Created in COMSOL Multiphysics 6.2

Simply Supported Beam Rotor

Introduction

A simply supported rotor supported by two end bearings is considered. Eigenfrequency and transient with FFT analyses are performed to obtain the critical speed and stability characteristics of the rotor.

Model Definition

The model consists of a rotor supported by two end bearings, with multiple disks mounted at different locations on the rotor. The geometry of the rotor is shown in Figure 1.

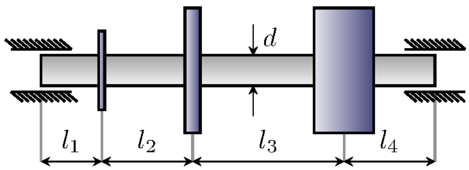

Figure 1: Rotor geometry.

Two different analyses are performed:

- An eigenfrequency analysis.
- A transient with FFT analysis for different angular speeds of the rotor. This analysis looks at the frequency spectrum of the rotor and how it changes with the rpm.

The properties of the shaft are given in Table 1.

TABLE 1: SHAFT PROPERTIES.

PROPERTY	**VALUE**
Young's modulus E	$2 \cdot 10^{11}$ N/m^2
Poisson's ratio ν	0.33
Density ρ	7800 kg/m^3
Diameter d	0.1 m
Distance between the left end of the shaft and first disk l_1	0.2 m
Distance between the first and second disks l_2	0.3 m
Distance between second and third disks l_3	0.5 m
Distance between third disk and the right end of the shaft l_4	0.3 m

Case 1 — Eigenfrequency Analysis

In this case, three circular disks are mounted on the rotor without any offset. The bearings are modeled by equivalent stiffness and damping constants. Bending stiffness and rotational damping in the bearings are neglected. The angular speed of the rotor is varied from 1000 rpm to 35,000 rpm in steps of 1000 rpm. The variations in natural frequencies and logarithmic decrements with angular speed of the rotor are analyzed.

Properties of the disks and bearings used in this analysis are given in Table 2 and Table 3:

TABLE 2: DISK PROPERTIES.

PROPERTY	DISK 1	DISK 2	DISK 3
Mass m (kg)	14.58	45.94	55.13
Polar moment of inertia I_p (kg m^2)	0.123	0.976	1.171
Diametral moment of inertia I_d (kg m^2)	0.064	0.498	0.602

TABLE 3: BEARING PROPERTIES.

PROPERTY	BEARING 1	BEARING 2
k_{yy} (N/m)	$7 \cdot 10^7$	$6 \cdot 10^7$
k_{zz} (N/m)	$5 \cdot 10^7$	$4 \cdot 10^7$
c_{yy} (N-s/m)	7000	6000
c_{zz} (N-s/m)	4000	5000

Case2 — Transient with FFT Analysis

In this case, there is only a single disk with a radial offset mounted on the rotor. The bearings are modeled by using the nonlinear stiffness and damping constants obtained by the short-bearing approximation of the Reynolds equation for a plain hydrodynamic bearing. This option is in-built in COMSOL Multiphysics. Bending stiffness and rotational damping of the bearing are neglected also in this case. Structural damping is added to damp the high frequency vibrations of the rotor and also to stabilize the time-dependent solver. The angular speed of the shaft is varied from 2000 rpm to 30,000 rpm in steps of 2000 rpm. Variations in the frequency spectrum and orbits of the various points on the rotor are studied.

In this analysis only the second disk from the first analysis is retained, and it is given an eccentricity of 0.1 mm. The bearing properties for this analysis are given in Table 4.

TABLE 4: BEARING PROPERTIES.

PROPERTIES	VALUES
Clearance C	10^{-4} m
Radius of the journal R	$d/2$

TABLE 4: BEARING PROPERTIES.

PROPERTIES	VALUES
Length of the journal L	d
Viscosity of the lubricant μ	0.072 Pa·s

The angular velocity of the rotor is linearly ramped to give a smooth startup of the simulation. The duration of the ramp is chosen such that the rotor completes one revolution with linearly increasing speed from 0 to Ω before it continues with the constant angular speed Ω. Then, assuming that the ramp duration is t_0,

$$2\pi = \int_0^{t_0} \Omega_0 \frac{t}{t_0} dt = \frac{\Omega_0 t_0}{2}$$

Therefore,

$$t_0 = \frac{4\pi}{\Omega_0} = \frac{2}{f} = \frac{120}{N}$$

where f is the frequency corresponding to the angular speed and N is the rpm. Therefore, the function describing the angular speed is

$$\Omega = \Omega_0 \left\{ \frac{t}{t_0}\left(\frac{t}{t_0} \le 1\right) + \left(\frac{t}{t_0} > 1\right) \right\} = \Omega_0 \mathrm{ramp}\left(\frac{t}{t_0}\right)$$

EIGENFREQUENCY ANALYSIS

The whirl plot for the third mode is shown in Figure 2. In this mode, the gyroscopic effect is not significant due to disk 1 and disk 2 because of their negligible tilting in this mode. However, disk 3 contributes significantly to the gyroscopic effects.

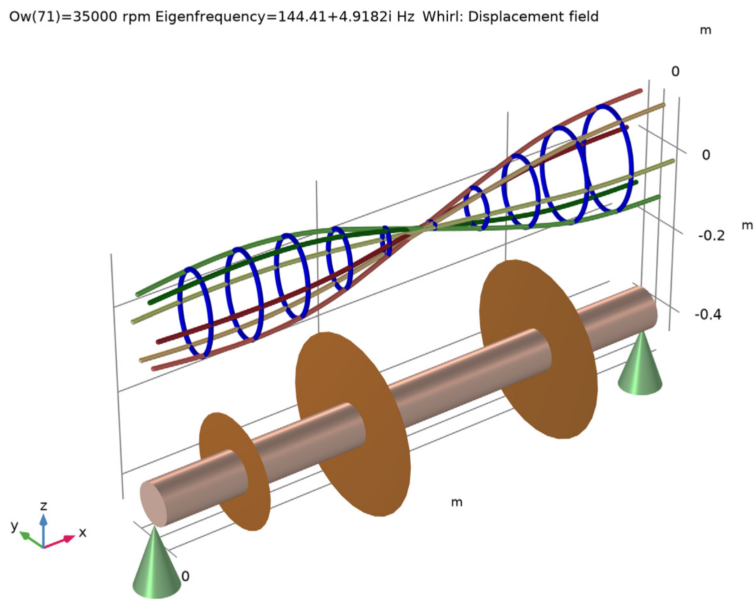

Figure 2: Whirl plot.

A Campbell plot, shown in Figure 3, gives a better overview of the gyroscopic effects on the rotor whirl. Modes influenced significantly by the gyroscopic effects show a larger split in the eigenfrequency for corresponding forward and backward whirls as the angular speed increases.

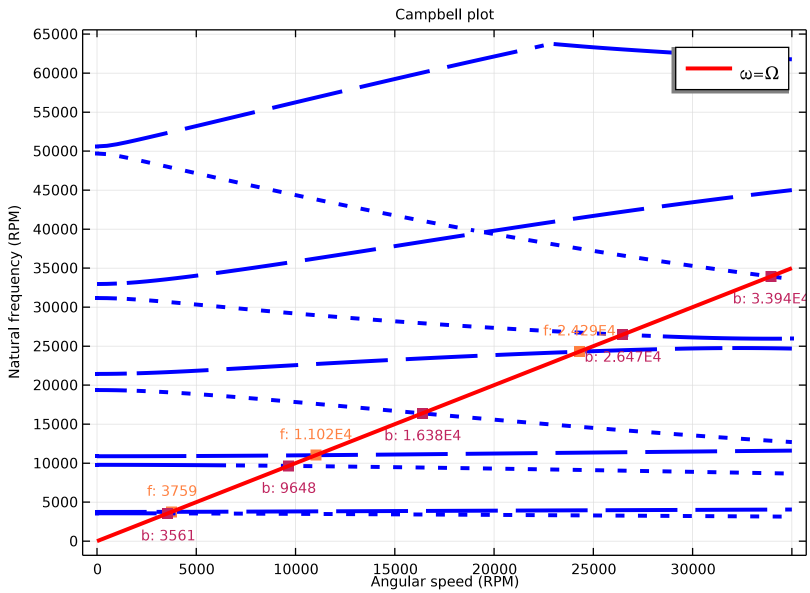

Figure 3: Campbell plot.

The logarithmic decrement is a parameter that can be used as a measure of the damping in the system. The expression for the logarithmic decrement in terms of eigenvalues is:

$$\delta = 2\pi \frac{\mathrm{imag}(\omega)}{\mathrm{abs}(\omega)}$$

A plot of the logarithmic decrement as a function of the rotor angular speed is shown in Figure 4. This plot shows how the damping in a particular mode changes with the angular speed of the rotor.

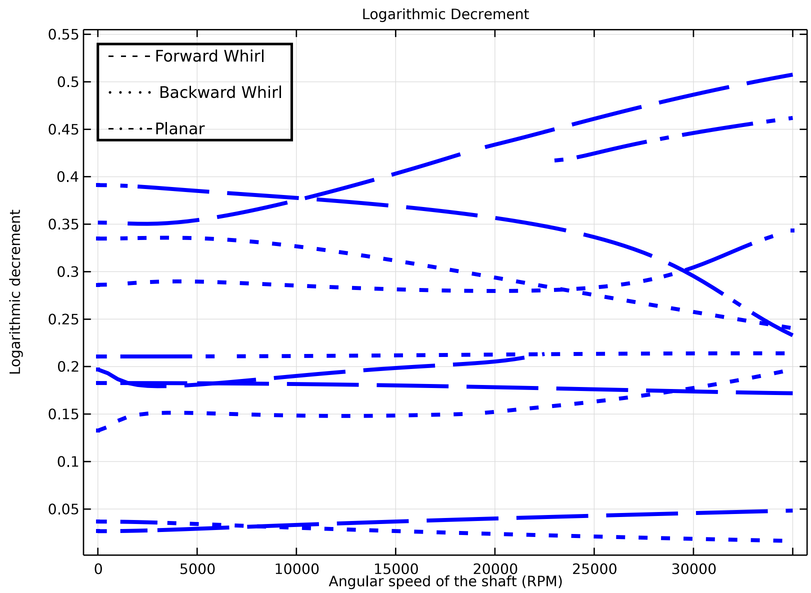

Figure 4: Logarithmic decrement.

TRANSIENT WITH FFT ANALYSIS

The waterfall plot for the displacement magnitude at the first bearing location is shown in Figure 5. The waterfall plot shows the variation in the frequency spectrum of the rotor with the change in its angular speed. In this case, three dominant frequencies are observed in the waterfall plot. A longer duration of the transient simulation will increase the frequency resolution and with the use of smaller time step higher frequencies can be captured too, but, it will require larger simulation time. The system may vibrate at different frequencies simultaneously due to various sources of the excitation. In such a case multiple peaks can be observed in the waterfall plot.

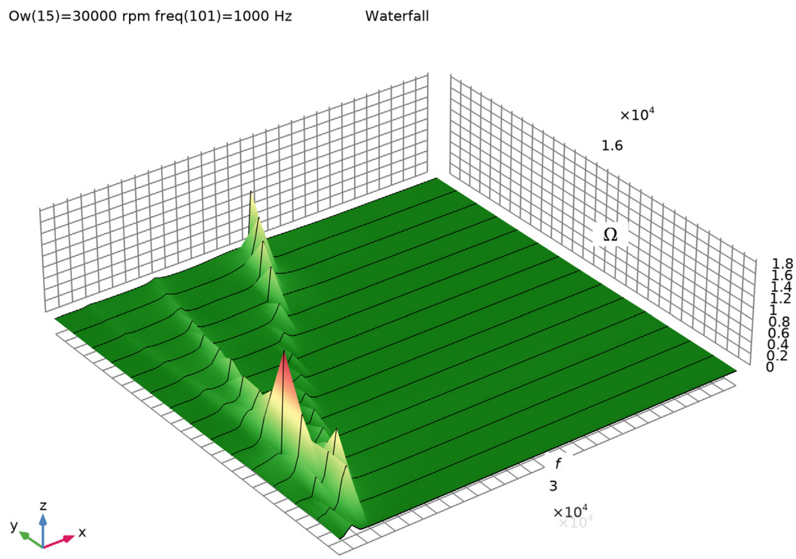

Figure 5: Waterfall plot.

Figure 6 shows an orbit plot at the first bearing location. The color of the orbit changes from blue to red as the simulation time increases. Color pattern shows that the point on the rotor first undergoes transient motion but eventually attains the steady state with orbit repeating itself.

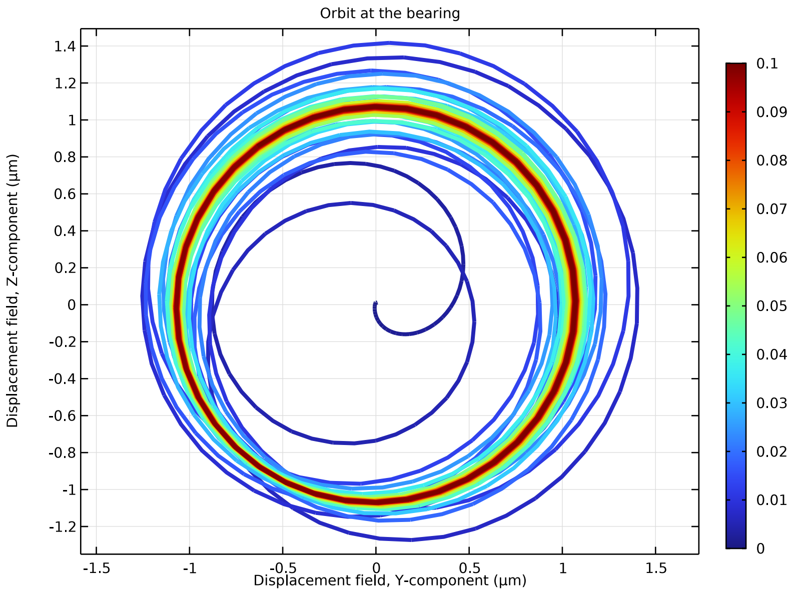

Figure 6: Orbit of the journal at the first bearing.

An orbit plot at the center of the disk is shown in Figure 7. Orbit of this point also has the similar behavior as that of the point in the bearing with a circular orbit at the steady state.

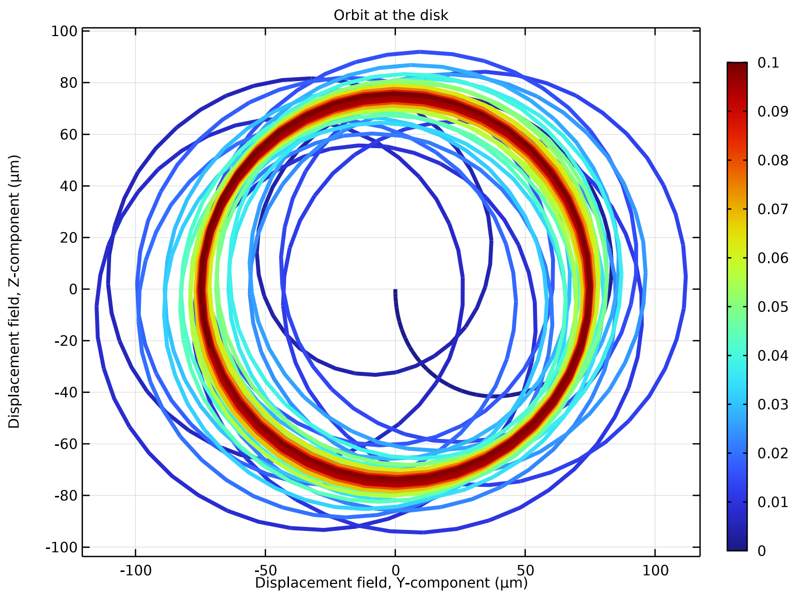

Figure 7: Orbit at the center of the disk.

Notes About the COMSOL Implementation

The **Plain hydrodynamic** option for the **Journal Bearing** feature uses the stiffness obtained from the short-bearing approximation in the Reynolds equation for the thin film flow in the hydrodynamic journal bearing. This option is used for the Transient with FFT analysis.

The **Transient with FFT** study first obtains the transient response of the rotor and subsequently takes the Fourier transform to convert it into a frequency spectrum. Note that using such a study sequence you lose all the transient solutions except the one for the last parameter. If you also want the transient solutions for each angular speed parameter, you need to store the solutions manually.

Application Library path: `Rotordynamics_Module/Tutorials/simply_supported_beam_rotor`

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 **3D**.
2 In the **Select Physics** tree, select **Structural Mechanics>Rotordynamics>Beam Rotor (rotbm)**.
3 Click **Add**.
4 Click **Study**.
5 In the **Select Study** tree, select **General Studies>Eigenfrequency**.
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
Ow	0[rpm]	0 1/s	Angular speed of the shaft
d_s	0.1[m]	0.1 m	Diameter of the shaft
l1	0.2[m]	0.2 m	Distance between the left end of the shaft and the first disk
l2	0.3[m]	0.3 m	Distance between the first and second disk
l3	0.5[m]	0.5 m	Distance between the second and third disk
l4	0.3[m]	0.3 m	Distance between the third disk and the right end of the shaft
m_d1	14.58[kg]	14.58 kg	Mass of the first disk
Jd_d1	0.064[kg*m^2]	0.064 kg·m²	Diametral moment of inertia of the first disk

Name	Expression	Value	Description
Jp_d1	0.123[kg*m^2]	0.123 kg·m²	Polar moment of inertia of the first disk
m_d2	45.94[kg]	45.94 kg	Mass of the second disk
Jd_d2	0.498[kg*m^2]	0.498 kg·m²	Diametral moment of inertia of the second disk
Jp_d2	0.976[kg*m^2]	0.976 kg·m²	Polar moment of inertia of the second disk
m_d3	55.13[kg]	55.13 kg	Mass of the first disk
Jd_d3	0.602[kg*m^2]	0.602 kg·m²	Diametral moment of inertia of the third disk
Jp_d3	1.171[kg*m^2]	1.171 kg·m²	Polar moment of inertia of the third disk
k1yy	7e7[N/m]	7E7 N/m	Stiffness of the first bearing in local y direction
k1zz	5e7[N/m]	5E7 N/m	Stiffness of the first bearing in local z direction
c1yy	7000[N*s/m]	7000 N·s/m	Damping constant of the first bearing in local y direction
c1zz	4000[N*s/m]	4000 N·s/m	Damping constant of the first bearing in local z direction
k2yy	6e7[N/m]	6E7 N/m	Stiffness of the second bearing in local y direction
k2zz	4e7[N/m]	4E7 N/m	Stiffness of the second bearing in local z direction
c2yy	6000[N*s/m]	6000 N·s/m	Damping constant of the second bearing in local y direction
c2zz	5000[N*s/m]	5000 N·s/m	Damping constant of the second bearing in local z direction
mu_l	0.072[Pa*s]	0.072 Pa·s	Viscosity of the lubricant
C	1e-4[m]	1E-4 m	Clearance in the bearing

GEOMETRY 1

Polygon 1 (pol1)

1 In the **Geometry** toolbar, click **More Primitives** and choose **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 From the **Data source** list, choose **Vectors**.

4 In the **x** text field, type `0 l1 l1+l2 l1+l2+l3 l1+l2+l3+l4`.

5 In the **y** text field, type `0`.

6 In the **z** text field, type `0`.

7 Click **Build All Objects**.

MATERIALS

Steel

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 In the **Settings** window for **Material**, type `Steel` in the **Label** text field.

3 Locate the **Material Contents** section. In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Young's modulus	E	`2e11[N/m^2]`	Pa	Young's modulus and Poisson's ratio
Poisson's ratio	nu	`0.33`	1	Young's modulus and Poisson's ratio
Density	rho	`7800[kg/m^3]`	kg/m³	Basic

BEAM ROTOR (ROTBM)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Beam Rotor (rotbm)**.

2 In the **Settings** window for **Beam Rotor**, locate the **Rotor Speed** section.

3 In the text field, type `Ow`.

Rotor Cross Section 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** click **Rotor Cross Section 1**.

2 In the **Settings** window for **Rotor Cross Section**, locate the **Cross-Section Definition** section.

3 In the d_o text field, type `d_s`.

Disk 1

1 In the **Physics** toolbar, click **Points** and choose **Disk**.

2 Select Point 2 only.

3 In the **Settings** window for **Disk**, locate the **Disk Properties** section.

4 In the m text field, type `m_d1`.

5 In the I_p text field, type `Jp_d1`.

6 In the I_d text field, type `Jd_d1`.

Disk 2

1 In the **Physics** toolbar, click **Points** and choose **Disk**.

2 Select Point 3 only.

3 In the **Settings** window for **Disk**, locate the **Disk Properties** section.

4 In the m text field, type `m_d2`.

5 In the I_p text field, type `Jp_d2`.

6 In the I_d text field, type `Jd_d2`.

Disk 3

1 In the **Physics** toolbar, click **Points** and choose **Disk**.

2 Select Point 4 only.

3 In the **Settings** window for **Disk**, locate the **Disk Properties** section.

4 In the m text field, type `m_d3`.

5 In the I_p text field, type `Jp_d3`.

6 In the I_d text field, type `Jd_d3`.

Journal Bearing 1

1 In the **Physics** toolbar, click **Points** and choose **Journal Bearing**.

2 Select Point 1 only.

3 In the **Settings** window for **Journal Bearing**, locate the **Bearing Properties** section.

4 From the **Bearing model** list, choose **Total spring and damping constant**.

5 In the $\mathbf{k}_u$ table, enter the following settings:

k1yy	0
0	k1zz

6 In the $\mathbf{c}_u$ table, enter the following settings:

c1yy	0
0	c1zz

Journal Bearing 2

1 In the **Physics** toolbar, click **Points** and choose **Journal Bearing**.

2 Select Point 5 only.

3 In the **Settings** window for **Journal Bearing**, locate the **Bearing Properties** section.

4 From the **Bearing model** list, choose **Total spring and damping constant**.

5 In the $\mathbf{k}_u$ table, enter the following settings:

k2yy	0
0	k2zz

6 In the $\mathbf{c}_u$ table, enter the following settings:

c2yy	0
0	c2zz

STUDY 1

Use a parametric step to sweep the angular speed of the rotor from 0 to 35,000 rpm in the steps of 500 rpm.

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
Ow (Angular speed of the shaft)	range(0,500,35000)	rpm

Step 1: Eigenfrequency

1 In the **Model Builder** window, click **Step 1: Eigenfrequency**.

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

3 Select the **Desired number of eigenfrequencies** check box. In the associated text field, type 20.

4 In the **Model Builder** window, click **Study 1**.

5 In the **Settings** window for **Study**, type `Study: Eigenfrequency` in the **Label** text field.

6 In the **Study** toolbar, click **Compute**.

RESULTS

Whirl (rotbm)

Follow the steps below to generate the whirl plot as shown in Figure 2.

1 In the **Settings** window for **3D Plot Group**, locate the **Data** section.

2 From the **Eigenfrequency (Hz)** list, choose **144.41+4.9182i**.

3 In the **Whirl (rotbm)** toolbar, click **Plot**.

Whirl 1

1 In the **Model Builder** window, expand the **Whirl (rotbm)** node, then click **Whirl 1**.

2 In the **Settings** window for **Whirl**, locate the **Coloring and Style** section.

3 In the **Number of planes** text field, type `6`.

4 In the **Whirl (rotbm)** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

Follow the instructions to add and edit the default Campbell plot shown in Figure 3.

ADD PREDEFINED PLOT

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

2 Go to the **Add Predefined Plot** window.

3 In the tree, select **Study: Eigenfrequency/Parametric Solutions 1 (sol2)>Beam Rotor>Campbell Plot (rotbm)**.

4 Click **Add Plot** in the window toolbar.

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

RESULTS

Forward Whirl Mode

1 In the **Model Builder** window, expand the **Campbell Plot (rotbm)** node, then click **Forward Whirl Mode**.

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

3 In the table, enter the following settings:

Expression	Unit	Description
`rotbm.omegaf*60/(2*pi)`	`rad/s`	`Forward Whirl Frequency (RPM)`

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `rotbm.Ovg*60/(2*pi)`.

Backward Whirl Mode

1 In the **Model Builder** window, click **Backward Whirl Mode**.

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

3 In the table, enter the following settings:

Expression	Unit	Description
`rotbm.omegab*60/(2*pi)`	`rad/s`	`Backward Whirl Frequency (RPM)`

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `rotbm.Ovg*60/(2*pi)`.

Planar or Torsional Mode

1 In the **Model Builder** window, click **Planar or Torsional Mode**.

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

3 In the table, enter the following settings:

Expression	Unit	Description
`rotbm.omegan*60/(2*pi)`	`rad/s`	`Nonwhirl Frequency (RPM)`

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `rotbm.Ovg*60/(2*pi)`.

omega=Omega

1 In the **Model Builder** window, click **omega=Omega**.

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

3 In the table, enter the following settings:

Expression	Unit	Description
`rotbm.Ovg*60/(2*pi)`	`rad/s`	`Angular Speed (RPM)`

4 Locate the **x-Axis Data** section. In the **Expression** text field, type `rotbm.Ovg*60/(2*pi)`.

Campbell Plot (rotbm)

1 In the **Model Builder** window, click **Campbell Plot (rotbm)**.

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

3 From the **Eigenfrequency selection** list, choose **Manual**.
4 In the **Eigenfrequency indices (1-20)** text field, type `range(1,1,10)`.
5 Locate the **Plot Settings** section.
6 Select the **x-axis label** check box. In the associated text field, type `Angular speed (RPM)`.
7 In the **y-axis label** text field, type `Natural frequency (RPM)`.
8 In the **Campbell Plot (rotbm)** toolbar, click **Plot**.
9 Click the **Zoom Extents** button in the **Graphics** toolbar.

The next few instructions set up a plot of the logarithmic decrement as a function of rpm, as shown in Figure 4.

Logarithmic Decrement

1 In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.
2 In the **Settings** window for **1D Plot Group**, type `Logarithmic Decrement` in the **Label** text field.
3 Locate the **Data** section. From the **Dataset** list, choose **Study: Eigenfrequency/ Parametric Solutions 1 (sol2)**.
4 From the **Eigenfrequency selection** list, choose **Manual**.
5 In the **Eigenfrequency indices (1-20)** text field, type `range(1,1,10)`.

Global 1

1 Right-click **Logarithmic Decrement** 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)>Beam Rotor> Whirl frequencies>rotbm.log_dec_f - Logarithmic decrement, forward whirl - 1**.
3 Locate the **x-Axis Data** section. From the **Axis source data** list, choose **Outer solutions**.
4 From the **Parameter** list, choose **Expression**.
5 In the **Expression** text field, type `Ow`.
6 From the **Unit** list, choose **RPM**.
7 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dashed**.
8 From the **Color** list, choose **Blue**.
9 From the **Width** list, choose **3**.
10 Click to expand the **Legends** section. Clear the **Show legends** check box.

11 Right-click **Global 1** and choose **Duplicate**.

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
`rotbm.log_dec_b`	1	Logarithmic decrement, backward whirl

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dotted**.
5 Right-click **Global 2** and choose **Duplicate**.

Global 3

1 In the **Model Builder** window, click **Global 3**.
2 In the **Settings** window for **Global**, locate the **y-Axis Data** section.
3 In the table, enter the following settings:

Expression	Unit	Description
`rotbm.log_dec_n`	1	Logarithmic decrement, planar

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Dash-dot**.

Annotation 1

1 In the **Model Builder** window, right-click **Logarithmic Decrement** and choose **Annotation**.
2 In the **Settings** window for **Annotation**, locate the **Annotation** section.
3 In the **Text** text field, type `\large\[-\, -\, -\, -\textrm{Forward Whirl}\]\[\cdot\, \cdot\, \cdot\, \cdot\, \cdot\,\,\,\, \textrm{Backward Whirl}\]\[-\cdot\, -\cdot -\, \textrm{Planar}\]`.
4 Locate the **Position** section. In the **Y** text field, type `0.54`.
5 Locate the **Coloring and Style** section. Clear the **Show point** check box.
6 Locate the **Annotation** section. Select the **LaTeX markup** check box.
7 Locate the **Coloring and Style** section. Select the **Show frame** check box.

Logarithmic Decrement

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

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

4 Locate the **Plot Settings** section.

5 Select the **y-axis label** check box. In the associated text field, type `Logarithmic decrement`.

6 In the **Logarithmic Decrement** toolbar, click **Plot**.

7 Click the **Zoom Extents** button in the **Graphics** toolbar.

The **Eigenfrequency** analysis is complete now. Refer to the next section for the **Transient with FFT** analysis.

Transient with FFT Analysis

Define the ramp function for the angular velocity to get a smooth startup of the simulation.

DEFINITIONS

Ramp 1 (rm1)

1 In the **Home** toolbar, click f(X) **Functions** and choose **Global>Ramp**.

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

3 Select the **Cutoff** check box.

Add a new **Beam Rotor** physics node. This step is not necessary. However, to run the Eigenfrequency and Transient with FFT studies independently, it is recommended.

ADD PHYSICS

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

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

3 In the tree, select **Structural Mechanics>Rotordynamics>Beam Rotor (rotbm)**.

4 Find the **Physics interfaces in study** subsection. In the table, clear the **Solve** check box for **Study: Eigenfrequency**.

5 Click **Add to Component 1** in the window toolbar.

6 In the **Home** toolbar, click **Add Physics** to close the **Add Physics** window.

BEAM ROTOR 2 (ROTBM2)

1 In the **Settings** window for **Beam Rotor**, locate the **Rotor Speed** section.

2 In the text field, type `Ow*rm1(Ow*t/2)`.

Linear Elastic Material 1

Add damping in the rotor to damp out the high-frequency vibrations. Damping parameters are chosen such that the minimum damping factor is 0.1.

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor 2 (rotbm2)** click **Linear Elastic Material 1**.

Damping 1

1 In the **Physics** toolbar, click **Attributes** and choose **Damping**.
2 In the **Settings** window for **Damping**, locate the **Damping Settings** section.
3 In the α_{dM} text field, type `109.62`.
4 In the β_{dK} text field, type `0.0001`.

Rotor Cross Section 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor 2 (rotbm2)** click **Rotor Cross Section 1**.
2 In the **Settings** window for **Rotor Cross Section**, locate the **Cross-Section Definition** section.
3 In the d_o text field, type `d_s`.

BEAM ROTOR (ROTBM)

Disk 2

Only **Disk 2** with eccentricity is considered in this analysis. Copy the feature from the **Beam Rotor** physics node to the current physics.

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** right-click **Disk 2** and choose **Copy**.

BEAM ROTOR 2 (ROTBM2)

In the **Model Builder** window, under **Component 1 (comp1)** right-click **Beam Rotor 2 (rotbm2)** and choose **Paste Disk**.

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor 2 (rotbm2)** click **Disk 2**.
2 In the **Settings** window for **Disk**, locate the **Disk Properties** section.
3 From the **Center of mass** list, choose **Offset from selected points**.
4 In the z_r text field, type `1e-4`.

Journal Bearing 1

1 In the **Physics** toolbar, click **Points** and choose **Journal Bearing**.

2 Select Points 1 and 5 only.

Bearings are modeled using the equivalent dynamic coefficients for a plain hydrodynamic bearing.

3 In the **Settings** window for **Journal Bearing**, locate the **Bearing Properties** section.

4 From the **Bearing model** list, choose **Plain hydrodynamic**.

5 From the μ list, choose **User defined**. In the associated text field, type `mu_l`.

6 In the C text field, type `C`.

7 In the R text field, type `d_s/2`.

8 In the L text field, type `d_s`.

9 Clear the **Include bending stiffness** check box.

ADD STUDY

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

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

3 Find the **Studies** subsection. In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces>Time Dependent with FFT**.

4 Find the **Physics interfaces in study** subsection. In the table, clear the **Solve** check box for **Beam Rotor (rotbm)**.

5 Click **Add Study** in the window toolbar.

6 In the **Home** toolbar, click **Add Study** to close the **Add Study** window.

STUDY: TRANSIENT WITH FFT

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

2 In the **Settings** window for **Study**, type `Study: Transient with FFT` in the **Label** text field.

3 Locate the **Study Settings** section. Clear the **Generate default plots** check box, because you will add the desired plots manually.

Add a parametric step to sweep the rpm from 2000 to 30,000 in steps of 2000.

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
Ow (Angular speed of the shaft)	`range(2000,2000,30000)`	`rpm`

5 Click to expand the **Advanced Settings** section. From the **Use parametric solver** list, choose **Off**.

Step 1: Time Dependent

1 In the **Model Builder** window, 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(0,5e-5,0.1)`.

Set the FFT solver to use the solution from the time-dependent study step.

Solution 74 (sol74)

In the **Study** toolbar, click **Show Default Solver**.

Step 2: Time to Frequency FFT

1 In the **Model Builder** window, under **Study: Transient with FFT** click **Step 2: Time to Frequency FFT**.

2 In the **Settings** window for **Time to Frequency FFT**, locate the **Study Settings** section.

3 From the **Input study** list, choose **Study: Transient with FFT, Time Dependent**.

4 In the **End time** text field, type `0.1`.

5 In the **Maximum output frequency** text field, type `1000`.

Solution 74 (sol74)

1 In the **Model Builder** window, expand the **Study: Transient with FFT>Solver Configurations>Solution 74 (sol74)** node.

2 Right-click **Study: Transient with FFT** and choose **Compute**.

RESULTS

Follow the steps below to generate the waterfall plot as shown in Figure 5.

Waterfall

1 In the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Waterfall` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study: Transient with FFT/Parametric Solutions 2 (sol76)**.

Waterfall 1

1 In the **Waterfall** toolbar, click **More Plots** and choose **Waterfall**.

2 In the **Settings** window for **Waterfall**, locate the **Data** section.

3 From the **Dataset** list, choose **Study: Transient with FFT/Parametric Solutions 2 (sol76)**.

4 Select Point 1 only.

5 Locate the **Expression** section. In the **Expression** text field, type `rotbm2.disp`.

6 Locate the **x-Axis Data** section. In the **Expression** text field, type `freq`.

7 In the **Unit** field, type `RPM`.

8 Locate the **y-Axis Data** section. In the **Expression** text field, type `Ow`.

9 From the **Unit** list, choose **RPM**.

10 Locate the **Coloring and Style** section. Click **Change Color Table**.

11 In the **Color Table** dialog box, select **Traffic>TrafficLight** in the tree.

12 Click **OK**.

Annotation 1

1 In the **Model Builder** window, right-click **Waterfall** and choose **Annotation**.

2 In the **Settings** window for **Annotation**, locate the **Position** section.

3 In the **X** text field, type `3e4`.

4 In the **Y** text field, type `2e3`.

5 Locate the **Annotation** section. In the **Text** text field, type `\[f\]`.

6 Select the **LaTeX markup** check box.

7 Locate the **Coloring and Style** section. Clear the **Show point** check box.

8 From the **Color** list, choose **From theme**.

9 From the **Background color** list, choose **From theme**.

10 Clear the **Show frame** check box.

11 Right-click **Annotation 1** and choose **Duplicate**.

Annotation 2

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

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

3 In the **Text** text field, type `\[\Omega\]`.

4 Locate the **Position** section. In the **X** text field, type `6e4`.

5 In the **Y** text field, type `1.5e4`.

6 In the **Z** text field, type `1e-6`.

7 In the **Waterfall** toolbar, click **Plot**.

8 Click the **Zoom Extents** button in the **Graphics** toolbar.

9 In the **Model Builder** window, expand the **Results>Views** node.

Camera

1 In the **Model Builder** window, expand the **Results>Views>View 3D 3** node, then click **Camera**.

2 In the **Settings** window for **Camera**, locate the **Grid** section.

3 Select the **Manual spacing** check box.

4 In the **x spacing** text field, type `2000`.

5 In the **y spacing** text field, type `1000`.

6 In the **z spacing** text field, type `2e-7`.

7 Click **Update**.

Waterfall

1 In the **Model Builder** window, under **Results** click **Waterfall**.

2 In the **Waterfall** toolbar, click **Plot**.

3 Click the **Scene Light** button in the **Graphics** toolbar.

To generate the orbit plot at the first bearing location shown in Figure 6, use the following instructions.

Orbit (Bearing)

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

2 In the **Settings** window for **1D Plot Group**, type `Orbit (Bearing)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study: Transient with FFT/ Solution Store 1 (sol75)**.

Point Graph 1

1 Right-click **Orbit (Bearing)** and choose **Point Graph**.

2 Select Point 1 only.

3 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.

4 In the **Expression** text field, type `w2`.

5 From the **Unit** list, choose **µm**.

6 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

7 In the **Expression** text field, type v2.

8 From the **Unit** list, choose **µm**.

9 Click to expand the **Coloring and Style** section. From the **Width** list, choose **3**.

Use the time in the color expression to highlight the time progress in the orbit.

Color Expression 1

1 Right-click **Point Graph 1** and choose **Color Expression**.

2 In the **Settings** window for **Color Expression**, locate the **Expression** section.

3 In the **Expression** text field, type t.

4 In the **Orbit (Bearing)** toolbar, click **Plot**.

Orbit (Bearing)

1 In the **Model Builder** window, under **Results** click **Orbit (Bearing)**.

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

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

4 In the **Title** text area, type `Orbit at the bearing`.

5 Locate the **Axis** section. Select the **Preserve aspect ratio** check box.

6 In the **Orbit (Bearing)** toolbar, click **Plot**.

7 Click the **Zoom Extents** button in the **Graphics** toolbar.

Duplicate the current plot to generate the orbit plot at the disk location shown in Figure 7.

8 Right-click **Results>Orbit (Bearing)** and choose **Duplicate**.

Orbit (Disk)

1 In the **Model Builder** window, under **Results** click **Orbit (Bearing) 1**.

2 In the **Settings** window for **1D Plot Group**, type `Orbit (Disk)` in the **Label** text field.

3 Locate the **Title** section. In the **Title** text area, type `Orbit at the disk`.

Point Graph 1

1 In the **Model Builder** window, expand the **Orbit (Disk)** node, then click **Point Graph 1**.

2 In the **Settings** window for **Point Graph**, locate the **Selection** section.

3 Click **Clear Selection**.

4 Select Point 3 only.

5 In the **Orbit (Disk)** toolbar, click **Plot**.

Orbit (Disk)

Click the Zoom Extents button in the **Graphics** toolbar.