Model Library

Power Transmission

The Power Transmission libraries in SimulationX support the efficient modeling and analysis of mechanical powertrains as well as the simulation-based design of controlled drive systems.

All models can be parameterized in a user-friendly manner by values available from product data sheets and design parameters. Alternatively, the internally used approaches can be substituted by the user with detailed information.

- Efficient modeling of drive components such as motors, engines, clutches and transmission elements
- Parameter input by design and/or catalog data with internal consideration of dynamic characteristics
- Exchangeable model elements for the analysis of electro-mechanical drives or combustion engine
- Free choice for modeling of quasistatic and/or rigid or dynamic properties

In combination with Animation Bodies, it is possible to create three-dimensional visualizations (animations).
Motors and Engines
The library Motors and Engines includes three different basic models of motors and engines, which are based on characteristics. These models can be used in wide field of applications in the automotive or mechanical engineering. All model types consider the inertia internally and allow connecting bearing structures. All models compute non-uniformities exciting the powertrain.

| Combustion Engines | • model of a 4-stroke combustion engine incl. the non-uniformities as result of combustion and compression  
|                    | • engine torque depends on engine speed, crank shaft position, and injection  
|                    | • parameterization by catalog data: no. of cylinders, nominal power, nominal speed  
|                    | • controlling by injection (gas pedal position)  
| Asynchronous Motor | • modeling of the dynamic properties of an asynchronous motor based on characteristics (without electric feedback)  
|                    | • consideration of the typical start-up behavior  
|                    | • parameterization by catalog data: nominal power, nominal speed, rel. locked rotor torque, rel. locked breakdown torque, power supply frequency  
|                    | • controlled by a switch (on or off)  
| Servo Motor        | • modeling of the dynamic behavior of a speed controlled servo motor with PI-controller, time dependent power, and limitation of the motor torque  
|                    | • external or internal speed preset  

There are also detailed motor and engine models available in the libraries Combustion Engines I and II, Electric Motors, and Stepping Motors.

Actuating Elements
The Actuating Elements library includes elements for gear shift simulations of manual or automated gearboxes.

The element Gear Selection compares desired and current gear, computes the shift force for disengaging and engaging, and controls the actuating elements for the gear change (selection of selector bar, selector shaft, or shift fork). Using the element Detent Mechanism it is possible to model detailed detents of shift actuators in MT or AMT gearboxes. The detent profile can be parameterized by geometry data and computes the detent forces including the self-locking effects.

| Gear Selection | • controller for manual and AMT gearbox models  
|                | • preset of the desired gears as a function of time  
|                | • detection of the desired gear change and the neutral position of the gearbox  
|                | • autonomous selection of selector bar  
|                | • computation of the shift force while engaging or disengaging (computation at every change in state)  
|                | • computation of the shift force based on characteristics (trapezoid approach or freely definable curve) or by referencing to another substructure in the model  
|                | • initialization of the shift force and shift signals for every selector bar  
| Detent Mechanism | • model of detent mechanism, as it is used in shift actuators of MT and AMT gearboxes  
|                  | • graphical interactive parameterization of the detent profile and the ball radius  
|                  | • consideration of the friction behavior and the self-locking effect as well as the behavior of the compression spring of the ball  
|                  | • result: computation (simulation) of the detent force  
|                  | • simple implementation in translatory mechanical structures  

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**Couplings and Clutches**

The library Couplings and Clutches contains a multitude model types to represent machine parts for the transmission of torques. The fast application of these powertrain components is ensured by preset default values. The elements can be used in a wide range of applications. The multifaceted possibilities of parameterization, taking into account non-linearities, allow the precise selection of model properties (such as stiffness, damping, hysteresis) very quickly.

<table>
<thead>
<tr>
<th>Couplings and Clutches</th>
<th>Description</th>
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</table>
| **Elastic Coupling**    | - modeling of highly elastic couplings incl. non-linear stiffness and hysteresis behavior  
- parameterization by nominal torque, relative damping, nominal angle or static stiffness, and type of construction  
- automatic modeling as tire, annular spring, jaw, pin-and-bushing, or disk coupling or, if necessary, modeling by free definition of the user |
| **Disc Clutch**         | - multiple disk friction clutch considering friction behavior dependent on speed and material properties (selection from catalog data or free definition by the user)  
- clutch opening and closing with time dependent force characteristics (automatic opening at overload)  
- automatic computation of stiffness, damping, and press-on force or preset of these values by the user  
- possibility of rigid modeling (without spring-damper behavior) |
| **Disc Clutch with Torsional Damper** | - automotive disk clutch considering friction behavior dependent on speed and material properties  
- consideration of the inertias of the primary side, secondary side, and disk  
- simulates the hysteresis behavior of the torsional damper |
| **Dual Mass Flywheel**  | - dual mass flywheel, as it is used in automotive powertrains  
- consideration of the inertias of the primary and the secondary side  
- simulates the hysteresis behavior |
| **Automatic Centrifugal Clutch** | - model of an automatic shifting centrifugal clutch (speed dependent shifting)  
- consideration of the weighted arms, the centripetal springs (extension springs in radial direction), the end stops, and the inertias of the clutch halves  
- speed dependent closing of the clutch by frictional connection (force closure) between the weighted arms and the secondary clutch half  
- pre-stress of the centripetal springs at end stops |
| **Cardan Joint**        | - model of Cardan joint (coupling) for the balancing of assembly angle differences  
- Consideration of the Cardan angle and the non-uniform speed transformations  
- can be modeled as rigid or elastic, with or without angular backlash |
| **Fluid Coupling**      | - model of a fluid coupling  
- based on a coupling map (parameterizable)  
- consideration of the pump and turbine inertia and also the oil inertia |
Transmission Elements

The Transmission Elements are considering much more than only one rotational degree of freedom, as it is known from the traditional torsional vibration analysis. Shaft and bearing properties (stiffness, damping ...) can be considered by the connection of further elements to the respective degrees of freedom (e.g., from the Linear or Rotational Mechanics libraries (1D)). The models types can be used for elastic or rigid powertrain components. If required, backlashes will be represented by ideal end stops (plastic, elastic, or impact coefficient).

<table>
<thead>
<tr>
<th>Gear Stage</th>
<th>Features</th>
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| Helical Gear Stage  | • modeling of the elastic tooth contact in helical gear stages  
• consideration of tooth stiffness and damping, stiffness fluctuations, and rotary backlash  
• stiffness fluctuations dependent on contact positions  
• optionally: damping in toothing backlash  
• alternatively: rigid modeling of the tooth contact and consideration of the backlash by impact laws  
• consideration of losses in the tooth contact and in the gear bearings (efficiency) |
| Bevel Gear Stage    | • modeling of the tooth contact in analogy to the Helical Gear Stage  
• incl. pins for the consideration of the inclination of the wheels as result of the tooth contact forces  
• spur, helical, or spiral toothancing  
• alternatively: rigid modeling of the tooth contact and consideration of the backlash by impact laws |
| Rack & Pinion Gear Stage | • modeling of the tooth contact in analogy to the Helical Gear Stage  
• incl. pins for the consideration of the wheel inclination and the displacements of the rack as a result of the tooth contact forces  
• input of the shaft angle  
• consideration of friction between the tooth flanks (screw behavior, if the shaft angle is not equal to zero)  
• input of a variable helix angle of the rack (e.g., in models of vehicle steering systems)  
• alternatively: rigid modeling of the tooth contact and consideration of the backlash by impact laws |
| Worm Gear Stage     | • 90° - worm gear stage  
• modeling of the tooth contact in analogy to the Helical Gear Stage  
• self-locking  
• incl. pin for the consideration of the inclination of the worm as result of the tooth contact forces  
• alternatively: rigid modeling of the tooth contact and consideration of the backlash by impact laws |
| Ball Screw Drive    | • model of a screw drive (e.g., ball screw drive)  
• consideration of the spring-damper-backlash behavior at the rotary and/or translatory side  
• transmission depends on the thread pitch  
• alternatively: rigid model with translatory or rotary backlash and ideal end stop |
| Belt Drive          | • belt drive model with geometry-dependent transmission ratio  
• automatic, load dependent computation and consideration of the strand tension  
• toothed, flat, round, vee, or other belts  
• indirect parameterization by test force / bending or direct preset of the stiffness |
<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
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| Continuously Variable Transmission (Belt Drive) | • rigid model of a CVT belt drive (continuously variable transmission)  
• Consideration of the inertias and masses of the pulleys and the belt as well as their variable effects  
• Computation of the speed transmission between the rotating pulley and the displacement ratio between the flexible pulley halves based on the variable pulley geometry  
• Definition of the transmission ratio by moving the flexible pulley halves  
• Preset of the initial pulley diameters or the initial speed ratio and the belt length |
| Crank Mechanism                          | • crank mechanism model  
• elastic or rigid connecting rod with backlash  
• alternatively: rigid model with translatory or rotary backlash and ideal end stop |
| Differential Gearbox                     | • model of a differential gearbox  
• consideration of the spring-damper properties and the backlash of the gearbox  
• alternatively: rigid modeling incl. consideration of the backlash by impact laws |
| Planetary Gearbox                        | • model of a planetary gearbox  
• models multi-stage gearboxes can be created through combination of several planetary gearbox elements  
• two or three shaft operations  
• consideration of the spring-damper behavior of the gearbox with or without backlash  
• alternatively: rigid modeling incl. consideration of the backlash by impact laws |
| Ravigneaux Gearset                       | • model of a Ravigneaux gearset (planetary gearset), which is used for instance in vehicle automatic transmissions  
• preset of standing ratios or numbers of teeth  
• two, three, or four shaft operations  
• separate consideration of the spring-damper-backlash behavior of both gearset sides  
• alternatively: rigid modeling incl. consideration of the backlash by impact laws |
| Simpson Gearset                          | • model of a Simpson gearset (planetary gearset), which is used for instance in vehicle automatic transmissions  
• preset of the standing ratios or numbers of teeth  
• two, three, or four shaft operations  
• separate consideration of the spring-damper-backlash behavior of both gearset sides  
• alternatively: rigid modeling incl. consideration of the backlash by impact laws |
| Cardan Shaft                             | • model of an elastic cardan shaft with consideration of the shaft and flange intransias  
• different possibilities of parameterization of the stiffness and damping  
• consideration of the joint backlashes and the non-uniform transmission behavior of the cardan joints under inclination |
| Wheel Ground Contact                     | • model of the wheel ground contact with slip  
( see also Tire Plane Contact, library Power Transmission MBS)  
• applicable to automotive or rail car models for analyzing traction effects  
• parameterization by a slip curve |
| Torque Converter                         | • characteristics-based model of a torque converter, e.g. for the application in automotive powertrains with automatic gearboxes  
• consideration of the pump and turbine inertias  
• internal representation of the lock-up clutch and the one-way clutch |
Planetary Gears

The library Planetary Gears contains model types to create structures of helical planetary gears. All planetary gears can be represented by these base structures, which model the kinetic and kinematic relationships (elastic and/or rigid) between a central wheel, a planet wheel and the planet carrier. The combination of these structures with the masses and the inertias of the gearbox components give the possibility to model all kinds of planetary gearboxes, e.g., also Ravigneaux or Wolfram gearsets.

Forces, motion quantities, and parametric excitations can be analyzed in an efficient way. The elements have pins to connect elastic bearing structures, rigid fixings, and preloads. It is possible to simulate stiffness oscillations of the tooth contact and centrifugal and unbalance forces of the central wheel (sun or ring), the planet carrier, and the planet.
**Drive Accessory**

The library Drive Accessory contains models that simplifies the creation of drivetrains.

For the modeling and analysis of mounting torques, which act on rotary mass systems, e.g., engines, gearboxes, or differential gearboxes, the element Mount can be used. At the same time, this element overlays the rotational motion of the frame or housing with the rotational motion of the rotary mass system, so that the interaction between shaft model and housing is considered. It is possible to use it in reduced drivetrain models as well as in drivetrain models with physical parameters.

The element Shaft Segment represents a two-mass model of a shaft (whole part or segment) and can be used for efficient modeling of shaft systems. It computes inertia, stiffness, and damping by geometrical parameters and material data.

Each element can modeled as rigid or elastic, optionally.

| Mount | • all-purpose physical model for modeling the mounting torques in rotary systems (e.g., engine-gearbox-unit, gearboxes, rotational systems)  
• interactions between shaft systems and housings  
• rigid or elastic mount  
• consideration of inner acceleration torques  
• consideration of reduced powertrains as option |
| --- | --- |
| Shaft Segment | • rotational two-mass model of a shaft segment  
• preset of the segment geometry and the material: the element computes inertia, stiffness, and damping  
• alternatively: preset of inertia, stiffness, and damping  
• consideration of additional inertias at the segment sides (i.e. of flanges)  
• option: rigid modeling  
• computation of the torsional torque, the torsional stress and more |
**Synchronization with Friction and Tooth Contact**

The Synchronizers library contains model types, which enable the user to model synchronization systems or dog clutch shift systems, used in manual gearboxes or AMTs.

Typical fields of applications are gearbox models, which have to shift during the simulation run or where the shifting process itself has to be analyzed. The models compute, whether dogs are in contact, and if so, at which angle. Dogs can be rejected and skipped. This is the prerequisite for shift comfort studies. First and second pressure point (also multiply), reverse rotation, and free motion phases after overcoming the locking condition can be simulated.

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**Dog Clutch**

- model of a shiftable dog clutch
- application for the representation of selector and locking tooth contacts in synchronizer mechanisms and dog clutch mechanisms
- input of the different dog geometries (tooth geometries) based on three basic shapes including undercuts
- stiffness and damping at the tooth flanks in normal direction and friction in tangential direction
- automatic estimation of dog contacts and contact angles
- separate consideration of left and right flanks
- computation and consideration of the backlash depending on the engagement progress

**Borg-Warner Single Synchronizer**

- model of a one-sided synchronizer mechanism of Borg-Warner type
- parameterization as single- or multi-cone mechanism
- translation and rotation of the sliding sleeve, the synchromeshes, and the idler gear
- consideration of the pre-synchronization force, the locking and selector tooth contacts (Dog Clutch), and the friction cones for the speed synchronization
- consideration of the tooth geometries, stiffness and damping, and the load dependent friction at the tooth flanks (Dog Clutch)
- the model simulates all phases during gear synchronization and engagement in detail: pre-synchronization, synchronization, locking, and engagement

**Borg-Warner Double Synchronizer**

- model of a double synchronizer mechanism of the Borg-Warner type
- includes two Borg-Warner Single Synchronizers separate modeling, parameterization, and analysis of both sides
- includes inertias of the sliding sleeve and the synchronizer hub
- consideration of the spline contact between hub and sleeve
- representation of the friction between shift fork and sliding sleeve groove

All models can be extended and edited by the user. This is a very comfortable way to create alternative synchronization systems (such as Mercedes-Benz, Porsche-, or Lever synchronizer)
Combustion Engines I

SimulationX provides many element types for modeling combustion engines. These combustion engine structures can be used as components in powertrain models or for the analysis of combustion engines itself. The library Combustion Engines I includes model types to represent the excitation in engines (Fourier coefficients, characteristics of cylinder pressure or excitation torques, engine map), rigid or elastic inline cylinders or V-cylinder pairs, and several complete engine models (Diesel or gasoline engines, 2-stroke or 4-stroke).

**Mechanical Cylinder Structures**

- mechanical structures of inline cylinders (left) and vee cylinder pairs (right)
- modeling of the crank mechanism between crank shaft and piston (rigid connecting rods)
- consideration of the oscillating mass
- pins for excitation model substructures and further cylinder or crank shaft model structures
- consideration of an absolute damping at the crank modeling speed-dependent losses (e.g., losses in the oil sump)

**Inline Cylinder Models incl. several excitation structures**

- modeling of the combustion based on characteristic curves or maps
- interpolation between two load cases based on the injection setting (e.g., full load and drag)
- parameterization of the excitation by pressure or torque depending on crank angle and engine speed, by maps, curve families, or Fourier coefficients

**Vee Cylinder Models incl. several excitation structures**
Engine Models

- Engine models, which include the cylinder models shown above as substructures
- Modeling of the engine damper and the crank shaft pivot
- Parameterization by the properties dialog of the engine model (engine parameters, characteristics and maps of the excitation, geometry and controlling data)
- Includes characteristics based sub-models to represent the excitation with full load and drag curves
- Signal oriented modeling of the engine controller
- Computation of the injection based on accelerator pedal position and crank shaft speed by an engine map

Torsional vibrations, misfiring, and various load cases can be analyzed. In difference to the simple engine models of the library Motors and Engines, these models consider the elastic or rigid crank shaft properties. Furthermore, every cylinder is modeled separately with its own excitation. The models compute non-uniformities (torques or pressure forces) during combustion and compression depending on engine speed, injection, and crank shaft position. Inertias, stiffnesses, and dampings of the cranks and the influences of the oscillating masses are taken into account.

All cylinder and engine models can be edited and extended by the user and can be used as templates or examples for further models. Thus, they can be adapted to your special simulation tasks.

Example: Model of an Inline Four-Cylinder Engine
Combustion Engines II

The SimulationX library Combustion Engines II provides further element types for the modeling of combustion engines in powertrain or component models.

The purchase of the library Combustion Engines includes all element types of the library Combustion Engines I. The element of both libraries can be combined arbitrarily in own models.

The library Combustion Engines II contains element types for the dynamic computation of the combustion in the cylinders. The combustion is computed by an approach of VIBE and it depends on the injected fuel mass, the crank position, and further parameters. With these elements, there is no need for presetting characteristics of cylinder pressures or excitation torques. Furthermore, the library includes an element, which can be used for the controlling of the engine.

<table>
<thead>
<tr>
<th>Elements of Combustion Engines I</th>
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<tbody>
<tr>
<td><img src="image" alt="elements" /></td>
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<tr>
<td>• description see section Combustion Engines I</td>
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<table>
<thead>
<tr>
<th>Inline and Vee Cylinder Models</th>
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<tbody>
<tr>
<td><img src="image" alt="cylinder models" /></td>
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<tr>
<td>• modeling of the combustion process based on an approach by VIBE</td>
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<tr>
<td>• internal computation of the cylinder pressure, depending on crank position and injection (fuel mass)</td>
</tr>
<tr>
<td>• representation of all load states from full load to drag</td>
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<tr>
<td>• internal computation of the losses, e.g., cylinder wall friction losses</td>
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<tr>
<td>• parameterizing by geometric, mechanic, and thermodynamic data</td>
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<tr>
<td>• parameterizing of the combustion data separately for each cylinder bank</td>
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<tr>
<td>• analysis of misfiring possible</td>
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<thead>
<tr>
<th>VIBE Combustion Function</th>
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<tr>
<td><img src="image" alt="VIBE combustion" /></td>
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<tr>
<td>• model for the simulation of the combustion based on the VIBE approach</td>
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<tr>
<td>• parameterization by thermodynamic data</td>
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<tr>
<td>• is included within the four cylinder models above</td>
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<tr>
<td>• e.g., computation of the cylinder pressure, the cylinder temperature, and the mean loss torque of a cylinder</td>
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<tr>
<td>• several possibilities for the connection of signal oriented model structures</td>
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<table>
<thead>
<tr>
<th>EDC (Electronic Diesel Control)</th>
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<tr>
<td><img src="image" alt="EDC" /></td>
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<tr>
<td>• model of an Electronic Diesel Control (EDC) for the engine controlling</td>
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<tr>
<td>• incl. maximum and idle speed controllers, as well as full load limiter</td>
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<tr>
<td>• computation of the fuel mass depending on the accelerator pedal position and the ignition angle</td>
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<tr>
<td>• preset of the controller characteristics</td>
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<tr>
<td>• application fields are engine models</td>
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</table>
Engine model

- model of an six cylinder inline engine, which includes the cylinder models and the EDC model described above
- modeling of the engine damper and the crank shaft pivot
- parameterization by the properties dialog of the engine model
- computation of the injection depending on the accelerator pedal position and the crank shaft speed
- application fields are powertrain models or combustion engine models itself

All cylinder and engine models can be edited and extended by the user and can be used as templates or examples for further models. Thus, they can be adapted to your special simulation tasks.

Example: Model of a Six Cylinder Inline Engine

- efficient multi-level modeling
- every level can be individually edited or extended
- summarization of relevant parameters and result values in the element properties dialog
- documentation of every level in an separate HTML help, which can be opened directly from the properties dialog of the element