Created in COMSOL Multiphysics 6.0

Dynamic Behavior of a Spring Loaded Rotating Slider

Introduction

This model simulates the dynamic behavior of a spring loaded rotating slider. The motion of the slider is analyzed under various forces such as the centrifugal force, spring force and damping force.

This is modeled using the Multibody Dynamics interface present in COMSOL Multiphysics and the results of the analysis are compared with the analytical results.

Model Definition

The slider geometry used in this model is shown in Figure 1. The geometry consists of two parts, a slider and a base. The base is rotating around its center of rotation with a constant angular velocity. The slider is connected to the base such that it is free to translate along the base axis. A prismatic joint is used to connect the slider with the base. An elastic spring and a viscous damper are also attached on the prismatic joint to control the motion of the slider.

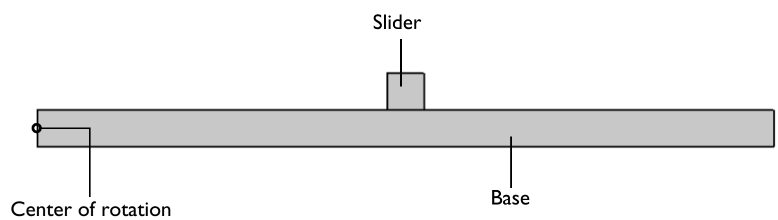

Figure 1: Model geometry.

The centrifugal force acting on the slider due to the base rotation moves the slider radially outward along the base axis. Due to the attached spring between the slider and the base, the slider oscillates about a mean position. The oscillations gradually decay due to the damper attached between the two components.

The computed results are compared with the analytical solution, which is obtained by solving an ODE for the equivalent system. In the system the motion of the slider is considered and therefore the external force acting on the system is equal to the centrifugal force acting on the slider.

The equations for the equivalent system can be written as

$$F = mr\omega^2$$

$$m\ddot{u} + c\dot{u} + ku = F$$

where m is the point mass, c is the damping coefficient, k is the spring constant, u is the displacement of the slider, F is the centrifugal force, r is the radial distance of the slider, and w is the angular velocity of the base.

Results and Discussion

Figure 2 shows the time history of the displacement of the slider in the radial direction. The computed displacement is in excellent agreement with its analytical counterpart. The time history of the displacement shows an oscillatory motion of the slider with respect to its base. The damping effect is also evident, as the amplitude of the oscillation decays over time.

Figure 3 displays the time variation of the velocity of the slider with respect to its base in the radial direction. The plot shows that the computed value of the radial velocity is also in excellent agreement with the analytical value.

Figure 4 shows the polar plot for the time variation of the radial position of the slider. It shows that the slider never crosses its initial position during one full revolution of its base.

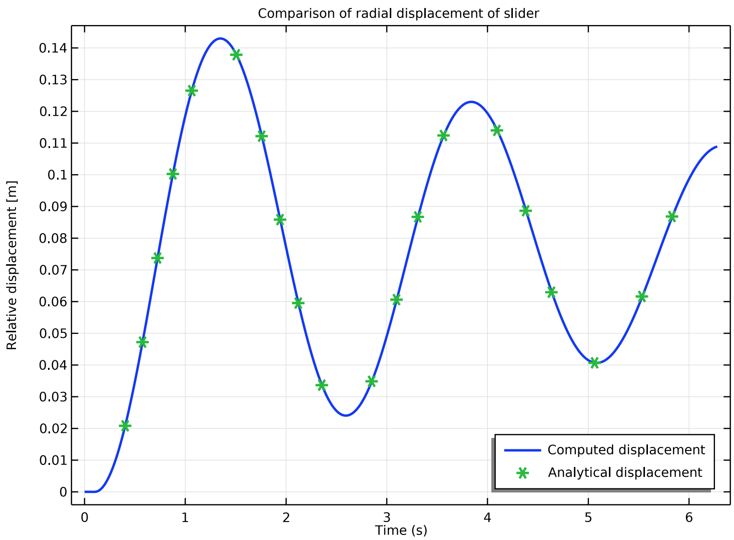

Figure 2: Comparison of radial displacement of the slider with the analytical solution.

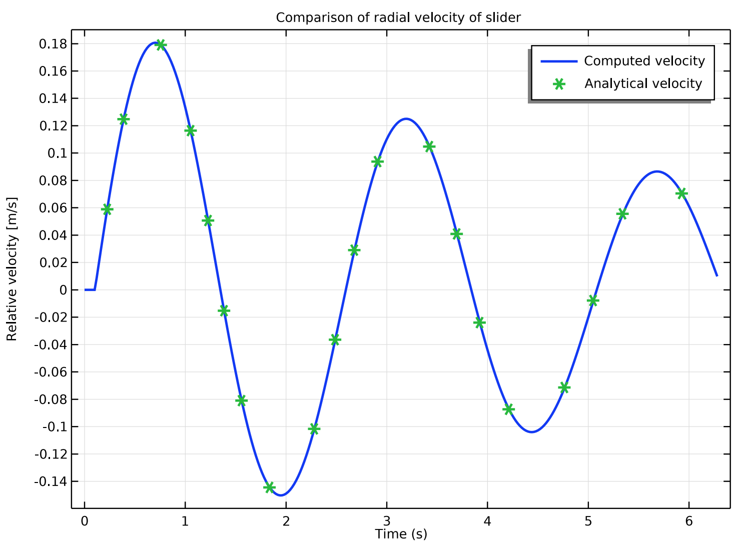

Figure 3: Comparison of radial velocity of the slider with the analytical solution.

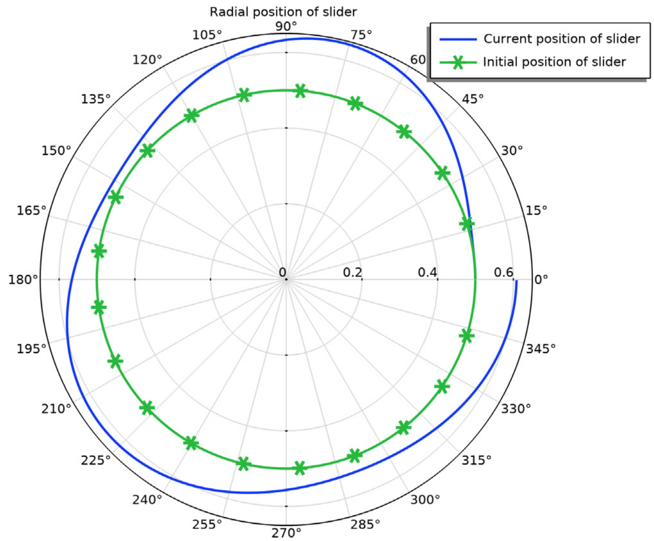

Figure 4: Polar plot for the radial position of the slider.

Figure 5 shows the polar plot for the time variation of the velocity of the slider with respect to its base in the radial direction. From the plot, it is evident that in one full revolution of the base, the slider completes two and a half oscillations (which is equal to the number of lobes in the velocity plot). The magnitude of the oscillation is also decaying which can be seen from the decreasing size of the successive lobes.

Figure 6 shows the polar plot for the time variation of the kinetic energy of the slider due to its relative motion with respect to the base. In this plot, there are five lobes, and they also indicate that the slider undergoes two and a half cycles of oscillation, as the kinetic energy completes one cycle in half a cycle of oscillation.

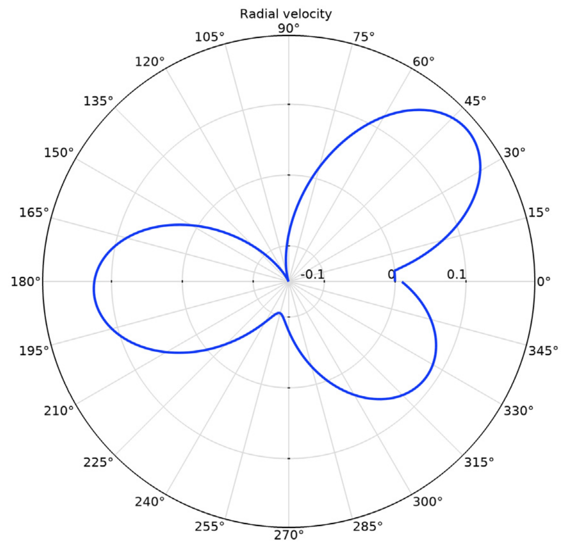

Figure 5: Polar plot for the radial velocity of slider.

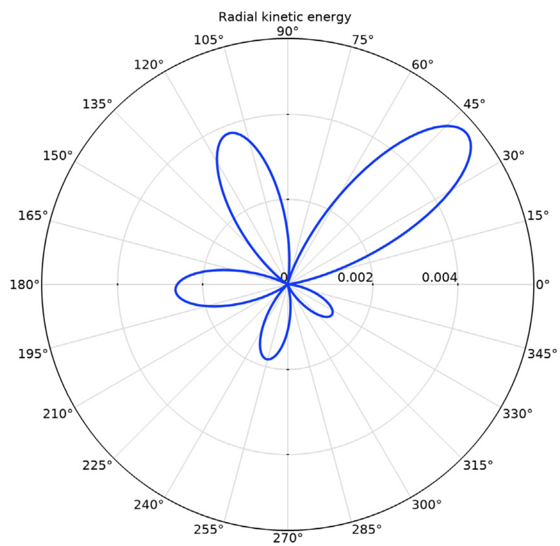

Figure 6: Polar plot for the kinetic energy of slider due to its radial motion.

Notes About the COMSOL Implementation

- In this model, the slider and the base are modeled as flexible elements using the **Linear Elastic Material** node. If the stresses and the deformation in the components are not of interest, they can also be modeled as rigid elements using the **Rigid Domain** node.
- A **Joint** node can establish a direct connection between **Rigid Domain** nodes. For flexible elements, however, **Attachment** nodes are needed to define the connection boundaries.
- Initial rigid body translation and rotation of a system can be defined at the physics node in the **Initial Values** section and can be inherited, if needed, by the feature node for rigid as well as flexible elements.

Application Library path: `Multibody_Dynamics_Module/Verification_Examples/spring_loaded_slider`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **2D**.

2 In the **Select Physics** tree, select **Structural Mechanics>Multibody Dynamics (mbd)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Time Dependent**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
a	0.05[m]	0.05 m	Side length of slider
p	0.5[m]	0.5 m	Initial position of slider
omega	1[rad/s]	1 rad/s	Angular velocity
k	2.5[N/m]	2.5 N/m	Spring constant
c	0.1[N*s/m]	0.1 N·s/m	Damping coefficient
rho	2700[kg/m^3]	2700 kg/m^3	Density
m	rho*a^3	0.3375 kg	Mass of slider

GEOMETRY 1

Rectangle 1 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Height** text field, type a.

Rectangle 2 (r2)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type a.

4 In the **Height** text field, type a.

5 Locate the **Position** section. In the **x** text field, type p-a/2.

6 In the **y** text field, type a.

Form Union (fin)

1 In the **Model Builder** window, under **Component 1 (comp1)>Geometry 1** click **Form Union (fin)**.

2 In the **Settings** window for **Form Union/Assembly**, locate the **Form Union/Assembly** section.

3 From the **Action** list, choose **Form an assembly**.

4 Clear the **Create pairs** check box.

5 In the **Geometry** toolbar, click **Build All**.

ADD MATERIAL

1 In the **Home** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Built-in>Aluminum**.

4 Click **Add to Component** in the window toolbar.

5 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

MULTIBODY DYNAMICS (MBD)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Multibody Dynamics (mbd)**.

2 In the **Settings** window for **Multibody Dynamics**, locate the **Thickness** section.

3 In the d text field, type `a`.

To model steady state rotation, define consistent initial values in the physics node. By default, these will be inherited by the **Initial Values** node.

4 Click to expand the **Initial Values** section. Specify the $\mathbf{X}_c$ vector as

0	x
a/2	y

5 In the **Angular velocity** text field, type `omega`.

Attachment 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Attachment**.

2 Select Boundary 3 only.

Attachment 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Attachment**.

2 Select Boundary 6 only.

Prismatic Joint 1

1 In the **Physics** toolbar, click **Global** and choose **Prismatic Joint**.

2 In the **Settings** window for **Prismatic Joint**, locate the **Attachment Selection** section.

3 From the **Source** list, choose **Attachment 1**.

4 From the **Destination** list, choose **Attachment 2**.

The default values for the joint properties apply, so no further settings are needed.

Spring and Damper 1

1 In the **Physics** toolbar, click **Attributes** and choose **Spring and Damper**.

2 In the **Settings** window for **Spring and Damper**, locate the **Spring and Damper: Translational** section.

3 In the k_u text field, type `k`.

4 In the c_u text field, type `c`.

Prismatic Joint 1

Constrain the relative motion between the slider and the base for a certain time duration.

1 In the **Model Builder** window, click **Prismatic Joint 1**.

Prescribed Motion 1

1 In the **Physics** toolbar, click **Attributes** and choose **Prescribed Motion**.

2 In the **Settings** window for **Prescribed Motion**, locate the **Prescribed Translational Motion** section.

3 From the **Activation condition** list, choose **Conditionally active**.

4 In the i_{up} text field, type `(t>=0.1)`.

Use the **Rigid Connector** node to rotate the system.

Rigid Connector 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Rigid Connector**.

2 Select Boundary 1 only.

3 In the **Settings** window for **Rigid Connector**, locate the **Prescribed Displacement at Center of Rotation** section.

4 Select the **Prescribed in x direction** check box.

5 Select the **Prescribed in y direction** check box.

6 Locate the **Prescribed Rotation** section. From the **By** list, choose **Prescribed rotation**.

7 In the **Angle of rotation** text field, type `omega*t`.

MODEL BUILDER

Use a **Global Equations** node to compute the analytical solution.

1 Click the **Show More Options** button in the **Model Builder** toolbar.

2 In the **Show More Options** dialog box, in the tree, select the check box for the node **Physics>Equation-Based Contributions**.

3 Click **OK**.

Global Equations 1

1 In the **Physics** toolbar, click **Global** and choose **Global Equations**.

2 In the **Settings** window for **Global Equations**, locate the **Global Equations** section.

3 In the table, enter the following settings:

Name	f(u,ut,utt,t) (1)	Initial value (u_0) (1)	Initial value (u_t0) (1/s)	Description
ua	m*uatt+c*uat+k*ua-(m*(p+ua)*omega^2)*(t>=0.1)	0	0	Analytical displacement

4 Locate the **Units** section. Click **Select Dependent Variable Quantity**.

5 In the **Physical Quantity** dialog box, type `displacement` in the text field.

6 Click **Filter**.

7 In the tree, select **General>Displacement (m)**.

8 Click **OK**.

9 In the **Settings** window for **Global Equations**, locate the **Units** section.

10 Click **Select Source Term Quantity**.

11 In the **Physical Quantity** dialog box, type `force` in the text field.

12 Click **Filter**.

13 In the tree, select **General>Force (N)**.

14 Click **OK**.

STUDY 1

Step 1: Time Dependent

1 In the **Model Builder** window, under **Study 1** click **Step 1: Time Dependent**.

2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.

3 In the **Output times** text field, type `range(0,0.02,2*pi)`.

4 In the **Home** toolbar, click **Compute**.

RESULTS

To reproduce a plot for the radial displacement shown in Figure 2, follow the instructions below:

Relative Displacement

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Relative Displacement` in the **Label** text field.

Global 1

1 Right-click **Relative Displacement** and choose **Global**.

2 In the **Settings** window for **Global**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)> Multibody Dynamics>Prismatic joints>Prismatic Joint 1>mbd.prj1.u - Relative displacement - m**.

3 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
mbd.prj1.u	m	Computed displacement

4 Click to expand the **Coloring and Style** section. In the **Width** text field, type 2.

Global 2

1 In the **Model Builder** window, right-click **Relative Displacement** and choose **Global**.

2 In the **Settings** window for **Global**, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Component 1 (comp1)> Multibody Dynamics>ua - Analytical displacement - m**.

3 Locate the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Asterisk**.

4 In the **Number** text field, type 20.

5 Find the **Line style** subsection. From the **Line** list, choose **None**.

Relative Displacement

1 In the **Model Builder** window, click **Relative Displacement**.

2 In the **Settings** window for **1D Plot Group**, click to expand the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Comparison of radial displacement of slider`.

5 Locate the **Plot Settings** section. Select the **y-axis label** check box.

6 In the associated text field, type `Relative displacement [m]`.

7 Locate the **Legend** section. From the **Position** list, choose **Lower right**.

8 In the **Relative Displacement** toolbar, click **Plot**.

Relative Velocity

1 Right-click **Relative Displacement** and choose **Duplicate**.

2 In the **Settings** window for **1D Plot Group**, type `Relative Velocity` in the **Label** text field.

Follow these instructions to reproduce the radial velocity plot shown in Figure 3:

Global 1

1 In the **Model Builder** window, expand the **Relative Velocity** node, then click **Global 1**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
mbd.prj1.u_t	m/s	Computed velocity

Global 2

1 In the **Model Builder** window, click **Global 2**.

2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
uat		Analytical velocity

Relative Velocity

1 In the **Model Builder** window, click **Relative Velocity**.

2 In the **Settings** window for **1D Plot Group**, locate the **Title** section.

3 In the **Title** text area, type `Comparison of radial velocity of slider`.

4 Locate the **Plot Settings** section. In the **y-axis label** text field, type `Relative velocity [m/s]`.

5 Locate the **Legend** section. From the **Position** list, choose **Upper right**.

6 In the **Relative Velocity** toolbar, click **Plot**.

The following instructions generate a polar plot for the radial position shown in Figure 4:

Radial Position of Slider

1 In the **Home** toolbar, click **Add Plot Group** and choose **Polar Plot Group**.

2 In the **Settings** window for **Polar Plot Group**, type `Radial Position of Slider` in the **Label** text field.

Global 1

1 Right-click **Radial Position of Slider** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **r-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
`mbd.prj1.u+p`	`m`	`Current position of slider`

4 Click to expand the **Coloring and Style** section. In the **Width** text field, type `2`.

Global 2

1 In the **Model Builder** window, right-click **Radial Position of Slider** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **r-Axis Data** section.

3 In the table, enter the following settings:

Expression	Unit	Description
`p`	`m`	`Initial position of slider`

4 Locate the **Coloring and Style** section. In the **Width** text field, type `2`.

5 Find the **Line markers** subsection. From the **Marker** list, choose **Asterisk**.

6 In the **Number** text field, type `20`.

7 In the **Radial Position of Slider** toolbar, click **Plot**.

Radial Position of Slider

1 In the **Model Builder** window, click **Radial Position of Slider**.

2 In the **Settings** window for **Polar Plot Group**, click to expand the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Radial position of slider`.

5 Locate the **Axis** section. Select the **Manual axis limits** check box.

6 In the **r minimum** text field, type `0`.

7 In the **Radial Position of Slider** toolbar, click **Plot**.

Follow the instructions below to reproduce the polar plot for the radial velocity shown in Figure 5.

Radial Velocity

1 In the **Home** toolbar, click **Add Plot Group** and choose **Polar Plot Group**.

2 In the **Settings** window for **Polar Plot Group**, type `Radial Velocity` in the **Label** text field.

Global 1

1 Right-click **Radial Velocity** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **r-Axis Data** section.

3 In the table, enter the following settings:

Expression	**Unit**	**Description**
mbd.prj1.u_t	m/s	Radial velocity

4 Locate the **Coloring and Style** section. In the **Width** text field, type 2.

5 Click to expand the **Legends** section. Clear the **Show legends** check box.

Radial Velocity

1 In the **Model Builder** window, click **Radial Velocity**.

2 In the **Settings** window for **Polar Plot Group**, locate the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type Radial velocity.

5 In the **Radial Velocity** toolbar, click **Plot**.

Follow these instructions to generate a polar plot for the radial kinetic energy similar to that shown in Figure 6.

Radial Kinetic Energy

1 In the **Home** toolbar, click **Add Plot Group** and choose **Polar Plot Group**.

2 In the **Settings** window for **Polar Plot Group**, type Radial Kinetic Energy in the **Label** text field.

Global 1

1 Right-click **Radial Kinetic Energy** and choose **Global**.

2 In the **Settings** window for **Global**, locate the **r-Axis Data** section.

3 In the table, enter the following settings:

Expression	**Unit**	**Description**
0.5*m*mbd.prj1.u_t^2		Radial kinetic energy

4 Locate the **Coloring and Style** section. In the **Width** text field, type 2.

5 Locate the **Legends** section. Clear the **Show legends** check box.

Radial Kinetic Energy

1 In the **Model Builder** window, click **Radial Kinetic Energy**.

2 In the **Settings** window for **Polar Plot Group**, locate the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Radial kinetic energy`.

5 In the **Radial Kinetic Energy** toolbar, click **Plot**.

Finally, to generate an animation of the slider motion, follow these instructions:

Animation 1

1 In the **Results** toolbar, click **Animation** and choose **Player**.

2 In the **Settings** window for **Animation**, locate the **Frames** section.

3 In the **Number of frames** text field, type `100`.

4 Click the **Zoom Out** button in the **Graphics** toolbar.

5 Click the **Play** button in the **Graphics** toolbar.