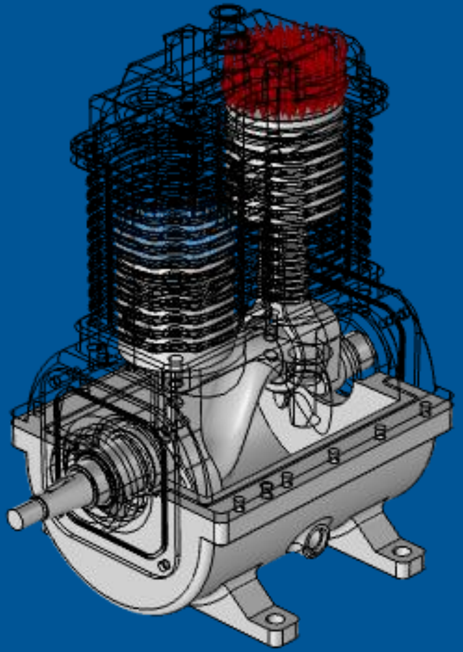

Simulation of Air Compressor with Hydrodynamics Bearings

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Application Engineer
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kozakovic@humusoft.com

Agenda

- Typical Users and User Story in MBD
- Brief Introduction to Multibody Dynamics functionality
- Compressor Model
- Multiphysical Environment of Hydrodynamic Bearing
- Results

COMSOL

Typical Users and Industries

- Users
  - Interested in flexible MBD
  - Interested in Multiphysics
  - Existing COMSOL users
  - Academics
- Industries
  - Automobile
  - Power Transmission
  - Manufacturing and Instrumentation
  - Machinery and Robotics
  - Universities

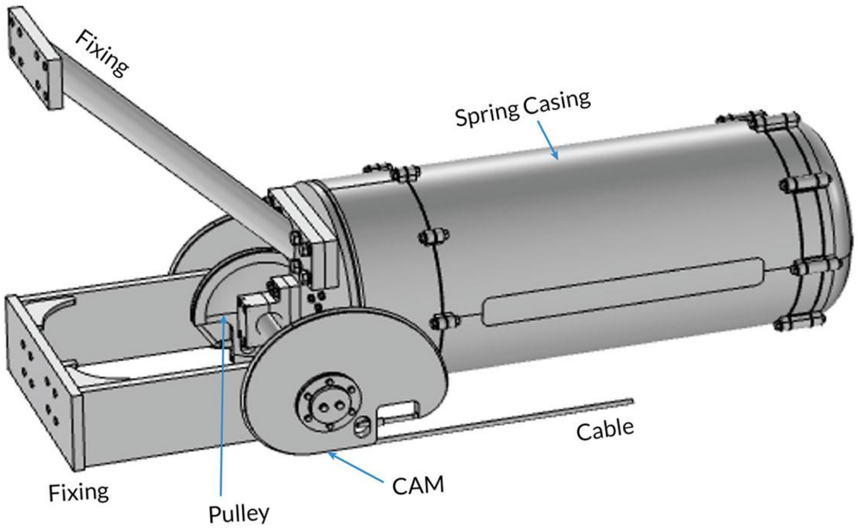
COMSOL

RAYCHEM RPG

Optimizing Railway Equipment Designs

- Two expected changes to the Indian railway network by 2030:
- Raychem used multiphysics simulation and topology optimization to design critical components for railway overhead equipment (OHE)
- Autotensioning devices (ATD)
- Modular cantilevers (MC)

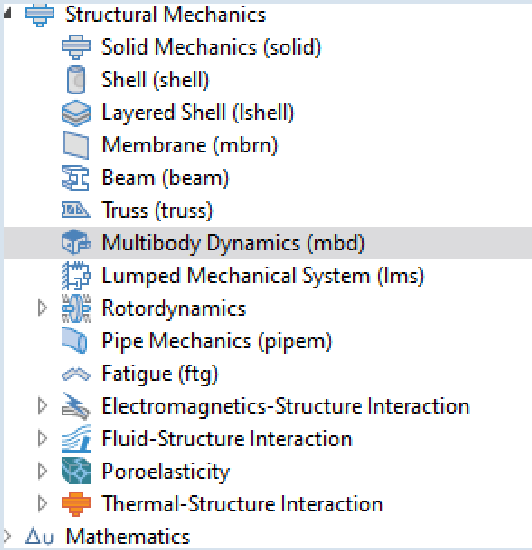
"*Improving Overhead Equipment Devices for a New Era of Railway Transportation*"
COMSOL News 2020: Ishant Jain, Raychem RPG, India



Autotensioning devices (ATD)

Multibody Dynamics Interface

- Available under Structural Mechanics
- Supported space dimensions:
  - 3D, 2D
- Supported analysis types:
  - Stationary, Parametric
  - Time dependent
  - Eigen frequency, Frequency Domain
  - Response Spectrum, Random Vibration
- Supported element types:
  - Rigid
  - Flexible (solid, shell, composite, beam)



Flexible Multibody System

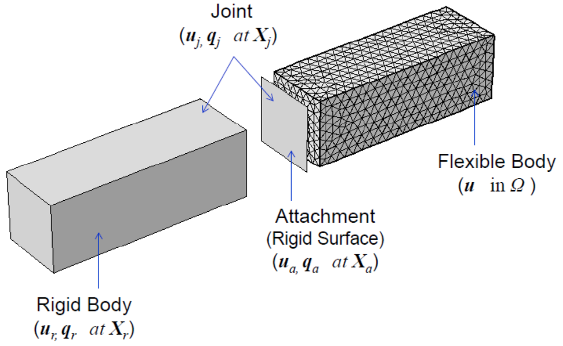
Joints (Rigid/Elastic)
(Constraints)

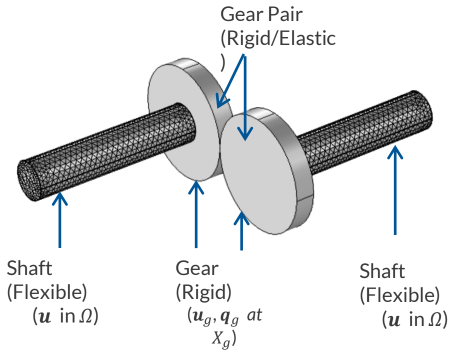
Chain Drives
(Constraints)

Rigid and Flexible Bodies
(Equations of motion)

Gear Pairs (Rigid/Elastic)
(Constraints)

Cam-Followers
(Constraints)

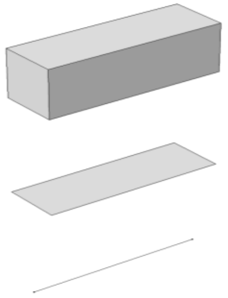




Rigid and Flexible Element

Rigid Domain

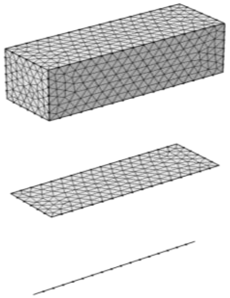
- Defined through *ODE* shape functions
- A very *coarse* mesh can be used
- Possible to directly enter inertial properties



Rigid (solid, shell, beam) elements

Linear Elastic Material

- Defined through FE discretization and shape functions
- Isotropic or anisotropic



Flexible (solid, shell, beam) elements

Stress and Equation of Motion

Common Formulation

$$M\ddot{\bar{q}} - A^T \bar{F}_A(\bar{q}, \dot{\bar{q}}) + \bar{\Phi}_{\bar{q}}^T \bar{\lambda} = \bar{0}$$
$$\bar{\Phi}(\bar{q}, t) = \bar{0}$$

M - system mass matrix,

$\bar{q}$ - the vector of coordinates q_i,

A^T - tranformation matrix projecting forces into coordinates q_i,

$\bar{F}_A$ -the vector of action forces and gyroscopic components of inertial forces,

$\bar{\Phi}$ - the vector of constraint equations,

$\bar{\Phi}_{\bar{q}}^T$ is the gradient of constraints and

$\bar{\lambda}$ is the vector of Lagrange multipliers.

Comsol Formulation

$$\varrho \frac{\partial^2 \boldsymbol{u}}{\partial t^2} = \nabla \cdot (FS)^T + \boldsymbol{F}_V, \qquad F = I + \nabla \boldsymbol{u}$$

ϱ- true density of the deformed material

$\boldsymbol{F}_V$- volumetric force

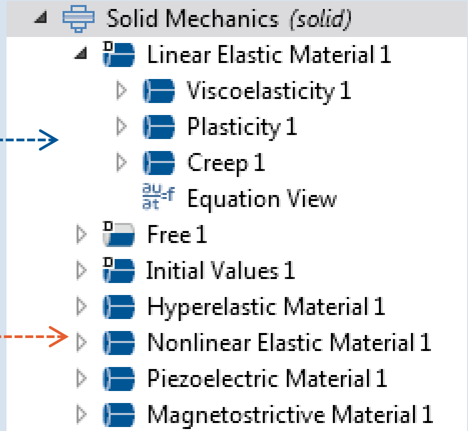
S- second Piola – Kirchhoff stress tensor

I – identity tensor

$\nabla \boldsymbol{u}$ **–** energetically conjugate deformation

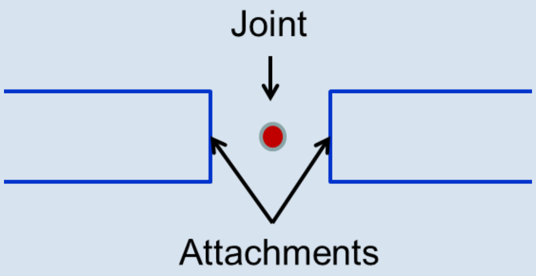
Flexible Element: Nonlinear Materials

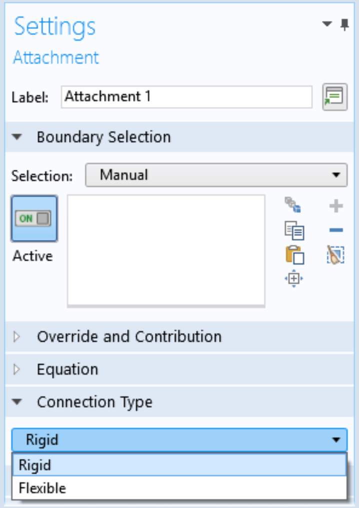
- *Linear Elastic Material*
  - *Viscoelasticity*
  - *Plasticity*
  - *Creep*
- *Hyperelastic Material*
- *Nonlinear Elastic Material*
- *Piezoelectric Material*
- *Magnetostrictive Material*
- Nonlinear materials are available through *Solid Mechanics* interface
- Nonlinear materials also require Nonlinear Structural Materials Module

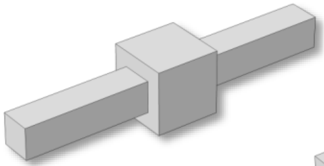


Attachments

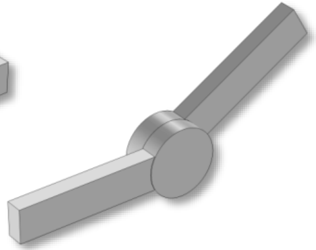
- Set of boundaries on a flexible body which is used to connect it with other bodies through joints, springs, dampers.
- Attachments can also be defined on a rigid body for an ease of modelling.
- Available in:
  - Multibody Dynamics interfaces
  - Solid Mechanics interfaces
  - Layered Shell interfaces
  - Shell interfaces
  - Beam interfaces



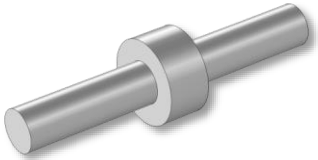




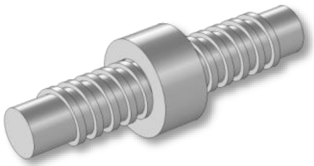
Prismatic



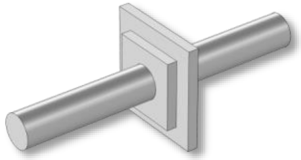
Hinge



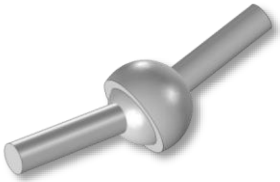
Cylindrical



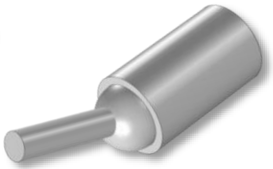
Screw



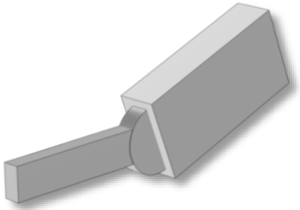
Planar



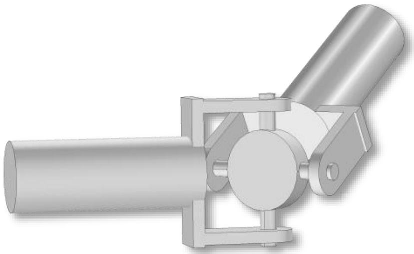
Ball



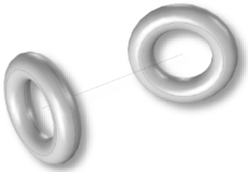
Slot



Reduced Slot



Universal

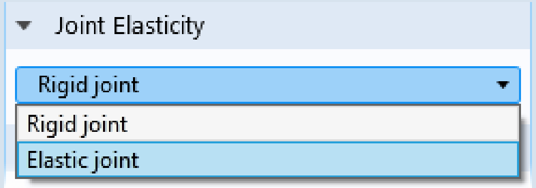


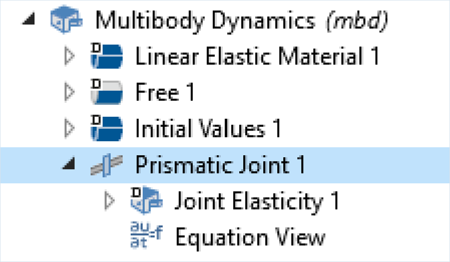
Distance

Joint Elasticity

Joint elasticity can be utilized:

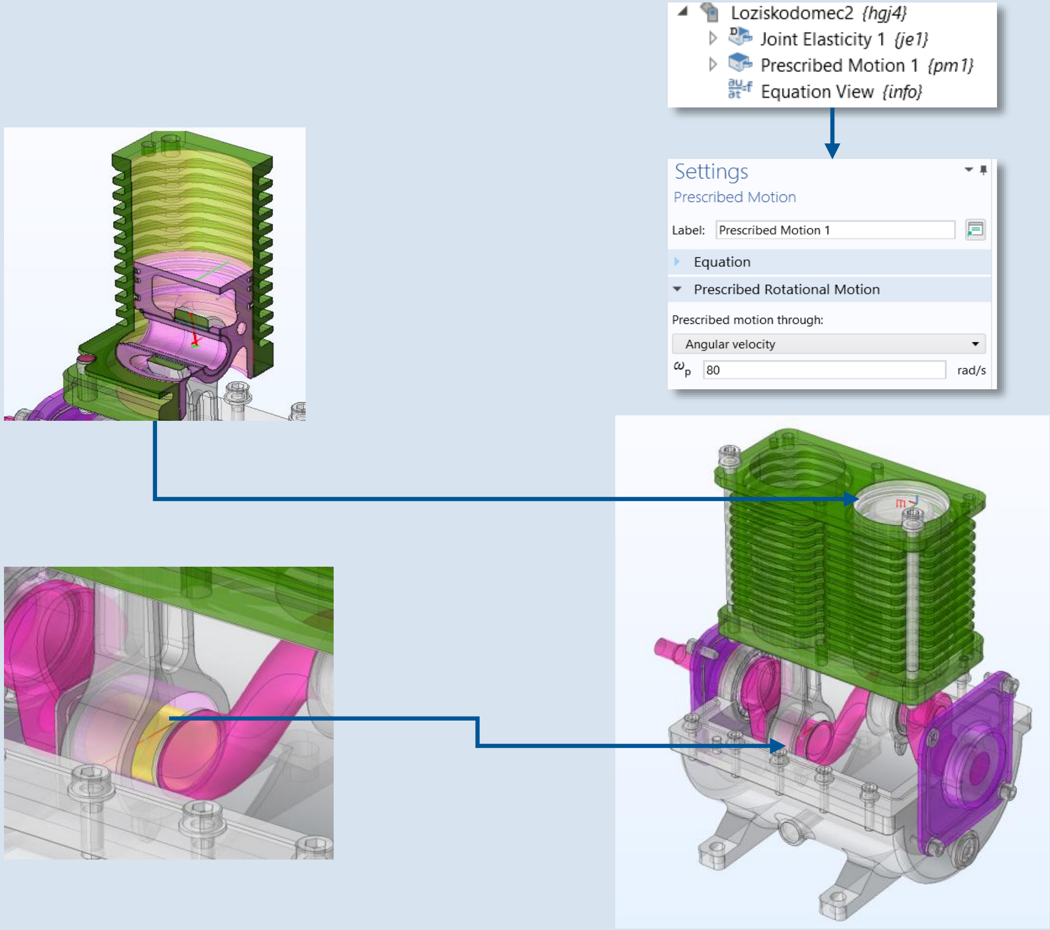
- To model bushings
- To customize joint types
- To relieve overconstraints in a rigid body system
- To conditionally deactivate joints during the simulation





Joint Functionality

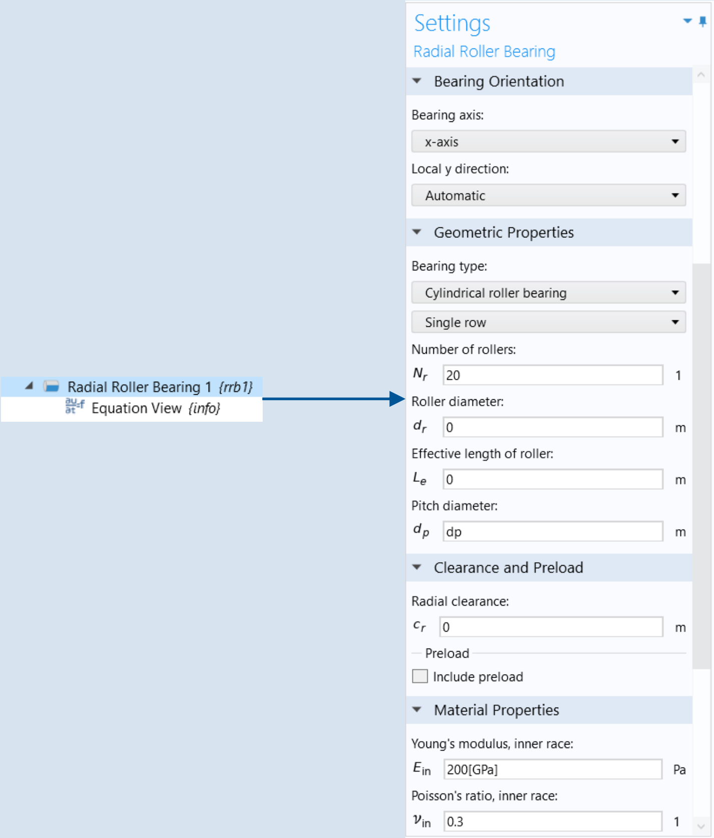
- **Constraints**
  - To limit the relative motion between the connected bodies
- **Locking**
  - To lock certain degrees of freedom at a joint
- **Spring and Damper**
  - To add spring and damper on the relative motion
- **Prescribed Motion**
  - To prescribe the relative motion as a function of time
- **Applied Force and Moment**
  - To apply forces and moments on the selected attachments
  - To apply forces or moments on the joint DOFs
- **Friction**
  - To add frictional losses on joints



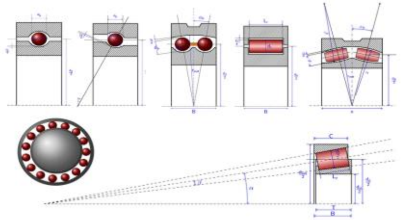
From top to bottom, from left to right: Two parts, connected by a prismatic joint, Two parts, connected by a hinge joint, Joint functionality

Radial Roller Bearing

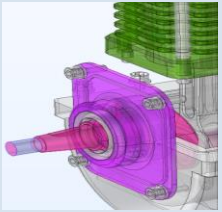
- Six rolling element bearings
  - Single or double row
- Enables modelling of bearing-supported rotating bodies
- Includes a nonlinear representation of the contact stiffness between rolling elements and inner and outer races
- Roller bearings also require Rotordynamics Module.



Available Bearings



Applied Boundaries



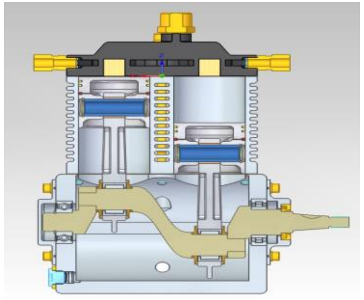
Problem Description

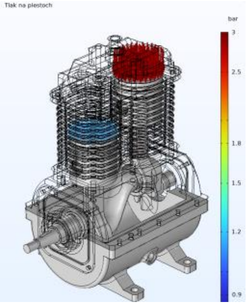
Adiabatic Air Compressor

- Pressure 3 bar
- Volume 150 cm^3 per piston
- Nonlinearities from:
  - Air compressing
  - HD bearing model
  - BC – friction contact wall/piston
  - Flexible joints with time dependent stiffness

Left and middle: Air compressor CAD geometry

Right: Compressive forces in COMSOL Multiphysics





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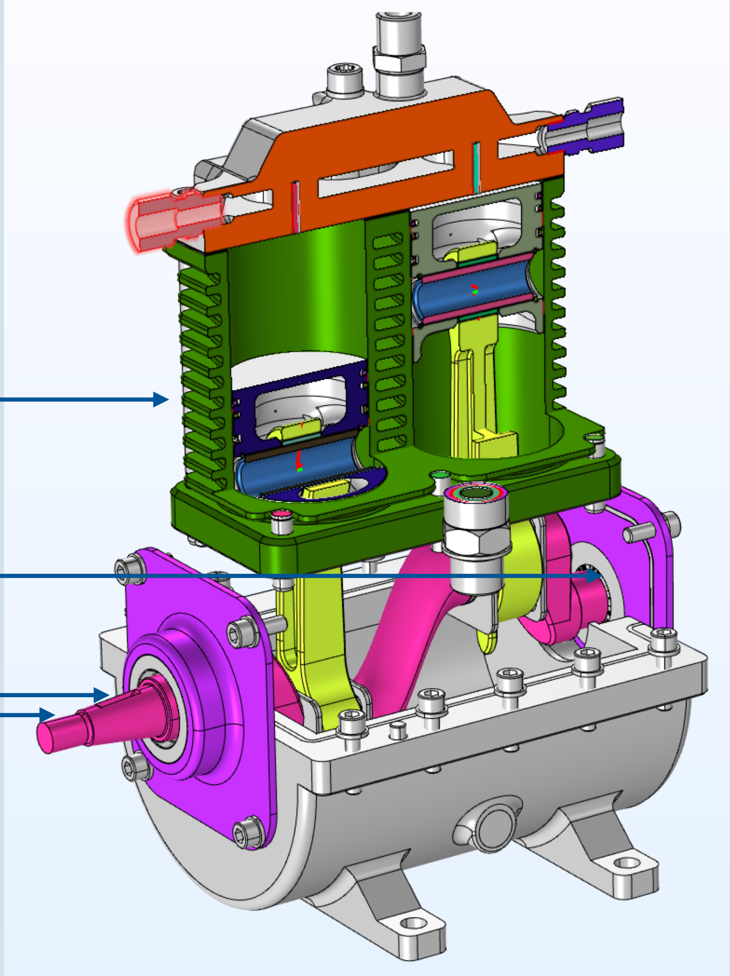
Compressor Model

- Friction contacts (wall/piston)
- Flexible joints (connecting rod/crankshaft, bearing house/crankshaft)
- HD bearing (right side)
- All parts are rigid except elastic crankshaft
- Virtual model of radial ball bearing



Equation of force

- Determined by thermodynamic equation for compressor

$$p.V^{\kappa} = C$$

p - pressure,

V - volume of the air in the compressor,

k - Poisson constant -1.4 for air

C is constant which is given by design properties

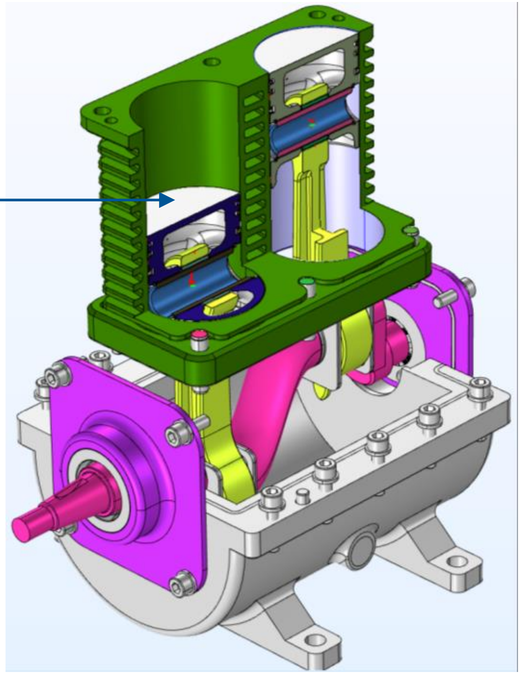
$$F = A.C(Al - Ax)^{-\kappa}$$

F - air force,

A – area of the piston,

l – working length of the piston

x – actual position of the piston



Forces acting on the upper piston area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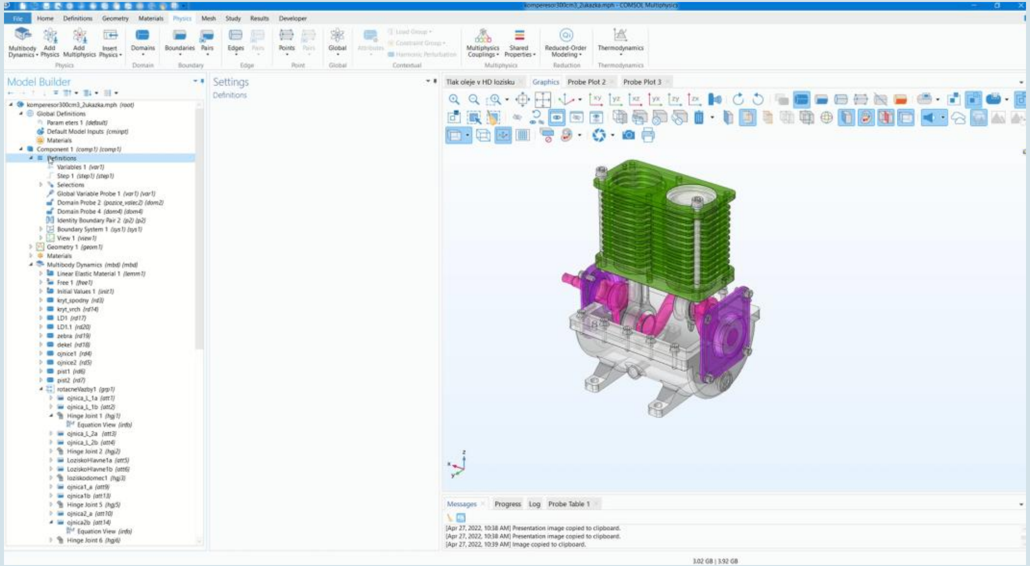
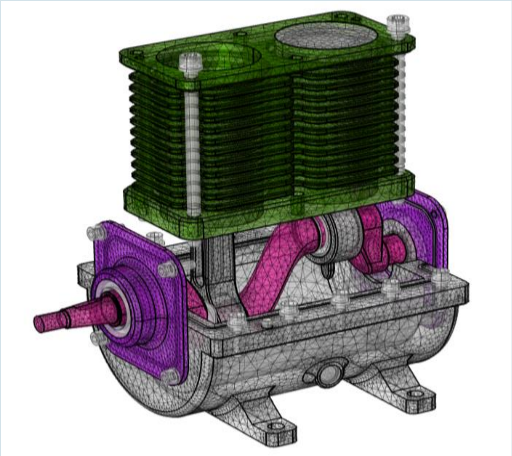
File
Home
Definitions
Geometry
Materials
Physics
Mesh
Study
Results
Developer
New
Model Wizard
Blank Model
Help
Cancel
Show on startup

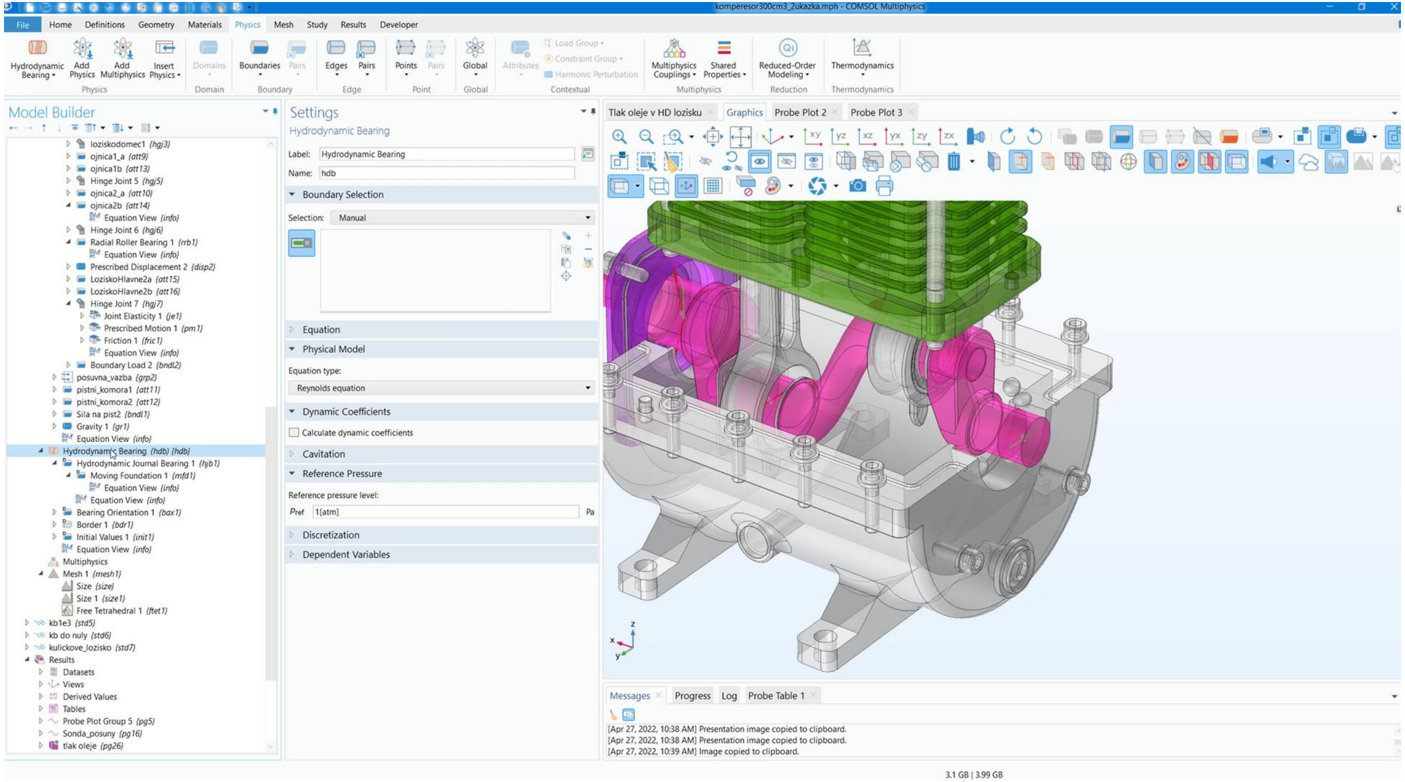
COMSOL Multiphysics

- Domain & Global Probe Definition
- MBD Domain Definition & Constrain
- Boundary Attachment
- Elastic Hinge Joint with Friction
- Time Dependent Stiffness of Joint
- Nonlinear Force Definition
- Meshing



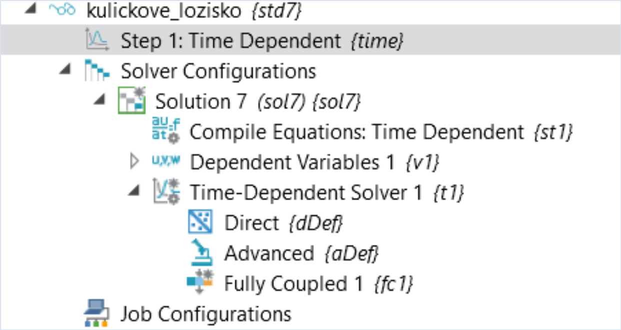


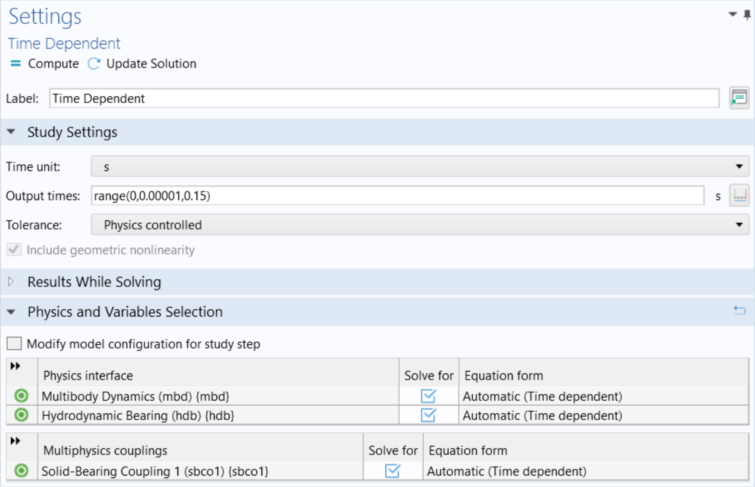
Multiphysical Environment of Hydrodynamic Bearings



Study Settings

- Selection of proper study type
- Time range and time step
- Physics selection

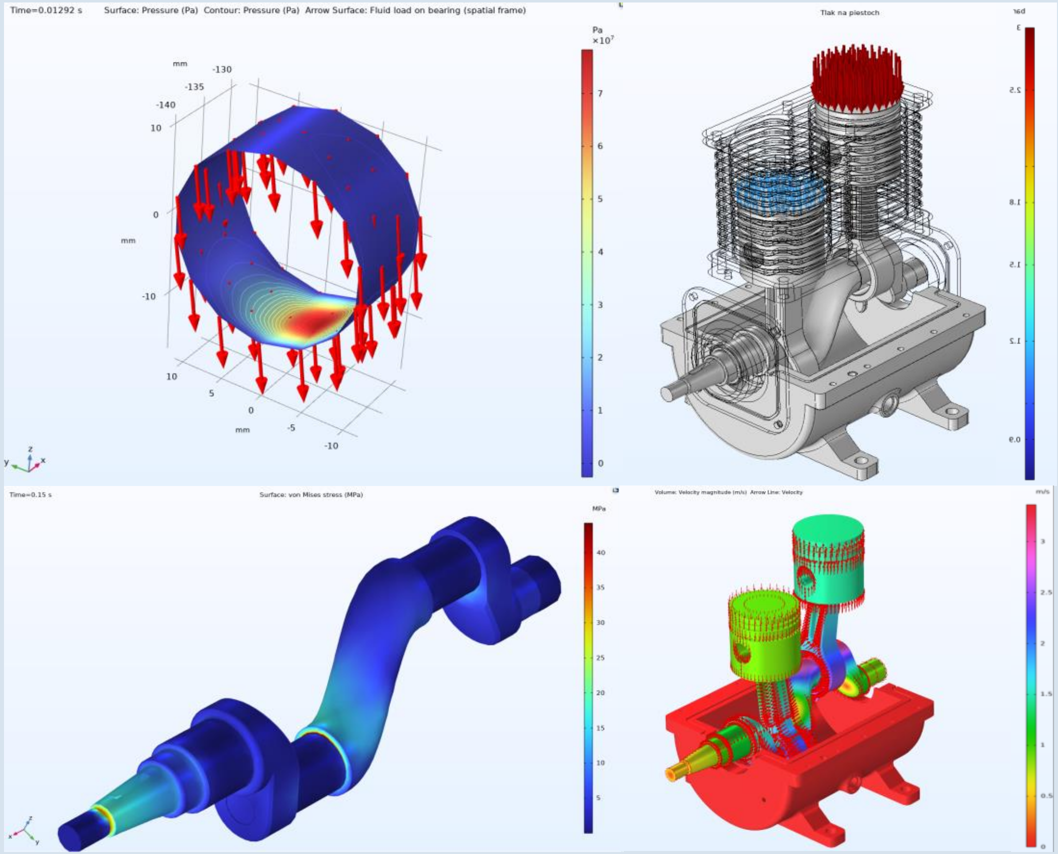




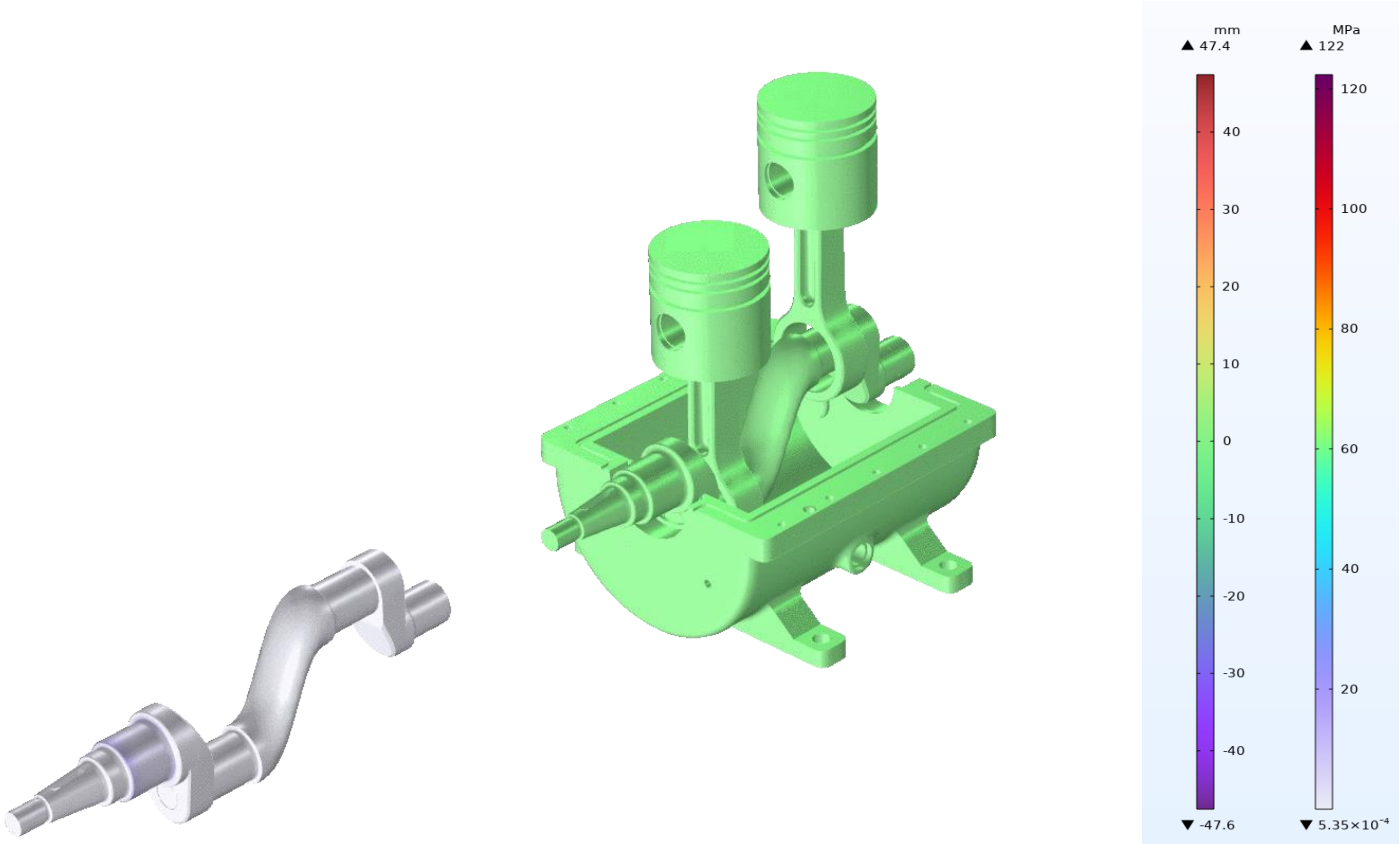
Left: time dependent study step, right: Multiphysics coupling activation

3D Results Sets

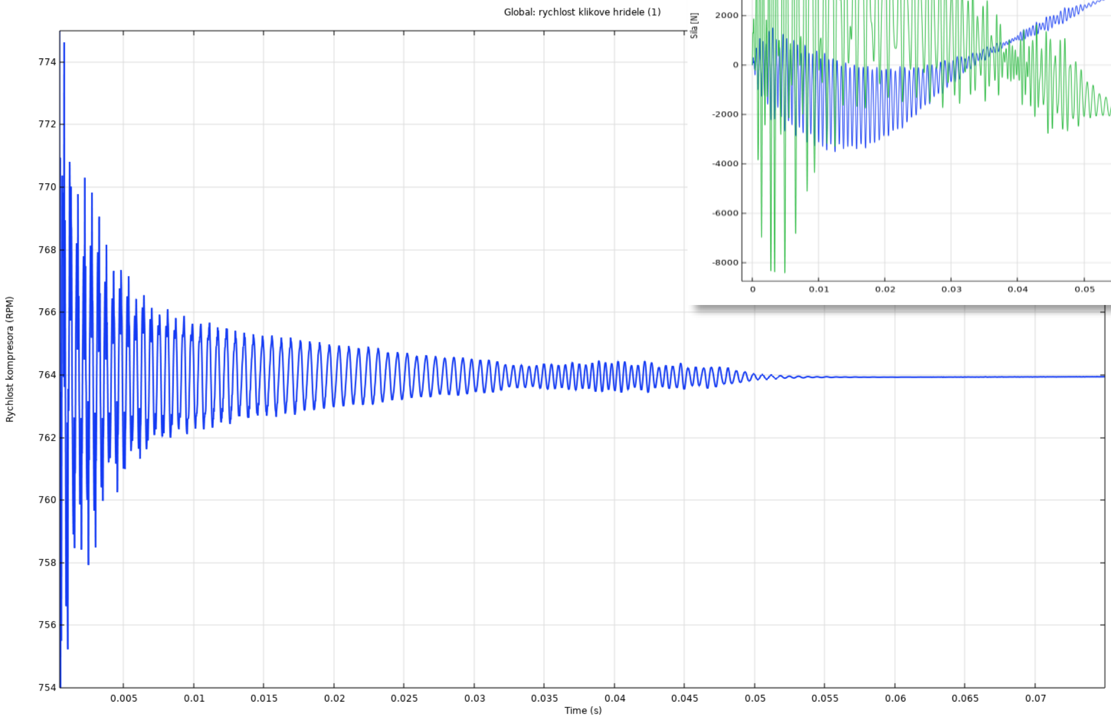
- Volume/Surface
- Vectors
- Contours
- Multiple Color Schemes

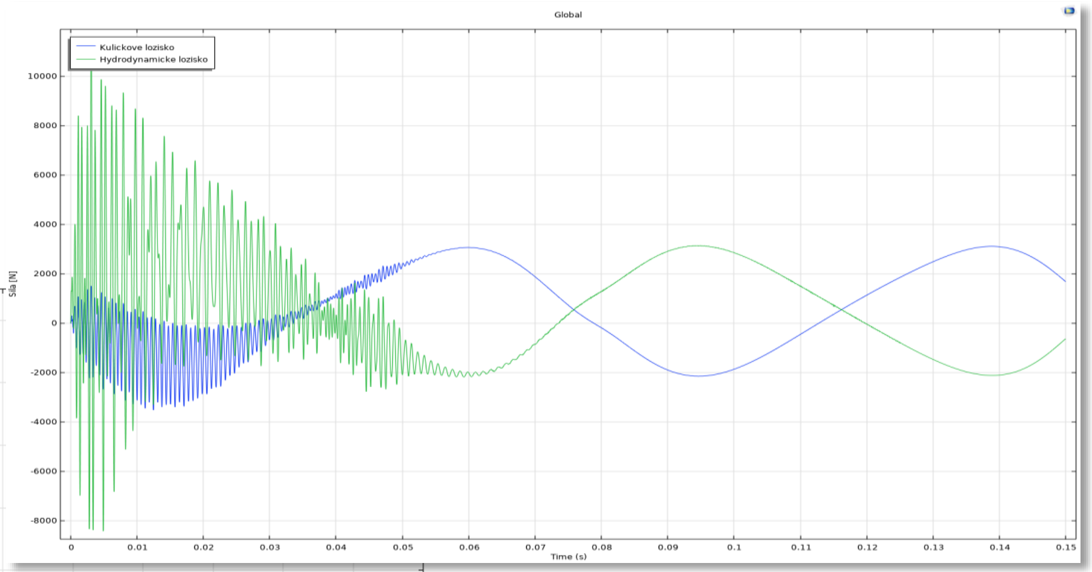


From left to right, top to bottom:
HD Oil Pressure Distr., Air Pressure Distr., von Mises Stress and Velocity Magnitude Field


mm
▲ 47.4
40
30
20
10
0
-10
-20
-30
-40
▼ -47.6
MPa
▲ 122
120
100
80
60
40
20
▼ 5.35×10⁻⁴

1D Results Plots

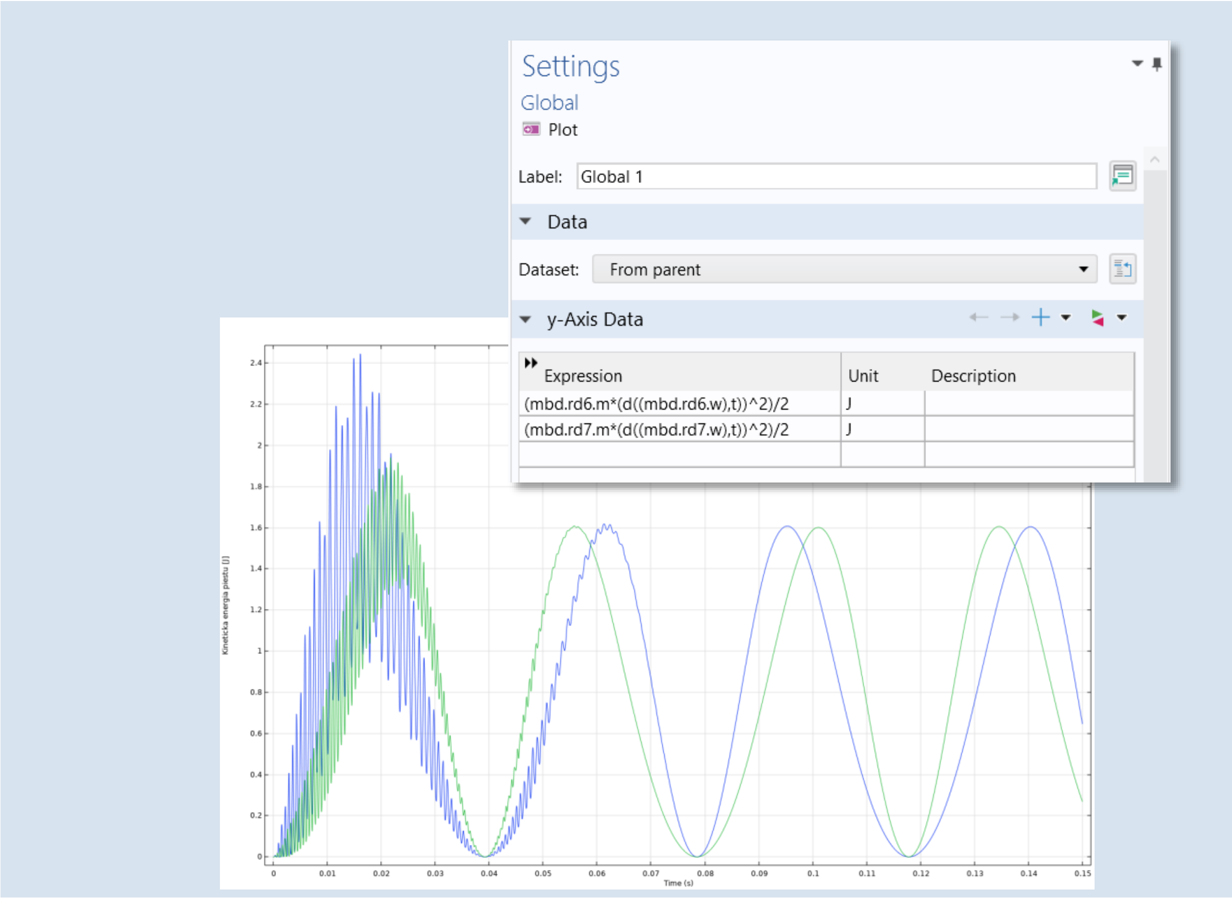




Piston Kinetic Energy

$$E_k = \frac{1}{2} m\dot{w}^2$$

- Define your own expressions in results
- Absolutely Unit Control and Clarity



As you try out COMSOL Multiphysics® ...

Ask any questions you may have or email support@humusoft.cz

Full support is included when you request your free trial.
You also have access to tutorial models and other learning resources.