.time

Purpose Extract time vector from simulation series

Syntax `ta = path_to_var.series.time`

Description `ta = path_to_var.series.time` returns a row vector of simulation times contained in the series. *path_to_var* is a full identifier path to the variable node associated with the series.

Examples Return simulation time data for the deformation of a Translational Spring block, located at the top level of the model diagram:

```
t1 = simlog.Translational_Spring.x.series.time

t1 =

         0
    0.0020
    0.0040
    0.0060
    0.0100
    0.0140
    0.0180
    0.0220
    0.0260
    0.0300
    0.0340
    0.0380
    0.0420
    0.0460
    0.0500
    0.0540
    0.0580
    0.0620
    0.0660
    0.0700
    0.0740
    0.0780
```

```
0.0820
0.0860
0.0900
0.0940
0.0980
0.1020
0.1060
0.1100
0.1140
0.1180
0.1220
0.1260
0.1300
0.1340
0.1380
0.1420
0.1460
0.1500
0.1540
0.1580
0.1620
0.1660
0.1700
0.1740
0.1780
0.1820
0.1860
0.1900
0.1940
0.1980
0.2000
```

See Also

`simscape.logging.Series` | `simscape.logging.Series.values`

Tutorials

- "Data Logging Example"

simscape.logging.Series.values

Purpose

Extract values vector from simulation series

Syntax

va = *path_to_var*.series.values
va = *path_to_var*.series.values('*unit*')

Description

va = *path_to_var*.series.values returns a row vector of variable values contained in the series, in default units. *path_to_var* is a full identifier path to the variable node associated with the series.

va = *path_to_var*.series.values('*unit*') returns a row vector of variable values in the specified units. *unit* must be commensurate with the default units of the variable.

For nonscalar variables of size *m*-by-*n*, this method returns a row vector of *m**n**steps* size, where *steps* is the number of steps in the series, and each *m**n* block represents the logged value for the variable in a column major form. For example, if a variable size is 2-by-2, then the first four elements in the row vector are the a_{11}, a_{21}, a_{12}, and a_{22} elements at the first time step.

Examples

Return the deformation values of a Translational Spring block, located at the top level of the model diagram:

```
v1 = simlog.Translational_Spring.x.series.values

v1 =

   1.0e-003 *

         0
    0.0000
    0.0000
    0.0001
    0.0002
    0.0004
    0.0007
    0.0012
    0.0018
```

```
0.0025
0.0034
0.0044
0.0056
0.0070
0.0085
0.0101
0.0119
0.0139
0.0160
0.0183
0.0207
0.0233
0.0260
0.0289
0.0319
0.0351
0.0384
0.0419
0.0455
0.0492
0.0531
0.0572
0.0614
0.0657
0.0702
0.0748
0.0796
0.0845
0.0895
0.0947
0.1000
0.1055
0.1111
0.1168
0.1227
0.1287
```

```
    0.1348
    0.1411
    0.1475
    0.1540
    0.1607
    0.1675
    0.1710
```

The previous command returns the deformation values in meters (the default unit of the series). To return the same deformation values in different units, for example, in inches, type:

```
v1 = simlog.Translational_Spring.x.series.values('in')

v1 =

         0
    0.0000
    0.0000
    0.0000
    0.0000
    0.0000
    0.0000
    0.0000
    0.0001
    0.0001
    0.0001
    0.0002
    0.0002
    0.0003
    0.0003
    0.0004
    0.0005
    0.0005
    0.0006
    0.0007
```

```
0.0008
0.0009
0.0010
0.0011
0.0013
0.0014
0.0015
0.0016
0.0018
0.0019
0.0021
0.0023
0.0024
0.0026
0.0028
0.0029
0.0031
0.0033
0.0035
0.0037
0.0039
0.0042
0.0044
0.0046
0.0048
0.0051
0.0053
0.0056
0.0058
0.0061
0.0063
0.0066
0.0067
```

See Also

`simscape.logging.Series` | `simscape.logging.Series.time`

Tutorials

- "Data Logging Example"

sl_postprocess

Purpose

Make postprocessing customizations when building custom block library

Syntax

```
sl_postprocess(h)
```

Description

`sl_postprocess(h)` takes a handle to the custom block library, `h`, and allows you to make library postprocessing customizations (for example, add a forwarding table).

If a Simscape file package being built contains a `sl_postprocess.m` file, then `ssc_build` calls `sl_postprocess` once the block library (*package_name*`_lib.mdl`) is generated but before it is saved to disk. If `sl_postprocess` generates an error, the library does not build.

You can include a `sl_postprocess.m` file at any level in the library package. At the top level, it makes postprocessing changes to the whole custom block library. Similarly, if the `sl_postprocess.m` file resides in a sublibrary in the package, it takes a handle to that sublibrary and makes the corresponding changes.

Examples

Consider the following directory structure:

```
- +MySimscape
|-- +Mechanical
| |-- spring.ssc
| |-- ...
```

For example, you have restructured your custom `Mechanical` library to have two sublibraries, `Rotational` and `Translational`, and moved the `spring` block to the `Rotational` sublibrary. To update old models that reference the block, you need to add a forwarding table.

Instead of manually adding a forwarding table, which will get overwritten every time you rebuild the library, you can include a `sl_postprocess.m` file in the library package, which will add the forwarding table automatically upon rebuilding the library:

```
- +MySimscape
|-- sl_postprocess.m
|-- +Mechanical
| |-- +Rotational
| | |-- spring.ssc
| | |-- ...
| |-- +Translational
| |-- ...
```

The `sl_postprocess.m` file contains a forwarding table:

```
function sl_postprocess(h)
% Forwarding table for the spring block
ft = { {'MySimscape_lib/Mechanical/spring', 'MySimscape_lib/Mechanical/Rotational/spring'} }
set_param(h, 'ForwardingTable', ft);
end
```

Note that if you have customized the library names (using `lib.m` files) or the block name, you have to use these custom names in the forwarding table (for example, `'Rotational Spring'` instead of `'spring'`).

See Also

`ssc_build`

ssc_build

Purpose Build custom library from collection of Simscape files

Syntax `ssc_build` *`package`*

Description `ssc_build` *`package`* generates a custom Simscape library file, named *`package`*`_lib.mdl`, containing all the sublibraries and blocks generated from the Simscape files (either source or protected) located in the package and its subdirectories. Simscape protected files have higher precedence than the source files when you build a library. If both the protected and the source files are present in the package, and the source files are out of date, `ssc_build` will use the protected files to build the library, but you will get a warning.

The argument, *`package`*, must be a top-level package name.

Note The package directory name begins with a leading + character, whereas the argument to `ssc_build` must omit the + character.

The package must be located in a directory on the MATLAB path. The *`package`*`_lib.mdl` is automatically placed in the package parent directory. For more information, see "Adding Custom Block Libraries Generated from Simscape Component Files".

If you run the `ssc_build` command from inside the package directory structure, you can omit the argument.

Examples For example, your top-level package directory, where you store your Simscape files, is named `+SimscapeCustomBlocks`. To generate a custom block library, at the MATLAB Command prompt, type:

```
ssc_build SimscapeCustomBlocks;
```

This command generates a file called `SimscapeCustomBlocks_lib.mdl` in the parent directory of the top-level package (that is, in the same directory that contains your `+SimscapeCustomBlocks` package).

See Also

ssc_clean

ssc_mirror

ssc_protect

ssc_clean

Purpose Clean all derived files generated by library build process

Syntax `ssc_clean` *`package`*

Description `ssc_clean` *`package`* deletes all derived files generated by `ssc_build` in the package named *`package`*, including the library file.

The argument, *`package`*, must be a top-level package name.

Note The package directory name begins with a leading + character, whereas the argument to `ssc_clean` must omit the + character.

Examples To clean all derived files from the package directory `+MyPackage`, invoke the following from the directory containing the package directory `+MyPackage`:

```
ssc_clean MyPackage;
```

See Also `ssc_build`

Purpose

Create protected mirror of library of Simscape files

Syntax

`ssc_mirror` *`package mirrordir`* `buildmirror`

Description

The `ssc_mirror` command lets you protect and build a whole package of Simscape files in one step.

`ssc_mirror` *`package mirrordir`* `buildmirror` creates a protected mirror of a package of Simscape files in a specified directory *`mirrordir`*, and also optionally builds a custom library from these files.

The first argument, *`package`*, must be a top-level package name.

Note The package directory name begins with a leading + character, whereas the argument to `ssc_mirror` must omit the + character.

The second argument, *`mirrordir`*, is the directory where the protected package is placed. The `ssc_mirror` command creates this directory, if it does not exist, recreates the whole package structure under it, generates the protected files, and places them in the appropriate mirror locations.

If the `buildmirror` flag is set to `true`, the `ssc_mirror` command also builds a custom Simscape library file, named *`package`*`_lib.mdl`, containing all the sublibraries and blocks generated from the Simscape files in the mirrored package (similar to the `ssc_build` command), and places the *`package`*`_lib.mdl` file in the *`mirrordir`* directory. The `buildmirror` flag is optional and the default is `false`, that is, by default the package is mirrored and protected but the library is not built.

For more information, see "Using Source Protection for Simscape Files".

Examples

For example, your top-level package directory, where you store your Simscape files, is named `+SimscapeCustomBlocks`. To protect, mirror, and generate a custom block library from this package in the directory `C:\Work\deploy`, at the MATLAB Command prompt, type:

```
ssc_mirror SimscapeCustomBlocks C:\Work\deploy true;
```

This command creates a mirror package, equivalent to the `+SimscapeCustomBlocks` package but consisting of Simscape protected files, in the directory `C:\Work\deploy`, and generates a file called `SimscapeCustomBlocks_lib.mdl` in the `C:\Work\deploy` directory.

See Also

`ssc_clean`

`ssc_mirror`

`ssc_protect`

Purpose

Create new Simscape model populated by required and commonly-used blocks

Syntax

```
ssc_new
ssc_new('modelname')
ssc_new('modelname','domain')
ssc_new('modelname','domain','solver')
```

Description

`ssc_new` creates a new Simscape model, with required and commonly-used blocks already on the model canvas, and opens the Simscape library. By default, it uses the Simulink default new model name `untitled` and the recommended solver `ode15s`.

`ssc_new('modelname')`creates a new Simscape model with the specified name.

`ssc_new('modelname','domain')`creates a new Simscape model with the specified name, and with domain-specific reference block added to the model canvas. Valid domains types are `'electrical'`, `'hydraulic'`, `'magnetic'`, `'pneumatic'`, `'rotational'`, `'translational'`, and `'thermal'`. You can use a cell array of domain types to add more than one type of reference block.

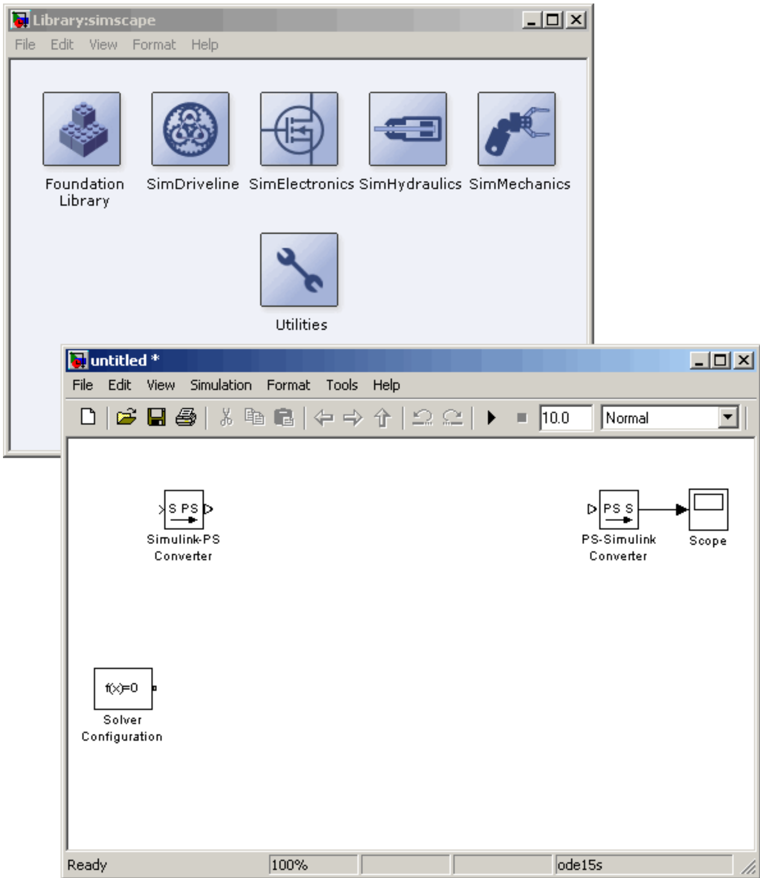
`ssc_new('modelname','domain','solver')` creates a new Simscape model with the specified name and domain type, and with the specified solver type. Recommended solver types for Simscape models are `'ode15s'`, `'ode23t'`, and `'ode14x'`. You can use other Simulink solvers, but, depending on the particular model, they may be less suitable. For more information, see "Working with Solvers".

Examples

To create a generic Simscape model, type:

```
ssc_new
```

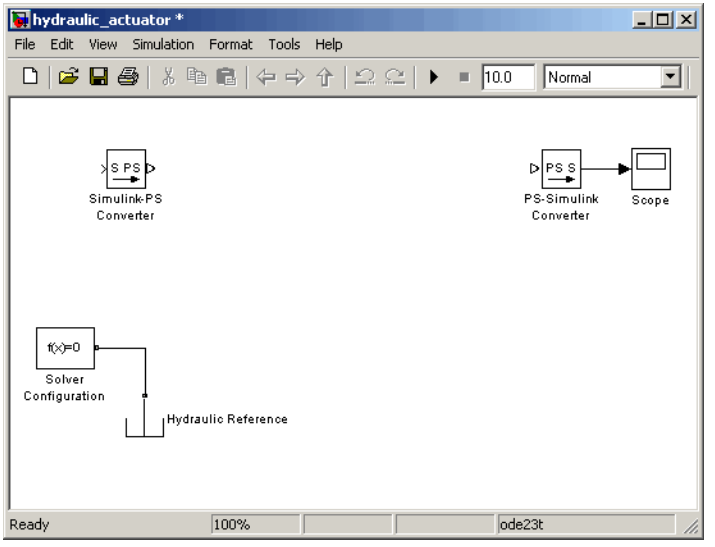
The software opens the main Simscape library and creates a new untitled model, which contains a Solver Configuration block with the default solver set to `ode15s`, a Simulink-PS Converter block, and a PS-Simulink Converter block connected to a Scope block.



To create a hydraulic model, called `hydraulic_actuator.mdl` and using the `ode23t` solver, type:

```
ssc_new('hydraulic_actuator','hydraulic','ode23t')
```

The software opens the main Simscape library and creates the following model.



After using `ssc_new`, continue developing your model by copying the blocks, as needed, and adding other blocks from the Simscape libraries.

See Also

"Creating a New Simscape Model"

ssc_protect

Purpose

Generate Simscape protected files from source files

Syntax

```
ssc_protect filename
ssc_protect filename -inplace
ssc_protect dirname
ssc_protect dirname -inplace
```

Description

The `ssc_protect` command creates content-obscured files (Simscape protected files) from Simscape source files, to enable model sharing without disclosing the component or domain source. While Simscape source files have the extension `.ssc`, Simscape protected files have the extension `.sscp`.

`ssc_protect` *`filename`* generates a Simscape protected file, named *`filename`*`.sscp`, from the Simscape source file named *`filename`*`.ssc`, and places the protected file in your current working directory. *`filename`* can include absolute path to the file, or relative path if the file is in a subfolder of the current working directory. If this path includes package directories, the package structure will be recreated under the current working directory (unless it already exists) and the protected file placed in the package (see examples). The extension `.ssc` in *`filename`* is optional.

`ssc_protect` *`filename`* `-inplace` generates a Simscape protected file, named *`filename`*`.sscp`, from the Simscape source file named *`filename`*`.ssc`, and places the protected file in the same directory as the source file.

`ssc_protect` *`dirname`* generates Simscape protected files from all the Simscape source files in the directory named *`dirname`*, and places the protected files under your current working directory. If the path to *`dirname`* includes package directories, the package structure will be recreated under the current working directory (unless it already exists) and the protected files placed in the package, similar to when protecting a single file.

`ssc_protect` *`dirname`* `-inplace` generates Simscape protected files from all the Simscape source files in the directory named *`dirname`*, and places the protected files in the same directory as the source files.

Note Existing Simscape protected files are overwritten without warning.

For more information, see "Using Source Protection for Simscape Files".

Simscape protected files have higher precedence than the source files when you build a library. If the protected and the source files are in the same directory, and protected files are out of date, `ssc_build` will use the protected files to build the library, but you will get a warning.

Examples

To protect a single file, with the protected file placed under your current working directory, at the MATLAB Command prompt, type:

```
ssc_protect C:\Work\libraries\source\+SimscapeLibrary\+MechanicalElements\my_spring.ssc
```

This command creates a folder called `+SimscapeLibrary` and a subfolder called `+MechanicalElements` in your current working directory (unless these folders already exist) and generates a file called `my_spring.sscp` in the `+MechanicalElements` folder.

To protect a single file, with the protected file placed in the same directory as the source file, type:

```
ssc_protect C:\Work\libraries\source\+SimscapeLibrary\+MechanicalElements\my_spring.ssc -inplace
```

This command generates a file called `my_spring.sscp` in the `C:\Work\libraries\source\+SimscapeLibrary\+MechanicalElements` folder.

To protect all files in a directory, with the protected files placed under your current working directory, type:

```
ssc_protect C:\Work\libraries\source\+SimscapeLibrary\+MechanicalElements
```

This command generates protected files for each source file in the `C:\Work\libraries\source\+SimscapeLibrary\+MechanicalElements` folder, and places the protected files in a folder called

+SimscapeLibrary\+MechanicalElements in your current working directory (creating this folder structure, if it does not exist).

To protect all files in a directory, with the protected files placed in the same directory as the source files, type:

```
ssc_protect C:\Work\libraries\source\+SimscapeLibrary\+MechanicalElements -inplace
```

This command generates protected files for each source file in the C:\Work\libraries\source\+SimscapeLibrary\+MechanicalElements folder, and places the protected files in the same folder.

See Also

ssc_build

ssc_clean

ssc_mirror

Purpose

List reserved words

Syntax

```
ssc_reserved
words = ssc_reserved
```

Description

`ssc_reserved` returns a list of reserved Simscape language words. Simscape language has certain words, in addition to its keywords, that you cannot use as model or member names. This list may change from release to release, as limitations are removed. Use the `ssc_reserved` command to see the current list of reserved words.

`words = ssc_reserved` returns a list of reserved words in `words` as a cell array of strings.

`ssc_reserved` does not list the Simscape language keywords.

Examples

List the currently reserved words:

```
ssc_reserved

ans =

    'across_variable'
    'build'
    'description'
    'descriptor'
    'element'
    'input'
    'interface_input'
    'interface_node'
    'interface_output'
    'item_type'
    'local_variable'
    'name'
    'node'
    'output'
    'parameter'
    'setup'
```

```
'signal'
'source'
'terminal'
'through_variable'
'variable'
```

You cannot use any of these words as model names (domain or component) or member names (parameter, variable, and so on). In addition to these reserved words, you cannot use any of the Simscape language keywords as model or member names.

Language Reference

across	Establish relationship between component variables and nodes
component	Component model keywords
der	Return time derivative of operand
domain	Domain model keywords
equations	Define component equations
inputs	Define component inputs, that is, Physical Signal input ports of block
nodes	Define component nodes, that is, conserving ports of block
outputs	Define component outputs, that is, Physical Signal output ports of block
parameters	Specify component parameters
setup	Prepare component for simulation
through	Establish relationship between component variables and nodes
time	Access global simulation time
value	Convert variable or parameter to unitless value with specified unit conversion
variables	Define domain or component variables

across

Purpose

Establish relationship between component variables and nodes

Syntax

```
across( variable1, node1.variableA, node2.variableB )
```

Description

`across( variable1, node1.variableA, node2.variableB )` establishes the following relationship between the three arguments: `variable1` is assigned the value (`node1.variableA`   `node2.variableB`). All arguments are variables. The first one is not associated with a node. The second and third must be associated with a node.

The following rules apply:

- All arguments must have consistent units.
- The second and third arguments do not need to be associated with the same domain. For example, one may be associated with a one-phase electrical domain, and the other with a 3-phase electrical.
- Either the second or the third argument may be replaced with `[]` to indicate the reference node.

Examples

If a component declaration section contains two electrical nodes, `p` and `n`, and a variable `v = { 0, 'V' };` specifying voltage, you can establish the following relationship in the setup section:

```
across( v, p.v, n.v );
```

This defines voltage `v` as an Across variable from node `p` to node `n`.

See Also

`through`

Purpose

Component model keywords

Syntax

```
component
nodes
inputs
outputs
parameters
variables
function setup
equations
```

Description

`component` begins the component model class definition, which is terminated by an `end` keyword. Only blank lines and comments can precede `component`. You must place a component model class definition in a file of the same name with a file name extension of `.ssc`.

See "Basic Simscape Grammar" in the *Simscape Language Guide* for more information on component model definition syntax.

A component file consists of a declaration section, with one or more member declaration blocks, followed by setup and equation sections.

The declarations section may contain any of the following member declaration blocks.

`nodes` begins a nodes declaration block, which is terminated by an `end` keyword. This block contains declarations for all the component nodes, which correspond to the conserving ports of a Simscape block generated from the component file. Each node is defined by assignment to an existing domain. See "Declaring Component Nodes" in the *Simscape Language Guide* for more information.

`inputs` begins an inputs declaration block, which is terminated by an `end` keyword. This block contains declarations for all the inputs, which correspond to the input Physical Signal ports of a Simscape block generated from the component file. Each input is defined as a value with unit. See "Declaring Component Inputs and Outputs" in the *Simscape Language Guide* for more information.

`outputs` begins an outputs declaration block, which is terminated by an `end` keyword. This block contains declarations for all the outputs, which correspond to the output Physical Signal ports of a Simscape block generated from the component file. Each output is defined as a value with unit. See “Declaring Component Inputs and Outputs” in the *Simscape Language Guide* for more information.

`parameters` begins a component parameters definition block, which is terminated by an `end` keyword. This block contains declarations for component parameters. Parameters will appear in the block dialog box when the component file is brought into a block model. Each parameter is defined as a value with unit. See “Declaring Component Parameters” in the *Simscape Language Guide* for more information.

`variables` begins a variables declaration block, which is terminated by an `end` keyword. This block contains declarations for all the variables associated with the component. Variables are internal to the component; they will not appear in a block dialog box when the component file is brought into a block model.

Variables can be defined either by assignment to an existing domain variable or as a value with unit. See “Declaring Component Variables” in the *Simscape Language Guide* for more information.

`function setup` begins the setup section, which is terminated by an `end` keyword. This section relates inputs, outputs, and variables to one another by using `across` and `through` functions. It can also be used for validating parameters, computing derived parameters, and setting initial conditions. See “Defining Component Setup” in the *Simscape Language Guide* for more information.

`equations` begins the equation section, which is terminated by an `end` keyword. This section contains the equations that define how the component works. See “Defining Component Equations” in the *Simscape Language Guide* for more information.

Table of Attributes

For component model attributes, as well as declaration member attributes, see “Attribute Lists” in the *Simscape Language Guide*.

Examples

This file, named `spring.ssc`, defines a rotational spring.

```
component spring
  nodes
    r = foundation.mechanical.rotational.rotational;
    c = foundation.mechanical.rotational.rotational;
  end
  parameters
    k = { 10, 'N*m/rad' };
  end
  variables
    theta = { 0, 'rad' };
    t = { 0, 'N*m' };
    w = { 0, 'rad/s' };
  end
  function setup
    if k < 0
      error( 'Spring rate must be greater than zero' );
    end
    through( t, r.t, c.t );
    across(  w, r.w, c.w );
  end
  equations
    t == k * theta;
    w == theta.der;
  end
end
```

See Also

`domain`

Purpose Return time derivative of operand

Syntax

```
der(x)
x.der
```

Description The `equations` function may contain `der` operator, which returns the time derivative of its operand:

`der(x)` = `x.der` = $\dot{x} = \frac{dx}{dt}$

`der` operator takes any numerical expression as its argument:

- `der` applied to expressions that are continuous returns their time derivative
- `der` applied to `time` argument returns 1
- `der` applied to expressions that are parametric or constant returns 0
- `der` applied to countable operands returns 0. For example, `der(a<b)` returns 0 even if *a* and *b* are variables.

The return unit of `der` is the unit of its operand divided by seconds.

The following restrictions apply:

- You cannot form nonlinear expressions of the output from `der`. For example, `der(x)*der(x)` would produce an error because this is no longer a linearly implicit system.
- Higher order derivatives are not allowed. For example, `der(der(x))` would produce an error.
- For a component to compile, the number of differential equations should equal the number of differential variables.

Examples This example shows implementation for a simple dynamic system:

$$\dot{x} = 1 - x$$

The Simscape file looks as follows:

```
component MyDynamicSystem
  variables
    x = 0;
  end
  equations
    x.der == (1 - x)*{ 1, '1/s' };  % x' = 1 - x
  end
end
```

The reason you need to multiply by `{ 1, '1/s' }` is that `(1-x)` is unitless, while the left-hand side (`x.der`) has the units of 1/s. Both sides of the equation statement must have the same units.

See Also

`equations`

domain

Purpose

Domain model keywords

Syntax

```
domain
variables
variables(Balancing = true)
parameters
```

Description

`domain` begins the domain model class definition, which is terminated by an `end` keyword. Only blank lines and comments can precede `domain`. You must place a domain model class definition in a file of the same name with a file name extension of `.ssc`.

See “Basic Simscape Grammar” in the *Simscape Language Guide* for more information on domain model definition syntax.

`variables` begins an Across variables declaration block, which is terminated by an `end` keyword. This block contains declarations for all the Across variables associated with the domain. A domain model class definition can contain multiple Across variables, combined in a single `variables` block. This block is required.

`variables(Balancing = true)` begins a Through variables declaration block, which is terminated by an `end` keyword. This block contains declarations for all the Through variables associated with the domain. A domain model class definition can contain multiple Through variables, combined in a single `through` block. This block is required.

Each variable is defined as a value with unit. See “Declaring Through and Across Variables for a Domain” in the *Simscape Language Guide* for more information.

`parameters` begins a domain parameters declaration block, which is terminated by an `end` keyword. This block contains declarations for domain parameters. These parameters are associated with the domain and can be propagated through the network to all components connected to the domain. This block is optional.

See “Propagation of Domain Parameters” in the *Simscape Language Guide* for more information.

Table of Attributes

For declaration member attributes, see "Attribute Lists".

Examples

This file, named `rotational.ssc`, declares a mechanical rotational domain, with angular velocity as an Across variable and torque as a Through variable.

```
domain rotational
% Define the mechanical rotational domain
% in terms of across and through variables

  variables
    w = { 1 , 'rad/s' }; % angular velocity
  end

  variables(Balancing = true)
    t = { 1 , 'N*m' }; % torque
  end

end
```

This file, named `t_hyd.ssc`, declares a hydraulic domain, with pressure as an Across variable, flow rate as a Through variable, and an associated domain parameter, fluid temperature.

```
domain t_hyd
  variables
    p = { 1e6, 'Pa' }; % pressure
  end
  variables(Balancing = true)
    q = { 1e-3, 'm^3/s' }; % flow rate
  end
  parameters
    t = { 303, 'K' }; % fluid temperature
  end
end
```

See Also `component`

Purpose

Define component equations

Syntax

```
equations
 Expression1 == Expression2;
end
equations
 if Expression
 ExpressionList
 { elseif Expression
 ExpressionList }
 else
 ExpressionList
 end
end
equations
 let
 declaration clause
 in
 expression clause
 end
end
```

Description

`equations` begins the equation section in a component file; this section is terminated by an `end` keyword. It is executed throughout the simulation. The purpose of the equation section is to establish the mathematical relationships among a component's variables, parameters, inputs, outputs, time and the time derivatives of each of these entities. All members declared in the component are available by their name in the equation section.

The following syntax defines a simple equation.

```
equations
Expression1 == Expression2;
end
```

equations

The statement `Expression1 == Expression2` is an equation statement. It specifies continuous mathematical equality between two objects of class `Expression`. An `Expression` is any valid MATLAB expression that does not use any of the relational operators: `==`, `<`, `>`, `<=`, `>=`, `~=`, `&&`, `||`. `Expression` may be constructed from any of the identifiers defined in the model declaration.

The equation section may contain multiple equation statements. You can also specify conditional equations by using `if` statements as follows:

```
equations
if Expression
ExpressionList
{ elseif Expression
ExpressionList }
else
ExpressionList
end
end
```

Note The total number of equation expressions, their dimensionality, and their order must be the same for every branch of the `if-elseif-else` statement.

You can define intermediate terms and use them in equations by using `let` statements as follows:

```
equations
let
declaration clause
in
expression clause
end
end
```

The declaration clause assigns an identifier, or set of identifiers, on the left-hand side of the equal sign (=) to an equation expression on the right-hand side of the equal sign:

```
LetValue = EquationExpression
```

The expression clause defines the scope of the substitution. It starts with the keyword `in`, and may contain one or more equation expressions. All the expressions assigned to the identifiers in the declaration clause are substituted into the equations in the expression clause during parsing.

Note The `end` keyword is required at the end of a `let-in-end` statement.

The following rules apply to the equation section:

- `EquationList` is one or more objects of class `EquationExpression`, separated by a comma, semicolon, or newline.
- `EquationExpression` can be one of:
  - `Expression`
  - Conditional expression (`if-elseif-else` statement)
  - Let expression (`let-in-end` statement)
- `Expression` is any valid MATLAB expression. It may be formed with the following operators:
  - Arithmetic
  - Relational (with restrictions, see "Use of Relational Operators in Equations")
  - Logical
  - Primitive Math

- Indexing
- Concatenation

- In the equation section, `Expression` may not be formed with the following operators:
  - Matrix Inversion
  - MATLAB functions not listed in Supported Functions on page 4-14
- The `colon` operator may take only constants or `end` as its operands.
- All members of the component are accessible in the equation section, but none are writable.

The following MATLAB functions can be used in the equation section. The table contains additional restrictions that pertain only to the equation section. It also indicates whether a function is discontinuous. If the function is discontinuous, it introduces a zero-crossing when used with one or more continuous operands.

Supported Functions

Name	Restrictions	Discontinuous
`plus`		
`uplus`		
`minus`		
`uminus`		
`mtimes`		
`times`		
`mpower`		
`power`		
`mldivide`	Nonmatrix denominator	

Supported Functions (Continued)

Name	Restrictions	Discontinuous
`mrdivide`	Nonmatrix denominator	
`ldivide`		
`rdivide`		
`eq`	Do not use with continuous variables	Yes
`ne`	Do not use with continuous variables	Yes
`lt`		Yes
`gt`		Yes
`le`		Yes
`ge`		Yes
`and`		Yes
`or`		Yes
`sin`		
`cos`		
`tan`		
`asin`		
`acos`		
`atan`		
`atan2`		
`log`		
`log10`		
`sinh`		

Supported Functions (Continued)

Name	Restrictions	Discontinuous
cosh		
tanh		
exp		
sqrt		
abs		Yes
logical		Yes
sign		Yes

Examples

For a component where x and y are declared as 1x1 variables, specify an equation of the form $y = x^2$:

```
equations
  y == x^2;
end
```

For the same component, specify the following piecewise equation:

$$y = \begin{cases} x & \text{for } -1 <= x <= 1 \\ x^2 & \text{otherwise} \end{cases}$$

This equation, written in the Simscape language, would look like:

```
equations
  if x >= -1 && x <= 1
    y == x;
  else
    y == x^2;
  end
end
```

See Also

`der`

`time`

"Defining Component Equations"

inputs

Purpose

Define component inputs, that is, Physical Signal input ports of block

Syntax

```
inputs
 in1 = { value , 'unit' };
end
inputs
 in1 = { value , 'unit' };  % label:location
end
```

Description

`inputs` begins a component inputs definition block, which is terminated by an `end` keyword. This block contains declarations for component inputs. Inputs will appear as Physical Signal input ports in the block diagram when the component file is brought into a Simscape model. Each input is defined as a value with unit, where `value` is a scalar. Specifying an optional comment lets you control the port label and location in the block icon.

The following syntax defines a component input, `in1`, as a value with unit. `value` is the initial value. `unit` is a valid unit string, defined in the unit registry.

```
inputs
in1 = { value , 'unit' };
end
```

You can specify the input port label and location, the way you want it to appear in the block diagram, as a comment:

```
inputs
in1 = { value , 'unit' }; % label:location
end
```

where `label` is a string corresponding to the input port name in the block diagram, `location` is one of the following strings: `left`, `right`, `top`, `bottom`.

Examples

The following example declares an input port `s`, with a default value of `1 Pa`, specifying the control port of a hydraulic pressure source. In the block diagram, this port will be named **Pressure** and will be located on the top side of the block icon.

```
inputs
    s = { 1 'Pa' };   % Pressure:top
end
```

See Also

`nodes`

`outputs`

nodes

Purpose

Define component nodes, that is, conserving ports of block

Syntax

```
nodes
 a = package_name.domain_name;
end
nodes
 a = package_name.domain_name;  % label:location
end
```

Description

`nodes` begins a nodes declaration block, which is terminated by an `end` keyword. This block contains declarations for all the component nodes, which correspond to the conserving ports of a Simscape block generated from the component file. Each node is defined by assignment to an existing domain. See "Declaring Component Nodes" in the *Simscape Language Guide* for more information.

The following syntax defines a node, `a`, by associating it with a domain, `domain_name`. `package_name` is the full path to the domain, starting with the top package directory. For more information on packaging your Simscape files, see "Adding Custom Block Libraries Generated from Simscape Component Files" in the *Simscape Language Guide*.

```
nodes
a = package_name.domain_name;
end
```

You can specify the port label and location, the way you want it to appear in the block diagram, as a comment:

```
nodes
a = package_name.domain_name; % label:location
end
```

where `label` is a string corresponding to the port name in the block diagram, `location` is one of the following strings: `left`, `right`, `top`, `bottom`.

Examples

The following example uses the syntax for the Simscape Foundation mechanical rotational domain:

```
nodes
    r = foundation.mechanical.rotational.rotational;
end
```

The name of the top-level package directory is `+foundation`. It contains a subpackage `+mechanical`, with a subpackage `+rotational`, which in turn contains the domain file `rotational.ssc`.

If you want to use your own customized rotational domain called `rotational.ssc` and located at the top level of your custom package directory `+MechanicalElements`, the syntax would be:

```
nodes
    r = MechanicalElements.rotational;
end
```

The following example declares an electrical node using the syntax for the Simscape Foundation electrical domain. In the block diagram, this port will be labelled **+** and will be located on the top side of the block icon.

```
nodes
    p = foundation.electrical.electrical; % +:top
end
```

See Also

`inputs`

`outputs`

outputs

Purpose

Define component outputs, that is, Physical Signal output ports of block

Syntax

```
outputs
 out1 = { value , 'unit' };
end
outputs
 out1 = { value , 'unit' };  % label:location
end
```

Description

`outputs` begins a component outputs definition block, which is terminated by an `end` keyword. This block contains declarations for component outputs. Outputs will appear as Physical Signal output ports in the block diagram when the component file is brought into a Simscape model. Each output is defined as a value with unit, where `value` is a scalar. Specifying an optional comment lets you control the port label and location in the block icon.

The following syntax defines a component output, `out1`, as a value with unit. `value` is the initial value. `unit` is a valid unit string, defined in the unit registry.

```
outputs
out1 = { value , 'unit' };
end
```

You can specify the output port label and location, the way you want it to appear in the block diagram, as a comment:

```
outputs
out1 = { value , 'unit' }; % label:location
end
```

where `label` is a string corresponding to the input port name in the block diagram, `location` is one of the following strings: `left`, `right`, `top`, `bottom`.

Examples

The following example declares an output port `p`, with a default value of `1 Pa`, specifying the output port of a hydraulic pressure sensor. In the block diagram, this port will be named **Pressure** and will be located on the bottom side of the block icon.

```
outputs
    p = { 1 'Pa' };   % Pressure:bottom
end
```

See Also

`inputs`

`nodes`

parameters

Purpose

Specify component parameters

Syntax

```
parameters
 comp_par1 = { value , 'unit' };
end
parameters
 comp_par1 = { value , 'unit' }; % Parameter name
end
```

Description

Component parameters let you specify adjustable parameters for the Simscape block generated from the component file. Parameters will appear in the block dialog box and can be modified when building and simulating a model.

`parameters` begins a component parameters definition block, which is terminated by an `end` keyword. This block contains declarations for component parameters. Parameters will appear in the block dialog box when the component file is brought into a Simscape model. Each parameter is defined as a value with unit. Specifying an optional comment lets you control the parameter name in the block dialog box.

The following syntax defines a component parameter, `comp_par1`, as a value with unit. `value` is the initial value. `unit` is a valid unit string, defined in the unit registry.

```
parameters
comp_par1 = { value , 'unit' };
end
```

To declare a unitless parameter, you can either use the same syntax:

```
par1 = { value , '1' };
```

or omit the unit and use this syntax:

```
par1 = value;
```

Internally, however, this parameter will be treated as a two-member value-unit array `{ value , '1' }`.

You can specify the parameter name, the way you want it to appear in the block dialog box, as a comment:

```
parameters
comp_par1 = { value , 'unit' }; % Parameter name
end
```

Examples

The following example declares parameter `k`, with a default value of `10 N*m/rad`, specifying the spring rate of a rotational spring. In the block dialog box, this parameter will be named **Spring rate**.

```
parameters
    k = { 10 'N*m/rad' };   % Spring rate
end
```

See Also

`variables`

setup

Purpose

Prepare component for simulation

Syntax

```
function setup
 [...]
end
```

Description

```
function setup
[...]
end
```

The body of the `setup` function can contain assignment statements, `if` and `error` statements, and `across` and `through` functions. The `setup` function is executed once for each component instance during model compilation. It takes no arguments and returns no arguments.

Use the `setup` function for the following purposes:

- Validating parameters
- Computing derived parameters
- Setting initial conditions
- Relating inputs, outputs, and variables to one another by using `across` and `through` functions

The following rules apply:

- The `setup` function is executed as regular MATLAB code.
- All members declared in the component are available by their name.
- All members (such as variables, parameters) that are externally writable are writable within setup. See "Member Summary" for more information.
- Local MATLAB variables may be introduced in the `setup` function. They are scoped only to the `setup` function.

The following restrictions apply:

- Command syntax is not supported in the `setup` function. You must use the function syntax. For more information, see "Command vs. Function Syntax" in the *MATLAB Programming Fundamentals* documentation.
- Persistent and global variables are not supported. For more information, see "Types of Variables" in the *MATLAB Programming Fundamentals* documentation.
- MATLAB system commands using the `!` operator are not supported.
- `try-end` and `try-catch-end` constructs are not supported.
- Passing declaration members to external MATLAB functions, for example, `my_function(param1)`, is not supported. You can, however, pass member values to external functions, for example, `my_function(param1.value)`.

Examples

The following `setup` function checks the value of a parameter `MyParam`, declared in the declaration section of a component file. It defines a maximum allowed value for this parameter, `MaxValue`, and if `MyParam` is greater than `MaxValue`, overrides it with `MaxValue` and issues a warning.

```
function setup
   MaxValue = {1, 'm' };
   if MyParam > MaxValue
      warning( 'MyParam is greater than MaxValue, overriding with MaxValue' );
      MyParam = MaxValue;
   end
end
```

See Also

`across`

`through`

through

Purpose

Establish relationship between component variables and nodes

Syntax

```
through( variableI, node1.variableA, node2.variableB )
```

Description

`through( variableI, node1.variableA, node2.variableB )` establishes the following relationship between the three arguments: for each `variableI`, `node1.variableA` is assigned the value `sum( variableI )` and `node2.variableB` is assigned the value `sum( -variableI )`. All arguments are variables. The first one is not associated with a node. The second and third must be associated with a node.

The following rules apply:

- All arguments must have consistent units.
- The second and third arguments do not need to be associated with the same domain. For example, one may be associated with a one-phase electrical domain, and the other with a 3-phase electrical.
- Either the second or the third argument may be replaced with `[]` to indicate the reference node.

Examples

For example, if a component declaration section contains two electrical nodes, `p` and `n`, and a variable `i = { 0, 'A' };` specifying current, you can establish the following relationship in the setup section:

```
through( i, p.i, n.i );
```

This defines current `i` as a Through variable from node `p` to node `n`.

See Also

`across`

Purpose Access global simulation time

Syntax

```
time
```

Description You can access global simulation time from the equation section of a Simscape file using the `time` function.

`time` returns the simulation time in seconds.

Examples The following example illustrates $y = \sin(\omega t)$:

```
component
  parameters
    w = { 1, `1/s' } % omega
  end
  outputs
    y = 0;
  end
  equations
    y == sin( w * time );
  end
end
```

See Also `equations`

value

Purpose

Convert variable or parameter to unitless value with specified unit conversion

Syntax

```
value(a,'unit')
value(a,'unit','type')
```

Description

`value(a,'unit')` returns a unitless numerical value, converting `a` into units `unit`. `a` is a variable or parameter, specified as a value with unit, and `unit` is a unit defined in the unit registry. `unit` must be commensurate with the units of `a`.

`value(a,'unit','type')` performs either linear or affine conversion of temperature units and returns a unitless numerical value, converting `a` into units `unit`. `type` specifies the conversion type and can be one of two strings: `linear` or `affine`. If the type is not specified when converting temperature units, it is assumed to be affine.

Use this function in the setup and equation sections of a Simscape file to convert a variable or parameter into a scalar value.

Examples

If `a = { 10, ` `` `cm' `` ` }`, then `value(a, 'm')` returns 0.1.

If `a = { 10, ` `` `C' `` ` }`, then `value(a, 'K', 'linear')` returns 10.

If `a = { 10, ` `` `C' `` ` }`, then `value(a, 'K', 'affine')` returns 283.15. `value(a, 'K')` also returns 283.15.

If `a = { 10, ` `` `cm' `` ` }`, then `value(a, 's')` issues an error because the units are not commensurate.

Purpose

Define domain or component variables

Syntax

```
variables
 comp_var1 = { value , 'unit' };
end
variables
 domain_across_var1 = { value , 'unit' };
end
variables(Balancing = true)
 domain_through_var1 = { value , 'unit' };
end
```

Description

`variables` begins a variables declaration block, which is terminated by an `end` keyword. In a component file, this block contains declarations for all the variables associated with the component. In a domain file, this block contains declarations for all the Across variables associated with the domain. Additionally, domain files must have a separate variables declaration block, with the `Balancing` attribute set to `true`, which contains declarations for all the Through variables associated with the domain.

In a component file, the following syntax defines an Across, Through, or internal variable, `comp_var1`, as a value with unit. `value` is the initial value. `unit` is a valid unit string, defined in the unit registry.

```
variables
comp_var1 = { value , 'unit' };
end
```

In a domain file, the following syntax defines an Across variable, `domain_across1`, as a value with unit. `value` is the initial value. `unit` is a valid unit string, defined in the unit registry.

```
variables
domain_across_var1 = { value , 'unit' };
end
```

variables

In a domain file, the following syntax defines a Through variable, `domain_through1`, as a value with unit. `value` is the initial value. `unit` is a valid unit string, defined in the unit registry.

```
variables(Balancing = true)
domain_through_var1 = { value , 'unit' };
end
```

Examples

The following example initializes the variable `w` (angular velocity) as 0 rad/s:

```
variables
    w = { 0, 'rad/s' };
end
```

The following example initializes the domain Through variable `t` (torque) as 1 N*m:

```
variables(Balancing = true)
    t = { 1, 'N*m' };
end
```

See Also

“Declaring Component Variables”

“Declaring Through and Across Variables for a Domain”

5

Simscape Foundation Domains

Domain Types and Directory Structure

Simscape software comes with the following Foundation domains:

- "Electrical Domain" on page 5-4
- "Hydraulic Domain" on page 5-5
- "Magnetic Domain" on page 5-7
- "Mechanical Rotational Domain" on page 5-8
- "Mechanical Translational Domain" on page 5-9
- "Pneumatic Domain" on page 5-10
- "Thermal Domain" on page 5-12

Simscape Foundation libraries are organized in a package containing domain and component Simscape files. The name of the top-level package directory is `+foundation`, and the package consists of subpackages containing domain files, structured as follows:

```
- +foundation
|-- +electrical
| |-- electrical.ssc
| |-- ...
|-- +hydraulic
| |-- hydraulic.ssc
| |-- ...
|-- +magnetic
| |-- magnetic.ssc
| |-- ...
|-- +mechanical
| |-- +rotational
| | |-- rotational.ssc
| | |-- ...
| |-- +translational
| | |-- translational.ssc
| | |-- ...
|-- +pneumatic
| |-- pneumatic.ssc
| |-- ...
```

```
|-- +thermal
| |-- thermal.ssc
| |-- ...
```

To use a Foundation domain in a component declaration, refer to the domain name using the full path, starting with the top package directory. The following example uses the syntax for the Simscape Foundation mechanical rotational domain:

```
r = foundation.mechanical.rotational.rotational;
```

The name of the top-level package directory is `+foundation`. It contains a subpackage `+mechanical`, with a subpackage `+rotational`, which in turn contains the domain file `rotational.ssc`.

The following sections describe each Foundation domain.

Electrical Domain

The electrical domain declaration is shown below.

```
domain electrical
% Electrical Domain

% Copyright 2005-2008 The MathWorks, Inc.

  parameters
    Temperature = { 300.15 , 'K'     }; % Circuit temperature
    GMIN        = { 1e-12  , '1/Ohm' }; % Minimum conductance, GMIN
  end

  variables
    v = { 0 , 'V' };
  end

  variables(Balancing = true)
    i = { 0 , 'A' };
  end

end
```

It contains the following variables and parameters:

- Across variable v (voltage), in volts
- Through variable i (current), in amperes
- Parameter *Temperature*, specifying the circuit temperature
- Parameter *GMIN*, specifying minimum conductance

To refer to this domain in your custom component declarations, use the following syntax:

```
foundation.electrical.electrical
```

Hydraulic Domain

The hydraulic domain declaration is shown below.

```
domain hydraulic
% Hydraulic Domain

% Copyright 2005-2008 The MathWorks, Inc.

  parameters
    density       = { 850   , 'kg/m^3' }; % Fluid density
    viscosity_kin = { 18e-6 , 'm^2/s'  }; % Kinematic viscosity
    bulk          = { 0.8e9 , 'Pa'     }; % Bulk modulus at atm. pressure and no gas
    alpha         = { 0.005 , '1'      }; % Relative amount of trapped air
  end

  variables
    p = { 0 , 'Pa' };
  end

  variables(Balancing = true)
    q = { 0 , 'm^3/s' };
  end

end
```

It contains the following variables and parameters:

- Across variable *p* (pressure), in Pa
- Through variable *q* (flow rate), in m^3/s
- Parameter *density*, specifying the default fluid density
- Parameter *viscosity_kin*, specifying the default kinematic viscosity
- Parameter *bulk*, specifying the default fluid bulk modulus at atmospheric pressure and no gas
- Parameter *alpha*, specifying the default relative amount of trapped air in the fluid

To refer to this domain in your custom component declarations, use the following syntax:

```
foundation.hydraulic.hydraulic
```

Magnetic Domain

The magnetic domain declaration is shown below.

```
domain magnetic
% Magnetic Domain

% Copyright 2009 The MathWorks, Inc.

  parameters
    mu0 = { 4*pi*1e-7 'Wb/(m*A)' };   % Permeability constant
  end

  variables
    mmf = { 0 , 'A' };
  end

  variables(Balancing = true)
    phi = { 0 , 'Wb' };
  end

end
```

It contains the following variables and parameters:

- Across variable *mmf* (magnetomotive force), in A
- Through variable *phi* (flux), in Wb
- Parameter *mu0*, specifying the permeability constant of the material

To refer to this domain in your custom component declarations, use the following syntax:

```
foundation.magnetic.magnetic
```

Mechanical Rotational Domain

The mechanical rotational domain declaration is shown below.

```
domain rotational
% Mechanical Rotational Domain

% Copyright 2005-2008 The MathWorks, Inc.

  variables
    w = { 0 , 'rad/s' };
  end

  variables(Balancing = true)
    t = { 0 , 'N*m' };
  end

end
```

It contains the following variables:

- Across variable *w* (angular velocity), in rad/s
- Through variable *t* (torque), in N*m

To refer to this domain in your custom component declarations, use the following syntax:

```
foundation.mechanical.rotational.rotational
```

Mechanical Translational Domain

The mechanical translational domain declaration is shown below.

```
domain translational
% Mechanical Translational Domain

% Copyright 2005-2008 The MathWorks, Inc.

  variables
    v = { 0 , 'm/s' };
  end

  variables(Balancing = true)
    f = { 0 , 'N' };
  end

end
```

It contains the following variables:

- Across variable *v* (velocity), in m/s
- Through variable *f* (force), in N

To refer to this domain in your custom component declarations, use the following syntax:

```
foundation.mechanical.translational.translational
```

Pneumatic Domain

The pneumatic domain declaration is shown below.

```
domain pneumatic
% Pneumatic 1-D Flow Domain

% Copyright 2008-2009 The MathWorks, Inc.

  parameters
    gam = { 1.4, '1' };               % Ratio of specific heats
    c_p = { 1005 , 'J/kg/K' };        % Specific heat at constant pressure
    c_v = { 717.86 , 'J/kg/K' };      % Specific heat at constant volume
    R   = { 287.05, 'J/kg/K' };       % Specific gas constant
    viscosity = { 18.21e-6, 'Pa*s' }; % Viscosity
    Pa  = { 101325, 'Pa' };           % Ambient pressure
    Ta  = { 293.15, 'K' };            % Ambient temperature
  end

  variables
    p = { 0 , 'Pa' };
    T = { 0 , 'K' };
  end

  variables(Balancing = true)
    G = { 0 , 'kg/s' };
    Q = { 0 , 'J/s' };
  end

end
```

It contains the following variables and parameters:

- Across variable p (pressure), in Pa
- Through variable G (mass flow rate), in kg/s
- Across variable T (temperature), in kelvin
- Through variable Q (heat flow), in J/s
- Parameter *gam*, defining the ratio of specific heats

- Parameter *c_p*, defining specific heat at constant pressure
- Parameter *c_v*, defining specific heat at constant volume
- Parameter *R*, defining specific gas constant
- Parameter *viscosity*, specifying the gas viscosity
- Parameter *Pa*, specifying the ambient pressure
- Parameter *Ta*, specifying the ambient temperature

These parameter values correspond to gas properties for dry air and ambient conditions of 101325 Pa and 20 degrees Celsius.

To refer to this domain in your custom component declarations, use the following syntax:

```
foundation.pneumatic.pneumatic
```

Thermal Domain

The thermal domain declaration is shown below.

```
domain thermal
% Thermal domain

% Copyright 2005-2008 The MathWorks, Inc.

  variables
    T = { 0 , 'K' };
  end

  variables(Balancing = true)
    Q = { 0 , 'J/s' };
  end

end
```

It contains the following variables:

- Across variable T (temperature), in kelvin
- Through variable Q (heat flow), in J/s

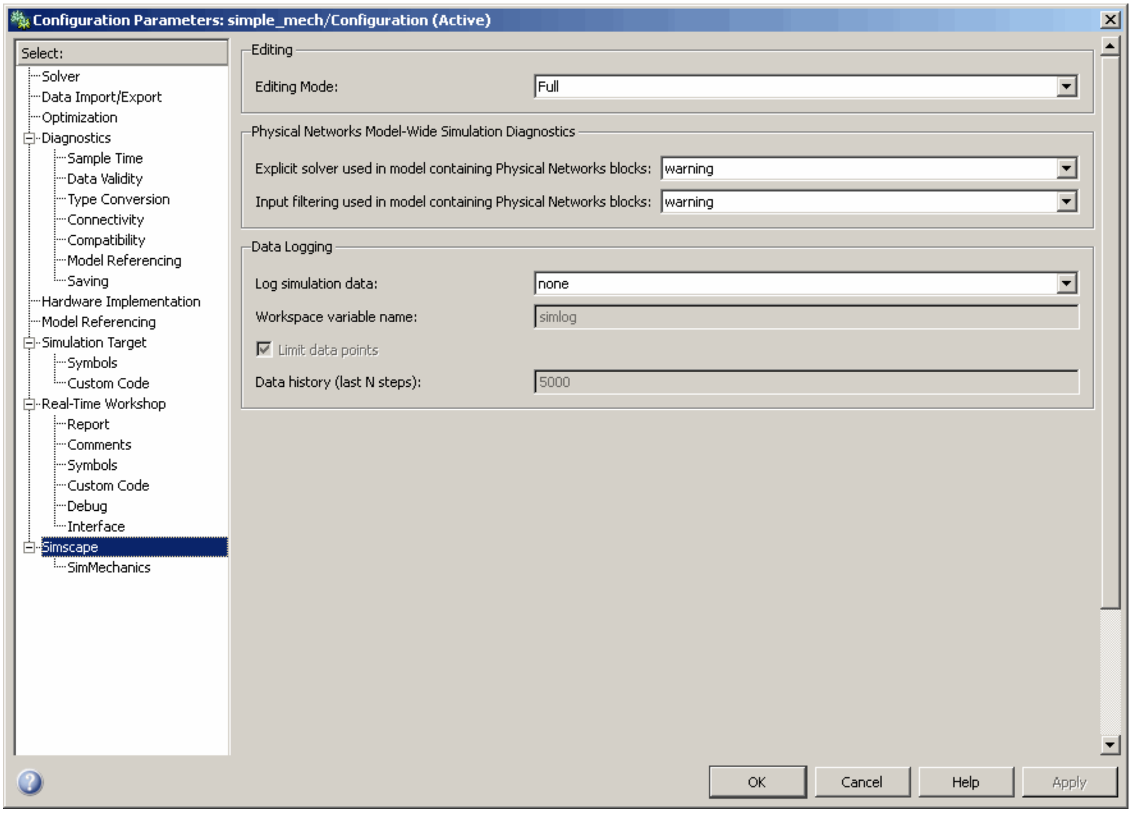
To refer to this domain in your custom component declarations, use the following syntax:

```
foundation.thermal.thermal
```

6

Configuration Parameters

Simscape Pane: General



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In this section...

Simscape Pane Overview

The **Editing Mode** parameter controls the Simscape Editing Mode functionality, which allows you to open, simulate, and save models that contain blocks from add-on products in Restricted mode, without checking out add-on product licenses, as long as the products are installed on your machine. Simscape add-on products include SimDriveline™, SimElectronics®, SimHydraulics, and SimMechanics. Use this functionality to perform multidomain physical modeling and simulation while minimizing the number of required licenses.

Note Unless your organization uses concurrent licenses, see the Simscape product page on the MathWorks Web site for specific information on how to install add-on products on your machine, to be able to work in Restricted mode.

The parameters in the **Physical Networks Model-Wide Simulation Diagnostics** section let you configure your preferences for solver-related warnings when you simulate models containing blocks from Simscape libraries.

The parameters in the **Data Logging** section let you log simulation data to workspace.

Configuration

This pane appears only if your model contains a block from the Simscape libraries (including Simscape add-on products).

See Also

- About the Simscape Editing Mode
- Working with Restricted and Full Modes
- Selecting a Solver
- Input filtering
- About Simulation Data Logging

Editing Mode

Set the editing mode of the model to either Full or Restricted.

Settings

Default: `Full`

`Full`

Sets the editing mode of the model to Full. In this mode, you can make any modifications to the model.

When you open a model in Full mode, the license manager checks out all the add-on product licenses for the blocks present in the model.

When you switch from Restricted to Full mode, the license manager checks whether the required add-on product licenses are available and checks them out. If some of the add-on product licenses are not available, the license manager issues an error and the model stays in Restricted mode.

`Restricted`

Sets the editing mode of the model to Restricted. In this mode, you can simulate the model, generate code, and make limited modifications.

When you open a model in Restricted mode, the license manager does not check out the add-on product licenses.

When you switch from Full to Restricted mode, all the add-on product licenses for the blocks present in the model remain checked out until the end of the MATLAB session.

Command-Line Information

Parameter: `EditingMode`
Type: string
Value: `'Full' | 'Restricted'`
Default: `'Full'`

See Also

- Saving a Model in Restricted Mode
- Switching from Restricted to Full Mode

Explicit solver used in model containing Physical Networks blocks

Specify whether or not the system will issue a warning or error upon simulation if the model uses an explicit solver.

Settings

Default: `warning`

`warning`

Makes the system issue a warning upon simulation if the model uses an explicit solver.

It is possible to choose any variable-step or fixed-step solver for models containing Simscape blocks. When you first create a model, the default Simulink solver is ode45. However, implicit solvers, such as ode14x, ode23t, and ode15s, are a better choice for a typical model. In particular, for stiff systems, implicit solvers typically take many fewer timesteps than explicit solvers, such as ode45, ode113, and ode1. To alert you to a potential issue, the system issues a warning when you use an explicit solver in a model containing Simscape blocks.

`error`

Makes the system issue an error upon simulation if the model uses an explicit solver.

If your model is stiff, and the use of explicit solvers undesirable, you may choose to select this option to avoid troubleshooting errors in the future.

`none`

Turns off issuing a warning or error upon simulation with explicit solver.

For models that are not stiff, explicit solvers can be effective, often taking fewer timesteps than implicit solvers. If you work with such models and use explicit solvers, select this option to turn off the warning upon simulation.

Command-Line Information

Parameter: `ExplicitSolverDiagnosticOptions`
Type: string
Value: `'warning'` | `'error'` | `'none'`
Default: `'warning'`

See Also

Selecting a Solver

Input filtering used in model containing Physical Networks blocks

Specify whether or not the system will issue a warning or error upon simulation if the model uses input filtering.

Settings

Default: `warning`

`warning`
: Makes the system issue a warning upon simulation if the model uses input filtering, because input filtering can appreciably change the input signal and drastically affect simulation results if the time constant is too large. The warning contains a list of Simulink-PS Converter blocks that use input filtering.

`error`
: Makes the system issue an error upon simulation if the model uses input filtering.

  If you select this option and use an explicit solver, you have to provide first derivative of the input signal as an additional input signal to each Simulink-PS Converter block.

`none`
: Turns off issuing a warning or error upon simulation when the model uses input filtering.

Command-Line Information

Parameter: `InputDerivativeDiagnosticOptions`
Type: string
Value: `'warning' | 'error' | 'none'`
Default: `'warning'`

See Also

Input filtering

Log simulation data

Specify whether or not the system logs simulation data to workspace.

Settings

Default: `none`

`none`
: Performs no data logging upon simulation.

`all`
: Upon simulating the model, logs all simulation data from Simscape blocks to a workspace variable specified by the **Workspace variable name** parameter.

Command-Line Information

Parameter: `SimscapeLogType`
Type: string
Value: `'none'` | `'all'`
Default: `'none'`

See Also

How to Log Simulation Data

Workspace variable name

Specify the name of the workspace variable for simulation data logging.

Settings

Default: `simlog`

- The default value logs all the simulation data to a workspace variable named `simlog`.
- You can specify any other valid string as the workspace variable name.

Command-Line Information

Parameter: `SimscapeLogName`
Type: string
Value: any valid value
Default: `'simlog'`

See Also

How to Log Simulation Data

Limit data points

Specify that the number of data points logged to workspace is limited to the value corresponding to the number of simulation steps specified by the **Data history (last N steps)** parameter.

Settings

Default: on

☑ On
Limits the number of data points exported to workspace to those for the number of steps specified by the **Data history (last N steps)** parameter.

☐ Off
Does not limit the number of data points.

Tips

- Saving data to workspace can slow down the simulation and consume memory. Use this parameter to limit the number of data points saved.
- You must select the **Limit data points** check box before specifying the number of steps in the **Data history (last N steps)** parameter.

Command-Line Information

Parameter: `SimscapeLogLimitData`
Type: string
Value: `'on'` | `'off'`
Default: `'on'`

See Also

How to Log Simulation Data

Data history (last N steps)

Specify the number of simulation steps to limit the number of data points output to workspace. The workspace variable defined by the **Workspace variable name** parameter contains the data points corresponding to the last N steps of the simulation, where N is the value you specify for the **Data history (last N steps)** parameter. If the simulation contains fewer steps than the number specified, the workspace variable contains the data points for the whole simulation.

Settings

Default: `5000`

- The default value logs simulation data for the last 5000 steps.
- You can specify any other positive integer number.

Tips

- Saving data to workspace can slow down the simulation and consume memory. Use this parameter to limit the number of data points saved.
- You must select the **Limit data points** check box before specifying the number of steps in the **Data history (last N steps)** parameter.

Command-Line Information

Parameter: `SimscapeLogDataHistory`
Type: numeric
Value: any positive integer value
Default: `5000`

See Also

How to Log Simulation Data

A

Bibliography

[1] Andersen, B. W. *The Analysis and Design of Pneumatic Systems*. New York: John Wiley & Sons, 1967.

[2] Armstrong, B., and C. C. de Wit. "Friction Modeling and Compensation."*The Control Handbook*. Boca Raton, Florida: CRC Press, 1995.

[3] Beater, P. *Pneumatic Drives. System Design, Modeling and Control*. New York: Springer, 2007.

[4] Brauer J.R. *Magnetic Actuators and Sensors*. Piscataway, NJ: Wiley-IEEE Press, 2006.

[5] Fitzgerald A.E., Kingsley C., Jr., and Umans S.D. *Electric Machinery*. Sixth edition. New Delhi: Tata McGraw Hill, 2002.

[6] Holcke, Jan. "Frequency Response of Hydraulic Hoses." Licentiate Thesis. Royal Institute of Technology, KTH, Stockholm, 2002.

[7] Kahaner, D., Cleve Moler, and Stephen Nash. *Numerical Methods and Software*. Englewood Cliffs, NJ: Prentice Hall, 1988.

[8] Lorenz R.D. and Haines L.P. *Understanding Modern Power Conversion*. Third edition. Madison: University of Wisconsin, 2000.

[9] Martin, H. *The Design of Hydraulic Components and Systems*. New York: Ellis Horwood, 1995.

[10] Meritt, H. E. *Hydraulic Control Systems*. New York: John Wiley & Sons, 1967.

[11] Moran M.J. and Shapiro H.N. *Fundamentals of Engineering Thermodynamics*. Second edition. New York: John Wiley & Sons, 1992.

[12] Pêcheux, F., B. Allard, C. Lallement, A. Vachoux, and H. Morel. "Modeling and Simulation of Multi-Discipline Systems using Bond Graphs and VHDL-AMS." International Conference on Bond Graph Modeling and Simulation (ICBGM). New Orleans, USA, 23–27 Jan. 2005.

[13] Press, W. H., B. P. Flannery, S. A. Teulkolsky, and W. T. Wetterling. *Numerical Recipes in C: The Art of Scientific Computing*. New York: Cambridge University Press, 1992.

[14] Sanville, F. E. “A New Method of Specifying the Flow Capacity of Pneumatic Fluid Power Valves.” Paper D3, p.37-47. BHRA. Second International Fluid Power Symposium, Guildford, England, 1971.

[15] Shapiro, A. H. *The Dynamics and Thermodynamics of Compressible Fluid Flow*. Vol. 1. New York: John Wiley & Sons, 1953.

[16] White, F. M. *Viscous Fluid Flow*. New York: McGraw-Hill, 1991.

[17] Yeapple, F. *Fluid Power Design Handbook*, Third edition. New York: Marcel Dekker, 1996.

Glossary

across variables
Variables that are measured with a gauge connected in parallel to an element.

add-on products
Products in the Physical Modeling family that use Simscape platform and, as a result, share common functionality such as physical units management, editing modes, and so on.

conserving ports
Bidirectional hydraulic or mechanical ports that represent physical connections and relate physical variables based on the Physical Network approach.

globally assigned positive direction
Direction considered positive for a model diagram.

nonrestricted parameters
Parameters that are available for modification when you open a model in Restricted mode. Usually, these are the block parameters with plain numerical values, such as **Chamber volume** or **Wheel radius**. Information on restricted and nonrestricted parameters is listed in block reference pages.

physical connections
Bidirectional connections between the blocks that mimic physical connections between elements.

physical signal ports
Unidirectional ports (inports and outports) transferring signals that use an internal Simscape engine for computations.

restricted parameters
Parameters that are not available for modification when you open a model in Restricted mode. You have to be in Full mode to modify them. Usually, these are the block parameterization options, such as **Chamber specification** or **Mechanism orientation**. Information

on restricted and nonrestricted parameters is listed in block reference pages.

through variables

Variables that are measured with a gauge connected in series to an element.

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