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Effect of Roller Bearing Clearance on Nonsynchronous Vibration of a Rotor

Introduction

Bearing clearance should be kept minimum to avoid the nonsynchronous vibration in the rotor. But, keeping the tolerance too low can reduce the durability of the bearing. Therefore, clearance should be kept at its optimum value to avoid the nonsynchronous vibration in the rotor at the same time to have sufficient durability of the bearing.

This example illustrates the modeling of a vibration induced by nonlinear bearing contact at different radial clearances. A rotor supported by two end roller bearings is considered. A disk is present at the center of the rotor with certain amount of eccentricity. A time dependent analysis is performed to capture the vibration in the rotor due to the bearing clearances. Results show that synchronous vibration is dominant when the bearing clearance is small and for large bearing clearance nonsynchronous vibrations start dominating.

Model Definition

The model consists of a rotor supported by two end bearings, with a disk mounted at the center of the rotor. The geometry of the rotor is shown in Figure 1.

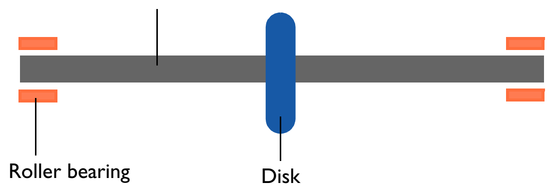

Figure 1: Rotor geometry.

The properties of the shaft are given in Table 1.

TABLE 1: SHAFT PROPERTIES.

PROPERTY	VALUE
Young's modulus E	$2\cdot10^{11}$ N/m^2
Poisson's ratio ν	0.33
Density ρ	7850 kg/m^3
Diameter d	0.04 m
Length of the shaft L	1 m
Distance between the first bearing and the disks l	0.5 m
Rotor angular speed	3000 rpm

Single row deep groove ball bearings are used at the both ends. The bearing properties are given in the Table 2.

TABLE 2: BEARING PROPERTIES.

PROPERTY	VALUE
No. of balls N	20
Pitch diameter d_p	0.045 m
Contour radius, inner race r_{in}	0.06 m
Contour radius, outer race r_{out}	0.07 m
Ball diameter d_b	0.01 m

Disk properties are given in the Table 3.

TABLE 3: DISK PROPERTIES.

PROPERTY	VALUE
Radius of the disk	0.08 m
Thickness of the disk	0.03 m
Density of the disk	7850 kg/m^3
Eccentricity	1e-4 m

Rotor is mounted horizontally and is subjected to gravitational force. Three different clearances in the bearing are considered, 1. $C = 2 \cdot 10^{-5}$ m, 2. $C = 5 \cdot 10^{-5}$ m, and 3. $C = 2 \cdot 10^{-4}$ m. The total time for the simulation is 0.2 sec, and the solution is store every $2 \cdot 10^{-4}$ sec.

The stress in the rotor at t = 0.2 sec for clearance C = 2e-4 m is shown in Figure 2.

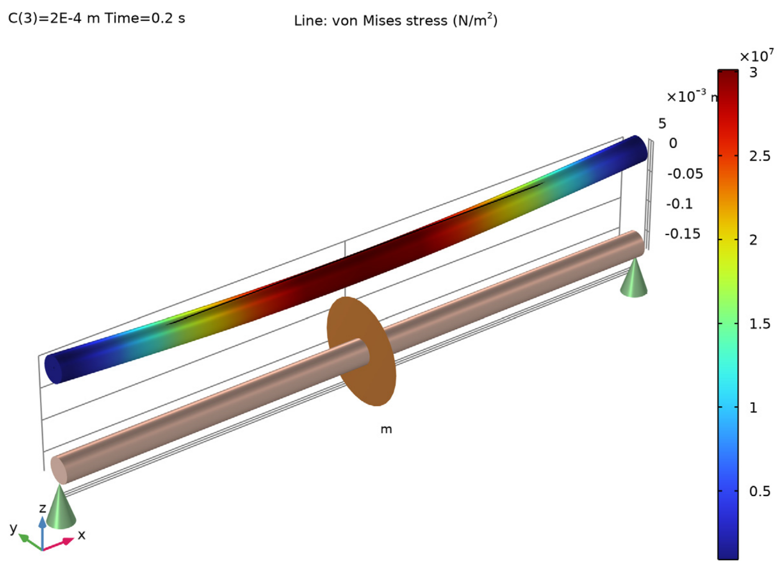

Figure 2: Stress in the rotor.

Orbit plots, shown in Figure 3, Figure 4 and Figure 5, are the orbits of the rotor at the first bearing and disk at different clearances. A smaller clearance, rotor becomes steady and remains in the contact with the bearing for a longer duration, whereas for larger clearance the contact with the bearing is intermittent.

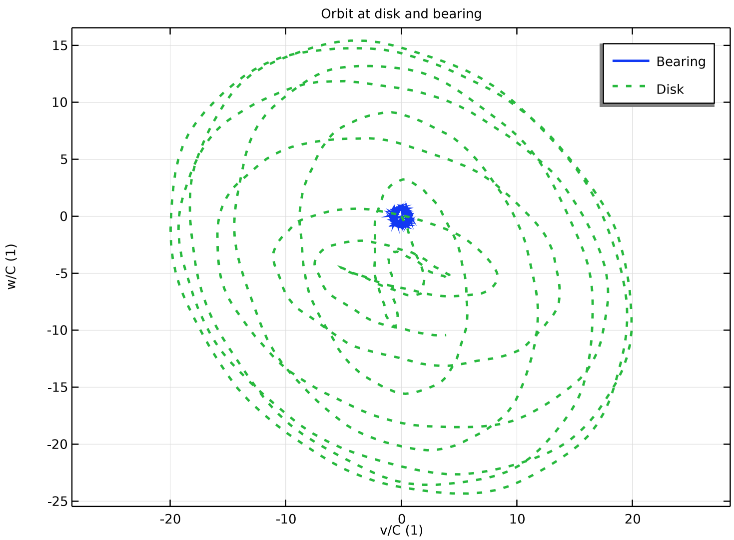

Figure 3: Rotor orbit at clearance $C = 2{\cdot}10^{-5}$ m.

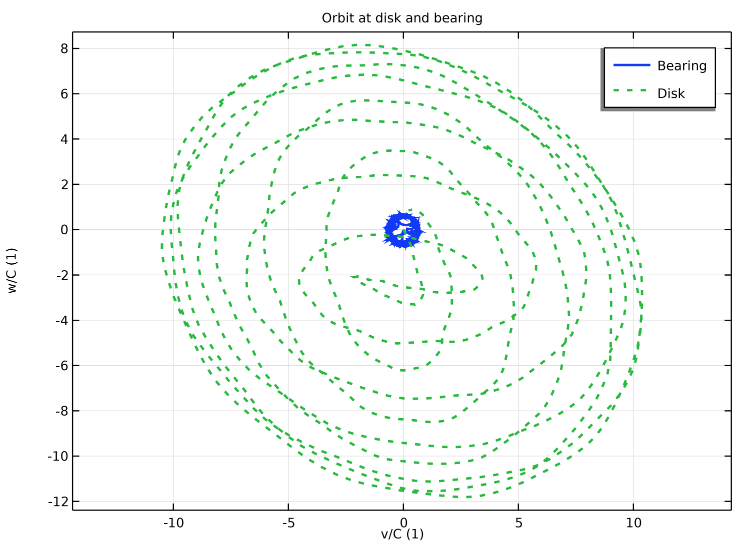

Figure 4: Rotor orbit at clearance $C = 5{\cdot}10^{-5}$ m.

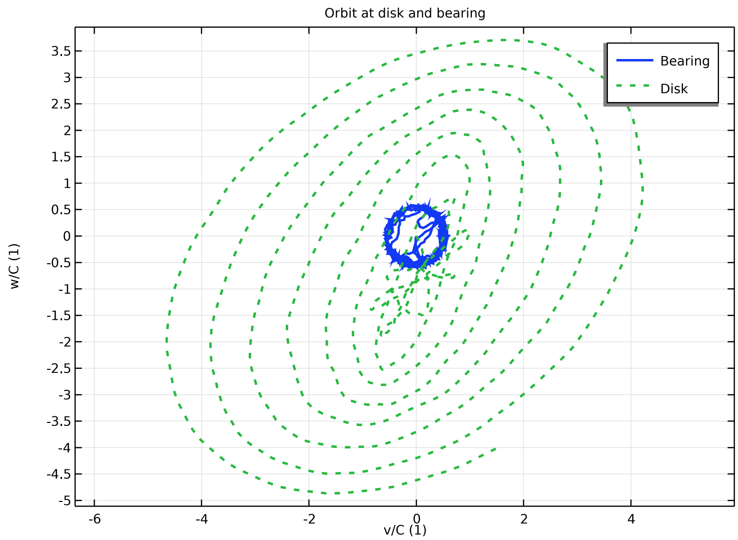

Figure 5: Rotor orbit at clearance $C = 2 \cdot 10^{-4}$ m.

A frequency spectrum of the *z*-component of the displacement is shown in Figure 6. From the spectrum it is clear that for low clearance the only dominant mode is the synchronous whirl at 50 Hz, as we increase the clearance participation from the nonsynchronous whirl modes increases.

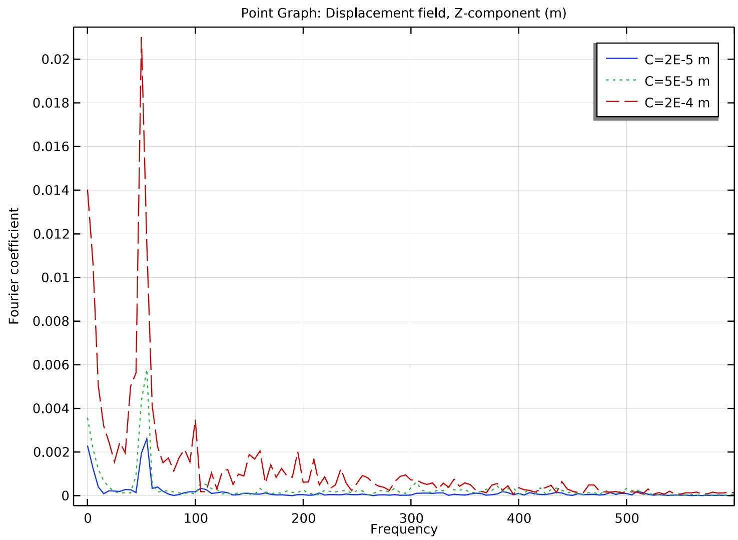

Figure 6: Frequency spectrum of the z-component of the displacement.

The bearing force, shown in Figure 7, gives a clear idea of the contact of the rotor with the bearing. For a smaller clearance the contact duration is larger and as the clearance increases the contact becomes more intermittent with lower overall duration of the contact. Also, the magnitude of the contact force is larger for the large clearance bearing due to the rotor impact on the bearing.

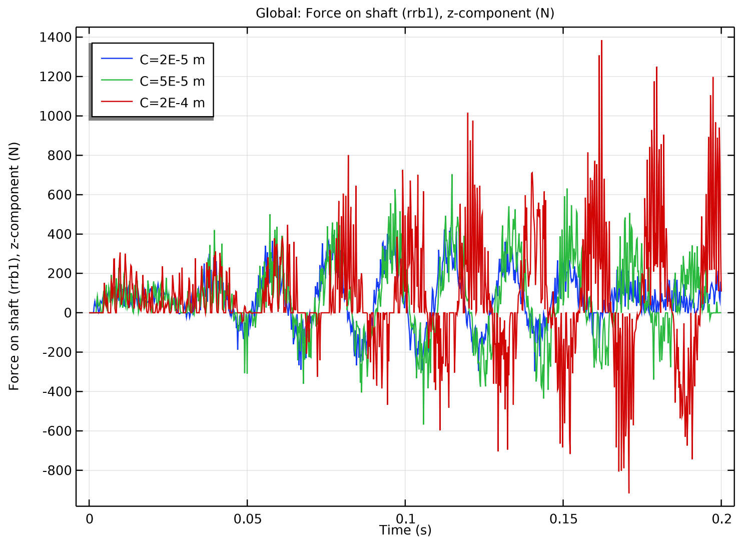

Figure 7: Bearing force on the shaft.

Figure 8 shows the bearing moment on the shaft.

Figure 8: Bearing moment on the shaft.

Application Library path: `Rotordynamics_Module/Tutorials/nonsynchronous_rotor_vibration_with_roller_bearing`

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>Time Dependent**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters: Rotor

Define the parameters for the rotor system.

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

2 In the **Settings** window for **Parameters**, type `Parameters: Rotor` in the **Label** text field.

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

Name	Expression	Value	Description
Ow	3000[rpm]	50 1/s	Angular speed of the rotor
d	0.04[m]	0.04 m	Rotor diameter
rho_disk	7850[kg/m^3]	7850 kg/m³	Density of the disk
R_disk	0.08[m]	0.08 m	Radius of the disk
h_disk	0.03[m]	0.03 m	Thickness of the disk

Parameters: Bearing

1 In the **Home** toolbar, click **Parameters** and choose **Add>Parameters**.

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

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

Name	Expression	Value	Description
C	1e-4[m]	1E-4 m	Radial clearance in bearing
f	0.7	0.7	Fill ratio
N	10	10	Number of rollers
db	d/(N/(f*pi)-1)	0.011276 m	Ball diameter
dp	d+db	0.051276 m	Pitch diameter
rin	0.53*db	0.0059764 m	Inner race radius
rout	0.53*db	0.0059764 m	Outer race radius

GEOMETRY 1

Polygon 1 (pol1)

1 In the **Model Builder** window, expand the **Component 1 (comp1)>Geometry 1** node.

2 Right-click **Geometry 1** and choose **More Primitives>Polygon**.

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

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

5 In the **x** text field, type `0 0.5 1`.

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

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

8 Click **Build All Objects**.

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>Structural steel**.

4 Click the right end of the **Add to Component** split button in the window toolbar.

5 From the menu, choose **Component 1 (comp1)**.

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

BEAM ROTOR (ROTBM)

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

2 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`.

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 From the **Center of mass** list, choose **Offset from selected points**.

5 In the z_r text field, type `1e-4[m]`.

6 From the **Specified by** list, choose **Geometric dimensions**.

7 In the ρ text field, type `rho_disk`.

8 In the d text field, type `2*R_disk`.

9 In the h text field, type `h_disk`.

Radial Roller Bearing 1

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

2 Select Point 1 only.

3 In the **Settings** window for **Radial Roller Bearing**, locate the **Geometric Properties** section.

4 In the N_b text field, type `N`.

5 In the d_b text field, type `db`.

6 In the d_p text field, type `dp`.

7 In the r_{in} text field, type `rin`.

8 In the r_{out} text field, type `rout`.

9 Locate the **Clearance and Preload** section. In the c_r text field, type `C`.

10 Right-click **Radial Roller Bearing 1** and choose **Duplicate**.

Radial Roller Bearing 2

1 In the **Model Builder** window, click **Radial Roller Bearing 2**.

2 In the **Settings** window for **Radial Roller Bearing**, locate the **Point Selection** section.

3 Click **Clear Selection**.

4 Select Point 3 only.

Gravity 1

In the **Physics** toolbar, click **Edges** and choose **Gravity**.

STUDY 1

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

2 In the **Show More Options** dialog box, select **Study>Batch and Cluster** in the tree.

3 In the tree, select the check box for the node **Study>Batch and Cluster**.

4 Click **OK**.

Batch Sweep

1 In the **Study** toolbar, click **Batch** and choose **Batch Sweep**.

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

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
C (Radial clearance in bearing)	`2e-5 5e-5 2e-4`	`m`

5 Locate the **Batch Settings** section. Find the **Before sweep** subsection. Clear the **Clear solutions** check box.

6 Clear the **Clear meshes** check box.

7 Select the **Synchronize solutions** check box.

8 Locate the **Advanced Settings** section. In the **Number of simultaneous jobs** text field, type `3`.

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(0,2e-4,0.2)`.

Batch Data

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

RESULTS

Stress (rotbm)

Stress is the default plot shown in Figure 2.

1 Click the **Zoom Extents** button in the **Graphics** toolbar.
2 In the **Model Builder** window, expand the **Results** node, then click **Stress (rotbm)**.
3 In the **Stress (rotbm)** toolbar, click **Plot**.

Follow the instructions below to plot the orbit of the left bearing and the disk as shown in Figure 3.

Orbit

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` 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 selection (C)** list, choose **Manual**.
5 In the **Parameter indices (1-3)** text field, type `1`.
6 Locate the **Axis** section. Select the **Preserve aspect ratio** check box.
7 Click to expand the **Title** section. From the **Title type** list, choose **Manual**.
8 In the **Title** text area, type `Orbit at disk and bearing`.

Point Graph 1

1 Right-click **Orbit** and choose **Point Graph**.
2 Select Points 1 and 2 only.
3 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
4 In the **Expression** text field, type `w/C`.
5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
6 In the **Expression** text field, type `v/C`.
7 Click to expand the **Coloring and Style** section. From the **Width** list, choose **2**.
8 Find the **Line style** subsection. From the **Line** list, choose **Cycle**.
9 Click to expand the **Legends** section. Select the **Show legends** check box.
10 From the **Legends** list, choose **Manual**.

11 In the table, enter the following settings:

Legends
`Bearing`
`Disk`

12 In the **Orbit** toolbar, click **Plot**.

Change clearance to see the corresponding orbits.

Orbit

1 In the **Model Builder** window, click **Orbit**.

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

3 In the **Parameter indices (1-3)** text field, type `2`.

4 In the **Orbit** toolbar, click **Plot**.

5 In the **Parameter indices (1-3)** text field, type `3`.

6 In the **Orbit** toolbar, click **Plot**.

Follow the instructions below to plot the frequency spectrum of the `z`-displacement in the left bearing and the disk as shown in Figure 6.

Frequency spectrum w

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

2 In the **Settings** window for **1D Plot Group**, type `Frequency spectrum w` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/ Parametric Solutions 1 (sol2)**.

Point Graph 1

1 Right-click **Frequency spectrum w** 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 `w`.

5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Discrete Fourier transform**.

6 From the **Show** list, choose **Frequency spectrum**.

7 Select the **Number of frequencies** check box. In the associated text field, type `400`.

8 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **Cycle**.

9 Locate the **Legends** section. Select the **Show legends** check box.

10 Find the **Include** subsection. Clear the **Point** check box.

11 In the **Frequency spectrum w** toolbar, click **Plot**.

Frequency spectrum w

1 In the **Model Builder** window, click **Frequency spectrum w**.

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

3 Select the **Manual axis limits** check box.

4 In the **x maximum** text field, type `600`.

5 In the **Frequency spectrum w** toolbar, click **Plot**.

Follow the instructions below to plot the `z`-component of the force on the shaft due to bearing shown in Figure 7.

Bearing Force

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

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

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (sol2)**.

4 In the **Label** text field, type `Bearing Force`.

Global 1

1 Right-click **Bearing Force** 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>Radial Roller Bearing 1>Force on shaft (rrb1) - N>rotbm.rrb1.Fsz - Force on shaft (rrb1), z-component**.

3 Click to expand the **Legends** section. Find the **Include** subsection. Clear the **Description** check box.

Bearing Force

1 In the **Model Builder** window, click **Bearing Force**.

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

3 From the **Position** list, choose **Upper left**.

4 In the **Bearing Force** toolbar, click **Plot**.

Follow the instructions below to plot the y-component of the moment on the shaft due to bearing shown in Figure 8.

Bearing Moment

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

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

3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/ Parametric Solutions 1 (sol2)**.

Global 1

1 Right-click **Bearing Moment** 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> Radial Roller Bearing 1>Moment on shaft (rrb1) - N·m>rotbm.rrb1.Msy - Moment on shaft (rrb1), y-component**.

3 Locate the **Legends** section. Find the **Include** subsection. Clear the **Description** check box.

Bearing Moment

1 In the **Model Builder** window, click **Bearing Moment**.

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

3 From the **Position** list, choose **Upper left**.

4 In the **Bearing Moment** toolbar, click **Plot**.