Created in COMSOL Multiphysics 6.2

Rotors Connected by a Spline Coupling

Introduction

This example demonstrates a method for coupling two rotors connected by a spline coupling. An eigenfrequency analysis is performed at different rotor speeds, and the results are compared with those obtained in Ref. 1.

Model Definition

The model consists an assembly of two rotors connected through a spline coupling. The rotor configuration is visualized in Figure 1. The first rotor, spanning from point A to C, has a fixed support at point A and is equipped with a disk at point B. The second rotor, spanning from point C to F, is simply supported at point D and F. A pulley is mounted at point E. The rotors are connected through point C. It is assumed that only translational motion is coupled between the rotors through the coupling, while the rotations are uncoupled.

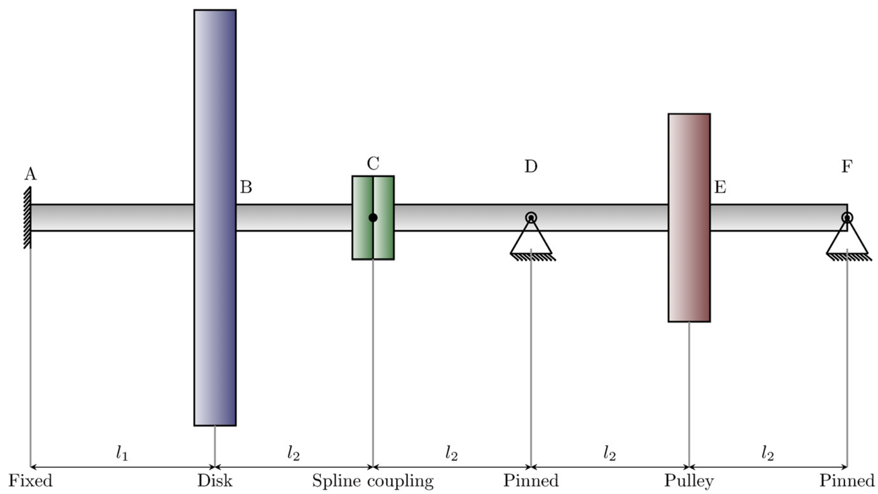

Figure 1: Rotor geometry.

The disk mounted on the cantilevered rotor has both mass and moment of inertia. The coupling has only mass with negligible moment of inertia. In addition, the pulley mounted on the simply supported rotor has only mass but negligible moment of inertia.

The properties of the shaft are summarized in the Table 1.

TABLE 1: PROPERTIES OF THE SHAFT.

PROPERTY	VALUE
Density ρ	7832 kg/m^3
Young's modulus E	206820 MPa
Shear modulus G	79546 MPa
Diameter D	12.7 mm
Length l_1	88.9 mm
Length l_2	76.2 mm

The properties of the mountings on the shafts are given in the Table 2.

TABLE 2: PROPERTIES OF THE MOUNTINGS.

PROPERTY	VALUE
Mass of the disk m_d	1.27 kg
Polar moment of inertia of the disk I_p	0.00256 kg/m^2
Diametral moment of inertia of the disk I_d	0.00128 kg/m^2
Mass of the coupling m_c	0.7 kg
Mass of the pulley m_p	0.87 kg

Results and Discussion

Figure 2 below shows the whirl plot for the second mode (backward whirl, $f = 312$ Hz) at 50,000 rpm. The discontinuity in the rotational degrees of freedom is clearly visible at the coupling location. The undeformed geometry of the rotor is also shown below the whirl plot.

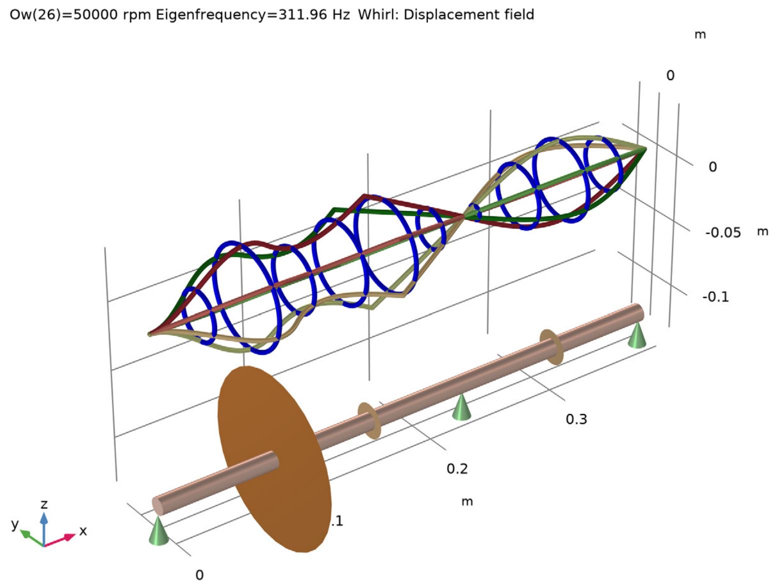

Figure 2: Whirl plot of backward whirl (f = 312 Hz) at 50,000 rpm.

The third mode for the forward whirl (f = 420 Hz) of the coupled rotors at 8,000 rpm is shown in Figure 3.

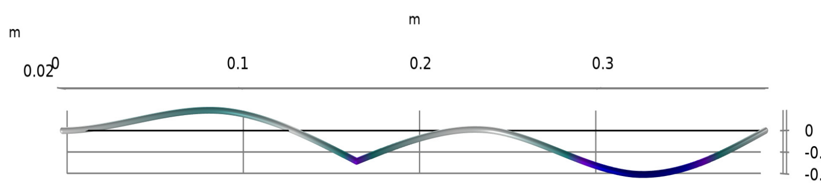

Figure 3: Mode shape of forward whirl (f = 420 Hz) at 8,000 rpm.

The gyroscopic effect in the rotor stiffens the forward modes and softens the backward modes. This phenomenon is illustrated in the Campbell plot shown in Figure 4. A comparison of the critical speeds (in rpm) with those of Ref. 1 is given in Table 3.

TABLE 3: COMPARISON OF CRITICAL SPEEDS WITH REF. 1.

MODE	COMSOL	REF. 1
First (backward)	7488	7489
First (forward)	8519	8521
Second (backward)	21690	21703
Second (forward)	21707	21720
Third (backward)	23387	23404
Third (forward)	25358	25373
Fourth (backward)	27052	27056

It is clear that the second mode is relatively unaffected by the gyroscopic effect. However, the fourth mode is very strongly influenced by the gyroscopic effect.

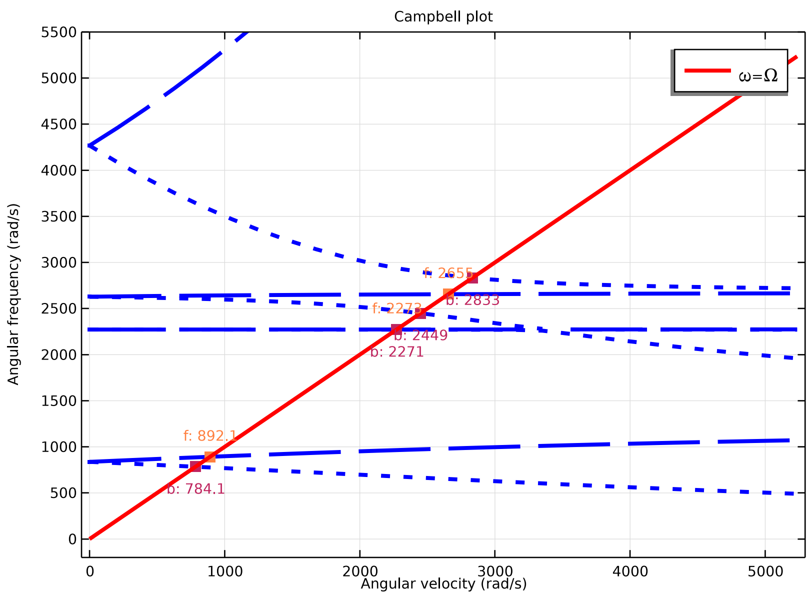

Figure 4: Campbell plot.

Reference

1. W.J. Chen and E.J. Gunter, *Introduction to the Dynamics of Rotor-Bearing Systems*, Example 5.3, pp. 186–189, Trafford Publishing, 2007.

Application Library path: `Rotordynamics_Module/Verification_Examples/coupled_rotors`

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
rho_shaft	7832[kg/m^3]	7832 kg/m³	Density of the shaft

Name	Expression	Value	Description
E_shaft	206820[MPa]	2.0682E11 Pa	Young's modulus of the shaft
G_shaft	79546[MPa]	7.9546E10 Pa	Shear modulus of the shaft
d_shaft	12.7[mm]	0.0127 m	Diameter of the shaft
m_disk	1.27[kg]	1.27 kg	Mass of the disk
Ip_disk	0.00256[kg*m^2]	0.00256 $kg\cdot m^2$	Polar moment of inertia of the disk
Id_disk	0.00128[kg*m^2]	0.00128 $kg\cdot m^2$	Diametral moment of inertia of the disk
m_coupling	0.7[kg]	0.7 kg	Mass of the coupling
m_pulley	0.87[kg]	0.87 kg	Mass of the pulley
l1	88.9[mm]	0.0889 m	Distance of the disk from the clamped end
l2	76.2[mm]	0.0762 m	Distance of the coupling end from the disk
x_disk	l1	0.0889 m	Position of the disk
x_coupling	l1+l2	0.1651 m	Position of the coupling
x_support1	l1+2*l2	0.2413 m	Position of the first pinned support
x_pulley	l1+3*l2	0.3175 m	Position of the pulley
x_support2	l1+4*l2	0.3937 m	Position of the second pinned support

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 x_disk x_coupling x_support1 x_pulley x_support2`.
5 In the **y** text field, type `0`.
6 In the **z** text field, type `0`.

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`.

Set the **Linear Elastic Material** to use the Young's modulus and shear modulus as the elastic properties.

Linear Elastic Material 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** click **Linear Elastic Material 1**.
2 In the **Settings** window for **Linear Elastic Material**, locate the **Linear Elastic Material** section.
3 From the **Specify** list, choose **Young's modulus and shear modulus**.

MATERIALS

Material 1 (mat1)

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.
2 In the **Settings** window for **Material**, locate the **Material Contents** section.
3 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Young's modulus	E	`E_shaft`	Pa	Young's modulus and shear modulus
Shear modulus	G	`G_shaft`	N/m²	Young's modulus and shear modulus
Density	rho	`rho_shaft`	kg/m³	Basic

BEAM ROTOR (ROTBM)

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_shaft`.

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_disk`.
5. In the I_p text field, type `Ip_disk`.
6. In the I_d text field, type `Id_disk`.

Disk: Coupling

1. In the **Physics** toolbar, click **Points** and choose **Disk**.
2. In the **Settings** window for **Disk**, type `Disk: Coupling` in the **Label** text field.
3. Select Point 3 only.
4. Locate the **Disk Properties** section. In the m text field, type `m_coupling`.
5. Right-click **Disk: Coupling** and choose **Duplicate**.

Disk: Pulley

1. In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** click **Disk: Coupling 1**.
2. In the **Settings** window for **Disk**, type `Disk: Pulley` in the **Label** text field.
3. Locate the **Point Selection** section. Click **Clear Selection**.
4. Select Point 5 only.
5. Locate the **Disk Properties** section. In the m text field, type `m_pulley`.

Journal Bearing: Fixed

1. In the **Physics** toolbar, click **Points** and choose **Journal Bearing**.
2. In the **Settings** window for **Journal Bearing**, type `Journal Bearing: Fixed` in the **Label** text field.
3. Select Point 1 only.

4 Right-click **Journal Bearing: Fixed** and choose **Duplicate**.

Journal Bearing: Pinned

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** click **Journal Bearing: Fixed 1**.

2 In the **Settings** window for **Journal Bearing**, type `Journal Bearing: Pinned` in the **Label** text field.

3 Locate the **Point Selection** section. Click **Clear Selection**.

4 Select Points 4 and 6 only.

5 Locate the **Bearing Properties** section. Clear the **Constrain bending rotation** check box.

Rotor Coupling 1

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

2 Select Point 3 only.

STUDY 1

Add a parametric step to sweep the rpm from 0 to 50000 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(0,2000,50000)`	`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 `10`.

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

RESULTS

Whirl (rotbm)

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

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

2 From the **Eigenfrequency (Hz)** list, choose **311.96**.

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 **Go to Default View** button in the **Graphics** toolbar.

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

Add and modify the predefined Campbell plot, shown in Figure 4, using the instructions below.

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 1/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

Campbell Plot (rotbm)

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

2 From the **Eigenfrequency selection** list, choose **Manual**.

3 In the **Eigenfrequency indices (1-10)** text field, type `range(1,1,8)`.

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

5 In the **y maximum** text field, type `5500`.

6 In the **y minimum** text field, type `-200`.

7 In the **Campbell Plot (rotbm)** toolbar, click **Plot**.

Follow the steps below to generate the mode shape shown in Figure 3.

Mode Shape

1 In the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.
2 In the **Settings** window for **3D Plot Group**, type `Mode Shape` in the **Label** text field.
3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/ Parametric Solutions 1 (sol2)**.
4 From the **Parameter value (Ow (rpm))** list, choose **8000**.
5 From the **Eigenfrequency (Hz)** list, choose **420.35**.

Line 1

1 Right-click **Mode Shape** and choose **Line**.
2 In the **Settings** window for **Line**, locate the **Coloring and Style** section.
3 From the **Line type** list, choose **Tube**.
4 In the **Tube radius expression** text field, type `rotbm.re`.
5 Click **Change Color Table**.
6 In the **Color Table** dialog box, select **Aurora>AuroraAustralis** in the tree.
7 Click **OK**.
8 In the **Settings** window for **Line**, locate the **Coloring and Style** section.
9 Clear the **Color legend** check box.

Deformation 1

1 Right-click **Line 1** and choose **Deformation**.
2 In the **Settings** window for **Deformation**, locate the **Scale** section.
3 Select the **Scale factor** check box. In the associated text field, type `0.3`.
4 Click the **Go to XY View** button in the **Graphics** toolbar.
5 In the **Mode Shape** toolbar, click **Plot**.
6 Click the **Zoom Extents** button in the **Graphics** toolbar.