# MECHMACS[c]

Mechanical Blockset for MATLAB[R] / Simulink[R]

MECHMACS[1] is a library of mechanical building blocks for MATLAB/Simulink[2]. With these blocks, mechanical systems like drivelines of vehicles, ships or cranes can be simulated. Most blocks consist of several components like spring, mass and damper for block SMD. MECHMACS includes models for elastic subsystems, clutches, engines, gear boxes and special subsystems. An animation block is available to visualize the dynamic behavior of simulated systems.

$$R = -\frac{r_2}{r_1 r_3}$$

$$M = \frac{J_g + J_r}{r_3^2} + m$$

Fig. 1   DC Engine with winch
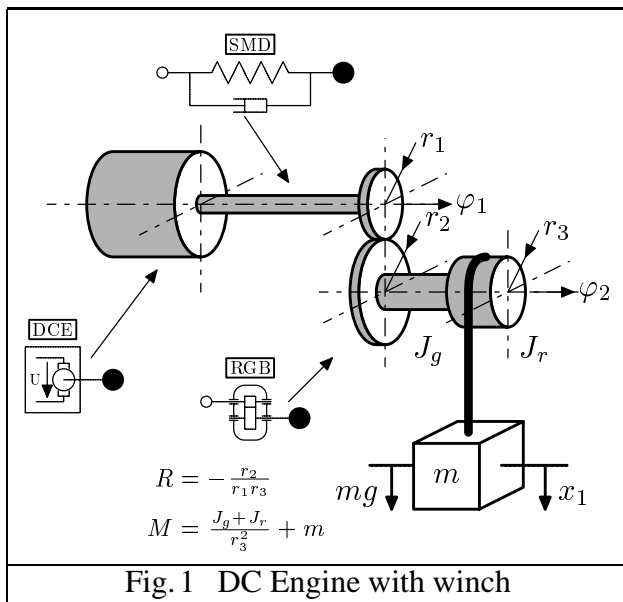
A typical application is shown in Fig. 1. An electric motor (direct current engine, DCE) with an attached rotating shaft drives a set of gears with radii r_1 and r_2. A drum with radius r_3, connected to the output gear, winds up a rope which carries a weight of mass m. The long rotating shaft is modeled by an SMD-block (Spring mass with damper) used in rotational mode. All MECHMACS blocks may be used either in translational or in rotational mode. The rigid gear block RGB models the gears and the drum and also performs the transition from rotation to translation.

To set up a simulation, the user wires blocks in the sequence of their occurence in the mechanical system into a Simulink block diagram and enters parameters into block-specific dialog boxes. These parameters determine the dynamic block behavior under implied displacements, velocities and external forces.
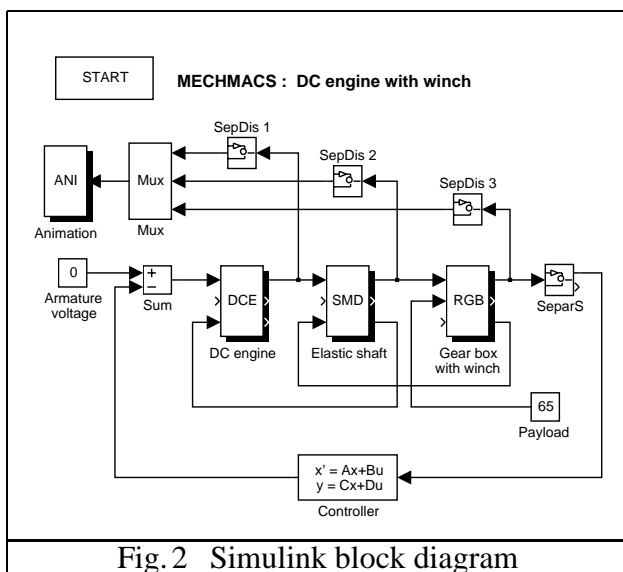

Fig. 2   Simulink block diagram

Fig. 2 shows the block diagram for the system in Fig. 1. Blocks ANI, DCE, SMD and RGB were copied from the MECHMACS block library. All other blocks are either standard Simulink blocks or user-created blocks (SepDis, SeparS). The controller gets displacement x_1 and velocity $\dot{x}_1$ of mass m as inputs and feeds an armature voltage to the DC motor such that the mass is held in place ($x_1 = $ const.) in the steady state. The controller is modeled by a linear state-space block with parameters which result in a PID characteristic. Simulation results are shown in Fig. 3 and 4.

For each MECHMACS block, Lagrangian equations of the second kind are set up to derive the complete system of differential equations which describe the dynamics to be simulated. The basic modeling law is the equilibrium of forces. Simulink as a block oriented simulation tool does not support the physical correctness of any system of equations. To guarantee the force equilibrium in MECHMACS, each successor block informs its predecessor block about its state of motion (displacement, velocity, acceleration and sticking or slipping). This is done for all blocks by connecting the last output of the successor block to the last input of the predecessor block.

Fig. 3   Simulation results


Fig. 4   Animation
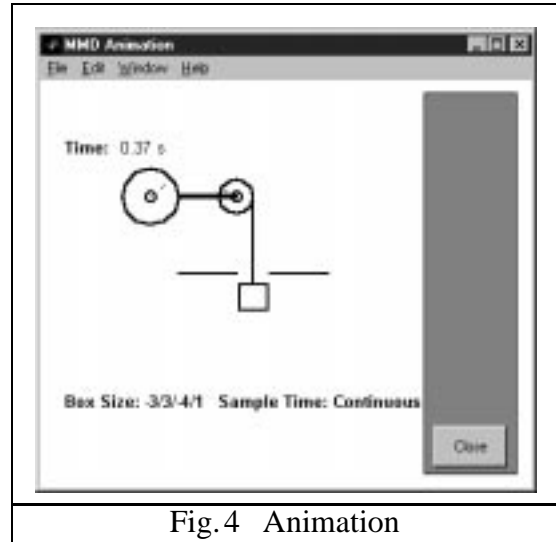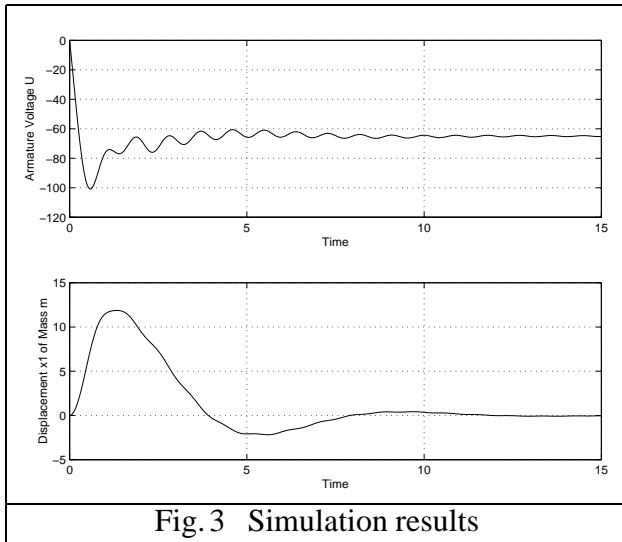
All MECHMACS blocks are open and user-readable, either as S-Functions in MATLAB-code or as block diagrams. Therefore, all details are available to the user who may study the equations and make modifications as desired. The following figures show all blocks in MECHMACS Version 2.0.


Fig. 5   Elastic blocks
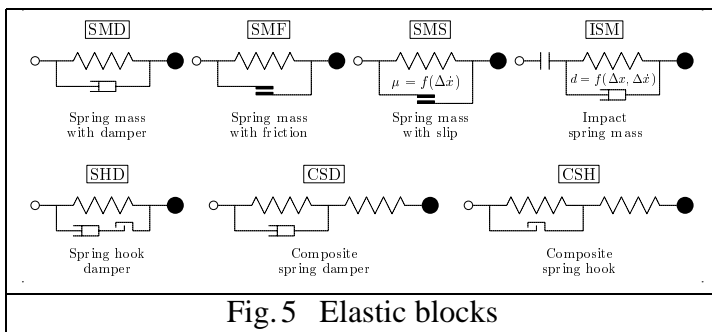
All elastic blocks consist of a discrete mass at one end which is connected to one or two massless spring(s) which model(s) the stiffness. The state of motion of the mass results from a combination of stiffness force, implied displacement, implied forces and from damping and friction forces.


Fig. 6   Clutches
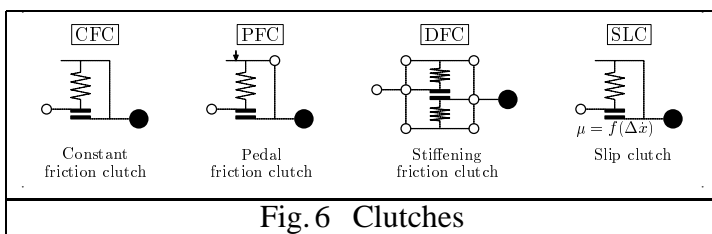
These clutch blocks have no stiffness. Motion of the mass results from implied displacement, implied forces and block friction forces. The clutch surfaces stick if the friction forces are greater than the reaction forces and if the relative velocity of the friction surfaces is small.

Fig. 7   Engines
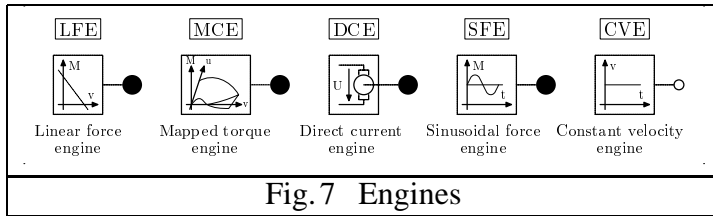
Five engine blocks are available for modeling flexibility. They imply a force or torque to accelerate a mass or moment of inertia. Block DCE is controlled by a voltage and LFE, MCE and SFE by a pedal position.

Fig. 8   Gear Boxes
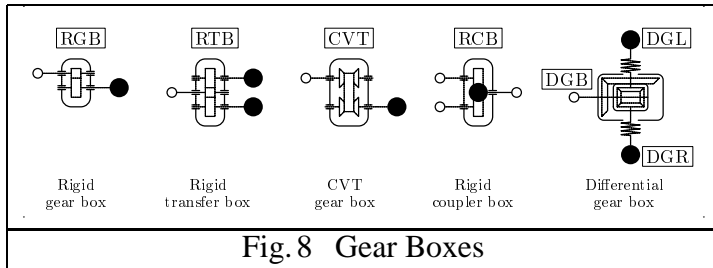
Blocks RGB, RTB and RCB are rigid gear box models, DGB with DGL and DGR model a differential gear box and CVT a time-dependant gear ratio. The gear box blocks can be used to model transition from rotation to translation and vice versa.


Fig. 9   Special Blocks
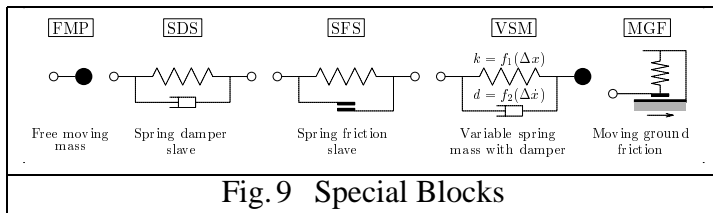
These blocks were included for ease of modeling in special situations. SDS may be used to couple two systems with internal states like two SMD or SMF blocks. VSM is similar to SMD but allows tables for stiffness and damping characteristics.

Data entry example for block SMD

This block models the dynamic behavior of a mass which is connected to a spring with a parallel damper. The damper acts either parallel to the spring or against ground. The ground switch selects the damping type. Input E1 is the vector of implied displacement/rotation and velocity/rotational velocity, input E2 is a scalar of implied force/moment and input E3 is the vector of reaction force/moment, stiffness and damping constant from the successor block. Output A1 is the vector of displacement/rotation, velocity/rotational velocity and acceleration/rotational acceleration, output A2 is a scalar for the elastic force of the spring and output A3 is a vector with the same physical quantities as E3 for connection to the predecessor block.

Block inputs and outputs
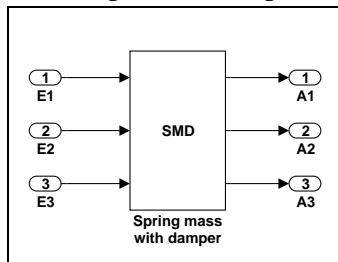
Symbol
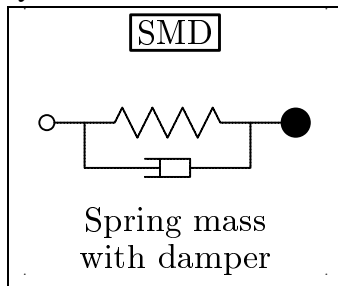
Fig. 10 Impact of three bodies
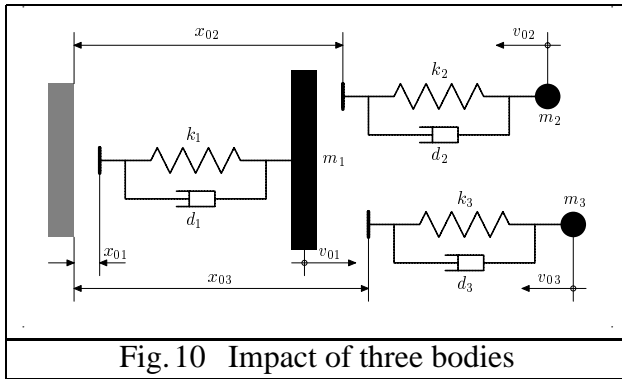
Another MECHMACS application is shown in Fig. 10. In a mechanical system of three elastic bodies, the positions (displacements) of the masses are x_{01}, x_{02} and x_{03}. Starting from known initial conditions, the time-dependent motion of the bodies for different impact stiffnesses and dampings is to be simulated. Forces and accelerations in the subsystems are also of interest.

Fig. 11 Simulink block diagram
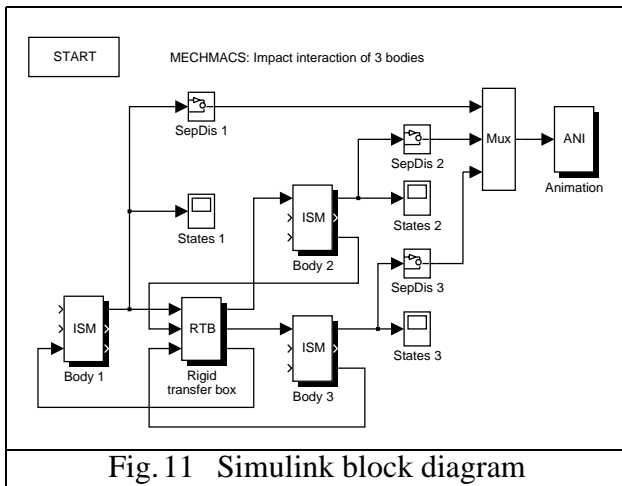
Each body is described by an ISM-block (Impact spring mass). The three bodies are kinematically coupled by an RTB-block (Rigid transfer box) which couples the three masses rigidly, one as input, the other two as output. Here, RTB has no own mass, as the three discrete masses are included in the ISM-blocks. Parameter values for impact stiffnesses and dampings are entered into the input masks of the ISM-blocks and can be changed easily for the various simulation studies to be performed.

Typical MECHMACS application areas are:

- Automotive systems

- Machine design, robotics, mechatronics

- Aerospace systems

- Control system analysis and design

- Educational training

Quite complex systems can be modeled in Simulink by wiring MECHMACS blocks, standard Simulink blocks and blocks from other blocksets. The dynamic behavior of the overall system can be analyzed in the time domain and MECHMACS animation may be used for visualization.

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