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. 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 so that it is free to translate along the base axis. A prismatic joint is used to connect the slider with the base. A linear spring and a damper are also attached on the prismatic joint to control the motion of the slider.

The centrifugal force acting on the slider due to the base rotation moves the slider radially outwards 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. Hence, the motion of the slider is governed by the centrifugal force, spring force and damping force.

The computed results are compared with the analytical solution which is obtained by solving an ODE for the equivalent system. In the equivalent system, the slider is considered to be located at a point. The equivalent spring and dashpot have the same values as used in the joint. 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 slider, F is the centrifugal force, r is the radial distance of slider, and w is the angular velocity of the base.

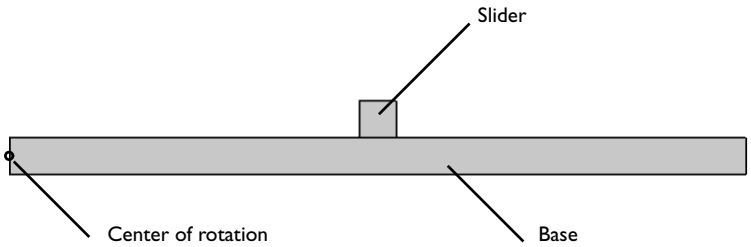

Figure 1: Model geometry.

Results and Discussion

Figure 2 shows the computed variation in time of the relative displacement of the slider with respect to its base in the radial direction. The analytical value is also plotted in the same figure. Thus, the computed displacement is in quite good agreement with its analytical counterpart. The time history of displacement shows the oscillatory motion of the slider with respect to its base. The damping effects are also evident, as the amplitude of the oscillation decays over time.

Figure 3 displays the time variation of the relative 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 quite good 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 that the slider never crossed its initial position during one full revolution of its base.

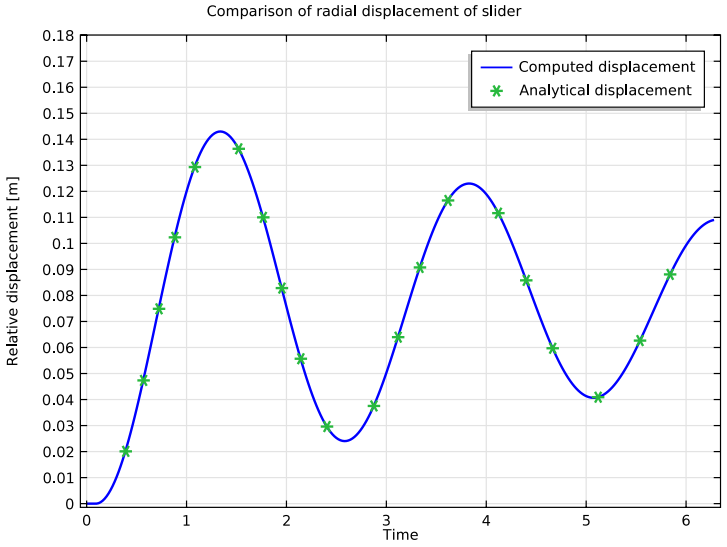

Figure 2: Comparison of radial displacement of slider with analytical solution.

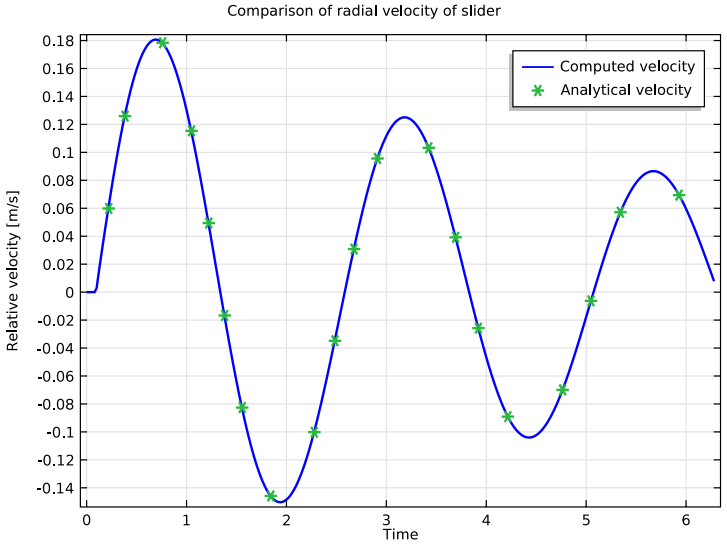

Figure 3: Comparison of radial velocity of slider with analytical solution.

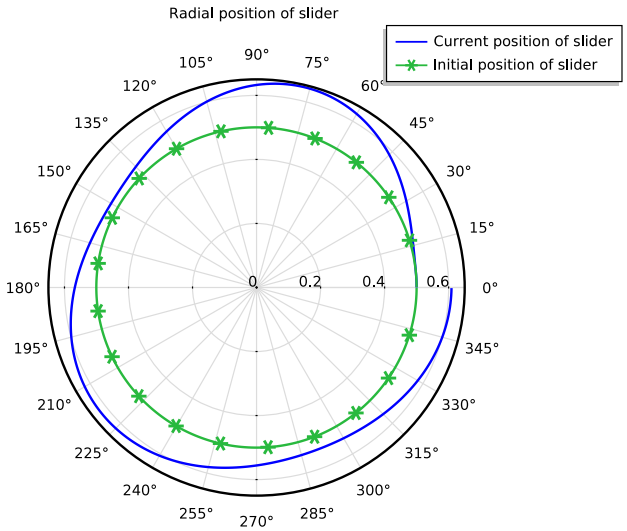

Figure 4: Polar plot for the radial position of slider.

Figure 5 shows the polar plot for the time variation of relative 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 form 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 cycle of oscillation.

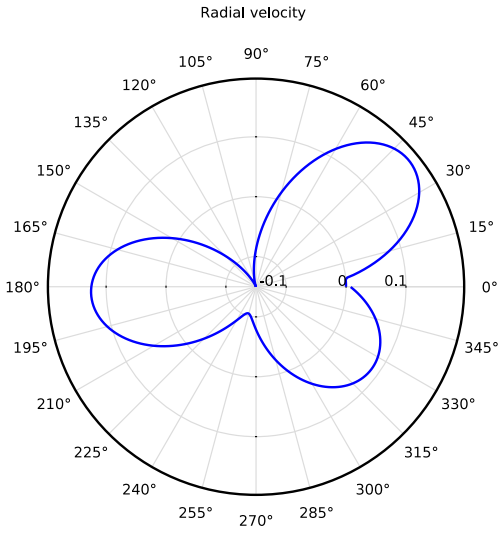

Figure 5: Polar plot for the radial velocity of slider.

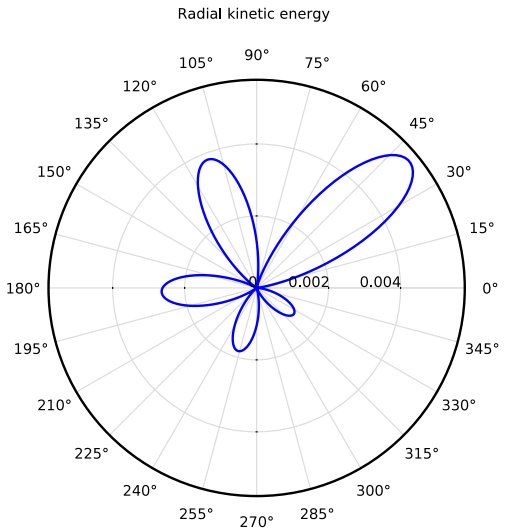

Figure 6: Polar plot for the kinetic energy of slider due to its radial motion.

Model Library path: `Multibody_Dynamics_Module/Verification_Models/spring_loaded_slider`

Modeling Instructions

MODEL WIZARD

1 Go to the **Model Wizard** window.

2 Click the **2D** button.

3 Click **Next**.

4 In the **Add physics** tree, select **Structural Mechanics>Multibody Dynamics (mbd)**.

5 Click **Next**.

6 Find the **Studies** subsection. In the tree, select **Preset Studies>Time Dependent**.

7 Click **Finish**.

GLOBAL DEFINITIONS

Parameters

1 In the **Model Builder** window, right-click **Global Definitions** and choose **Parameters**.

2 In the **Parameters** settings window, locate the **Parameters** section.

3 In the table, enter the following settings:

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

GEOMETRY 1

Rectangle 1

1 In the **Model Builder** window, under **Model 1** right-click **Geometry 1** and choose **Rectangle**.

2 In the **Rectangle** settings window, locate the **Size** section.

3 In the **Height** edit field, type `a`.

Rectangle 2

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Rectangle**.

2 In the **Rectangle** settings window, locate the **Size** section.

3 In the **Width** edit field, type `a`.

4 In the **Height** edit field, type `a`.

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

6 In the **y** edit field, type `a`.

Form Union

1 In the **Model Builder** window, under **Model 1>Geometry 1** click **Form Union**.

2 In the **Finalize** settings window, locate the **Finalize** section.

3 From the **Finalization method** list, choose **Form an assembly**.

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

5 Click the **Build All** button.

MATERIALS

Material Browser

1 In the **Model Builder** window, under **Model 1** right-click **Materials** and choose **Open Material Browser**.

2 In the **Material Browser** window, locate the **Materials** section.

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

4 Right-click and choose **Add Material to Model** from the menu.

MULTIBODY DYNAMICS

1 In the **Model Builder** window, under **Model 1** click **Multibody Dynamics**.

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

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

Attachment 1

1 Right-click **Model 1>Multibody Dynamics** and choose **Attachment**.

2 Select Boundary 3 only.

Attachment 2

1 In the **Model Builder** window, right-click **Multibody Dynamics** and choose **Attachment**.

2 Select Boundary 6 only.

Prismatic Joint 1

1 Right-click **Multibody Dynamics** and choose **Joints>Prismatic Joint**.

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

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

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

5 Locate the **Axis of Joint** section. In the *e* table, enter the following settings:

1	x
0	y

Spring and Damper 1

1 Right-click **Model 1>Multibody Dynamics>Prismatic Joint 1** and choose **Spring and Damper**.

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

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

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

Prismatic Joint 1

Constrain the relative motion between the slider and base for certain time duration to avoid any transient effects in the solution.

Prescribed Motion 1

1 Right-click **Prismatic Joint 1** and choose **Prescribed Motion**.

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

3 Select the **De-activation condition** check box.

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

Rigid Connector 1

1 In the **Model Builder** window, right-click **Multibody Dynamics** and choose **Rigid Connector**.

2 Select Boundary 1 only.

3 In the **Rigid Connector** settings window, 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 at Center of Rotation** section. From the **By** list, choose **Prescribed rotation at center of rotation**.

7 In the ϕ edit field, type `omega*t`.

Use a Global Equation feature to compute the analytical solution.

In the **Model Builder** window's toolbar, click the **Show** button and select **Advanced Physics Options** in the menu.

Global Equations 1

1 Right-click **Multibody Dynamics** and choose **Global>Global Equations**.

2 In the **Global Equations** settings window, locate the **Global Equations** section.

3 In the table, enter the following settings:

Name	f(u,ut,utt,t)
ua	`m*uatt+c*uat+k*ua-(m*(p+ua)*omega^2)*(t>=0.1)`

STUDY 1

Step 1: Time Dependent

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

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

3 In the **Times** edit field, type `range(0,0.02,2*pi)`.

4 In the **Model Builder** window, right-click **Study 1** and choose **Compute**.

RESULTS

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

1D Plot Group 2

1 In the **Model Builder** window, right-click **Results** and choose **1D Plot Group**.

2 Right-click **1D Plot Group 2** and choose **Global**.

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

4 In the **Global** settings window, locate the **y-Axis Data** section.

5 In the table, enter the following settings:

Description
Computed displacement

6 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. In the **Width** edit field, type 2.

7 In the **Model Builder** window, right-click **1D Plot Group 2** and choose **Global**.

8 In the **Global** settings window, click **Replace Expression** in the upper-right corner of the **y-Axis Data** section. From the menu, choose **Multibody Dynamics>State variable ua (ua)**.

9 In the **Global** settings window, locate the **y-Axis Data** section.

10 In the table, enter the following settings:

Description
Analytical displacement

11 Click to expand the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Asterisk**.

12 In the **Number** edit field, type 20.

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

14 In the **Model Builder** window, click **1D Plot Group 2**.

15 In the **1D Plot Group** settings window, click to expand the **Title** section.

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

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

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

19 In the associated edit field, type `Relative displacement [m]`.

20 Click to expand the **Axis** section. Select the **Manual axis limits** check box.

21 In the **y minimum** edit field, type `-0.00143`.

22 In the **y maximum** edit field, type `0.18`.

23 Click the **Plot** button.

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

1D Plot Group 3

1 Right-click **1D Plot Group 2** and choose **Duplicate**.

2 In the **Model Builder** window, expand the **1D Plot Group 3** node, then click **Global 1**.

3 In the **Global** settings window, locate the **y-Axis Data** section.

4 In the table, enter the following settings:

Expression	Unit	Description
`mbd.prj1.ut`	`m/s`	`Computed velocity`

5 In the **Model Builder** window, under **Results>1D Plot Group 3** click **Global 2**.

6 In the **Global** settings window, locate the **y-Axis Data** section.

7 In the table, enter the following settings:

Expression	Unit	Description
`uat`		`Analytical velocity`

8 In the **Model Builder** window, click **1D Plot Group 3**.

9 In the **1D Plot Group** settings window, locate the **Title** section.

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

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

12 Locate the **Axis** section. Clear the **Manual axis limits** check box.

13 Click the **Zoom Extents** button on the Graphics toolbar.

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

Polar Plot Group 4

1 In the **Model Builder** window, right-click **Results** and choose **Polar Plot Group**.

2 Right-click **Polar Plot Group 4** and choose **Global**.

3 In the **Global** settings window, locate the **r-Axis Data** section.

4 In the table, enter the following settings:

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

5 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. In the **Width** edit field, type 2.

6 In the **Model Builder** window, right-click **Polar Plot Group 4** and choose **Global**.

7 In the **Global** settings window, locate the **r-Axis Data** section.

8 In the table, enter the following settings:

Expression	Unit	Description
p	m	Initial position of slider

9 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. In the **Width** edit field, type 2.

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

11 In the **Number** edit field, type 20.

12 In the **Model Builder** window, click **Polar Plot Group 4**.

13 In the **Polar Plot Group** settings window, click to expand the **Title** section.

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

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

16 Click to expand the **Axis** section. Select the **Manual axis limits** check box.

17 In the **r minimum** edit field, type 0.

18 Click the **Plot** button.

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

1 In the **Model Builder** window, right-click **Results** and choose **Polar Plot Group**.

2 Right-click **Polar Plot Group 4** and choose **Global**.

Polar Plot Group 5

1 In the **Model Builder** window, right-click **Results** and choose **Polar Plot Group**.

2 Right-click **Polar Plot Group 5** and choose **Global**.

3 In the **Global** settings window, locate the **r-Axis Data** section.

4 In the table, enter the following settings:

Expression	Unit	Description
mbd.prj1.ut	m/s	Radial velocity

5 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. In the **Width** edit field, type `2`.

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

7 In the **Model Builder** window, click **Polar Plot Group 5**.

8 In the **Polar Plot Group** settings window, click to expand the **Title** section.

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

10 In the **Title** text area, type `Radial velocity`.

11 Click the **Plot** button.

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

Polar Plot Group 6

1 In the **Model Builder** window, right-click **Results** and choose **Polar Plot Group**.

2 Right-click **Polar Plot Group 6** and choose **Global**.

3 In the **Global** settings window, locate the **r-Axis Data** section.

4 In the table, enter the following settings:

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

5 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. In the **Width** edit field, type `2`.

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

7 In the **Model Builder** window, click **Polar Plot Group 6**.

8 In the **Polar Plot Group** settings window, click to expand the **Title** section.

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

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

11 Click to expand the **Axis** section. Select the **Manual axis limits** check box.

12 In the **r minimum** edit field, type `0`.

13 Click the **Plot** button.

Export

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

1 In the **Model Builder** window, under **Results** right-click **Export** and choose **Player**.

2 In the **Player** settings window, locate the **Frames** section.

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

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

5 Right-click **Results>Export>Player 1** and choose **Play**.