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Damping Coefficients of a Squeeze Film Damper

Introduction

Squeeze film dampers are components that provide additional damping to rotating machines. To simplify the modeling of a rotor assembly, squeeze film dampers are often modeled in terms of their damping coefficients. This model computes damping coefficients for a short squeeze film damper and compares them to analytically computed values. The damping coefficients depend on the journal location in the damper.

Model Definition

The plain squeeze film damper has a radius of 0.1 m and length of 0.01 m. The journal undergoes a circular whirl at 100 rpm, and the clearance between the journal and the damper bushing is 1 mm. The viscosity and density of the lubricant are taken as 0.02 Pa·s and 864 $\mathrm{kg/m^3}$, respectively. The relative eccentricity of the journal is varied from 0.02 to 0.96 in the steps of 0.02. The attitude angle is specified relative to the static load on the damper at $\phi = 10°$. The damping coefficients are computed for all eccentricity values by solving a perturbed form of Reynolds equation.

The local directions of the damper are aligned with the global y and z directions, with the negative z direction defining $\phi = 0°$. The attitude angle of the journal measured from the local y direction is therefore $\theta = 3\pi/2 + \phi$ .The coordinates of the journal location in the damper, in local directions, are given by

$$\mathbf{u}_\mathrm{J} = \begin{Bmatrix} 0 \\ C\varepsilon\cos\theta \\ C\varepsilon\sin\theta \end{Bmatrix} = \begin{Bmatrix} 0 \\ C\varepsilon\sin\phi \\ -C\varepsilon\cos\phi \end{Bmatrix}$$

where C is the clearance and ε is the relative eccentricity of the journal. Analytical values for the radial and tangential dimensionless damping coefficients (Ref. 1) are given by

$$c_\mathrm{rr} = c_0\left(\frac{\pi(1+2\varepsilon^2)}{2(1-\varepsilon^2)^{5/2}}\right)$$

$$c_\mathrm{rt} = c_0\left(\frac{2\varepsilon}{(1-\varepsilon^2)^2}\right)$$

$$c_\mathrm{tr} = c_{rt}$$

$$c_\mathrm{tt} = c_0\left(\frac{\pi}{2(1-\varepsilon^2)^{3/2}}\right)$$

where c_0 is a dimensional scaling factor for the damping coefficients. This is given by

$$c_0 = \mu R\left(\frac{L}{C}\right)^3$$

The damping coefficients are transformed from global to local coordinates as

$$\begin{bmatrix} c_{22} & c_{23} \\ c_{32} & c_{33} \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} c_{\mathrm{rr}} & c_{\mathrm{rt}} \\ c_{\mathrm{tr}} & c_{\mathrm{tt}} \end{bmatrix}\begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}^T$$

Results and Discussion

Figure 1 shows the various components of the computed damping coefficients and compares them to their analytical counterparts. The computed values match the analytical values.

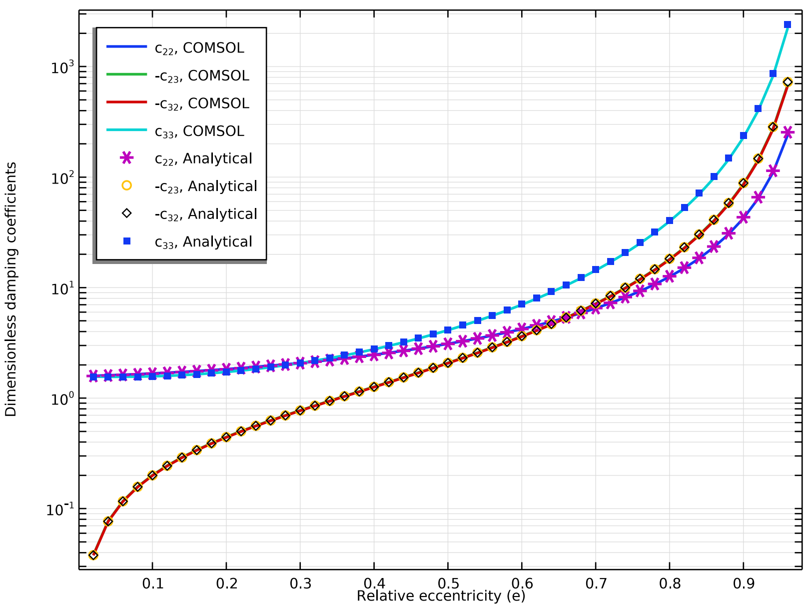

Figure 1: Damping coefficients.

Reference

1. W.J. Chen and E.J. Gunter, *Introduction to the Dynamics of Rotor-Bearing Systems*, sections 6.10 and 6.11, pp. 263–271, Trafford Publishing, 2007.

Application Library path: `Rotordynamics_Module/Verification_Examples/squeeze_film_damper_damping_coefficients`

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>Hydrodynamic Bearing (hdb)**.

3 Click **Add**.

4 Click **Study**.

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

6 Click **Done**.

Create the parameters for the damper and lubricants properties.

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
fr	100[rpm]	1.6667 1/s	Whirl speed
Rj	0.1[m]	0.1 m	Journal radius
H	0.01[m]	0.01 m	Journal length
C	1e-3[m]	0.001 m	Clearance
e	0	0	Eccentricity
phi	10[deg]	0.17453 rad	Attitude angle

Name	Expression	Value	Description
mu0	0.02[Pa*s]	0.02 Pa·s	Oil viscosity
rho0	864[kg/m^3]	864 kg/m³	Oil density

GEOMETRY 1

Cylinder 1 (cyl1)

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

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

3 In the **Radius** text field, type Rj.

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

5 Locate the **Axis** section. From the **Axis type** list, choose **x-axis**.

6 Locate the **Object Type** section. From the **Type** list, choose **Surface**.

7 Click **Build Selected**.

Define the variables for the analytical damping coefficients in local y and z directions.

DEFINITIONS

Variables 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Definitions** and choose **Variables**.

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

3 In the table, enter the following settings:

Name	Expression	Unit	Description
c0	mu0*Rj*(H/C)^3	kg/s	Damping scaling
c_rr	pi*(1+2*e^2)/(2*(1-e^2)^2.5)		Damping coefficient, rr component
c_rt	2*e/(1-e^2)^2		Damping coefficient, rt component
c_tr	c_rt		Damping coefficient, tr component
c_tt	pi/(2*(1-e^2)^1.5)		Damping coefficient, tt component
c_22	c_rr*(sin(phi))^2+c_rt*sin(2*phi)+c_tt*(cos(phi))^2		Damping coefficient, 22 component

Name	Expression	Unit	Description
c_23	(-c_rr+c_tt)*sin(phi)* cos(phi)-c_rt*cos(2*phi)		Damping coefficient, 23 component
c_32	c_23		Damping coefficient, 32 component
c_33	c_rr*(cos(phi))^2-c_rt* sin(2*phi)+c_tt* (sin(phi))^2		Damping coefficient, 33 component

HYDRODYNAMIC BEARING (HDB)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Hydrodynamic Bearing (hdb)**.
2 In the **Settings** window for **Hydrodynamic Bearing**, locate the **Dynamic Coefficients** section.
3 Select the **Calculate dynamic coefficients** check box.

Squeeze Film Damper 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Squeeze Film Damper**.
2 In the **Settings** window for **Squeeze Film Damper**, locate the **Boundary Selection** section.
3 From the **Selection** list, choose **All boundaries**.
4 Locate the **Damper Properties** section. In the C text field, type `C`.
5 From the $\mathbf{X}_c$ list, choose **From geometry**.
6 Locate the **Journal Properties** section. From the **Specify** list, choose **Eccentricity and direction**.
7 In the e text field, type `C*e`.
8 In the ϕ_y text field, type `270[deg]+phi`.
9 In the ω text field, type `2*pi[rad]*fr`.
10 Locate the **Film Boundary Condition** section. From the **Film type** list, choose **Gümbel**.
11 Locate the **Fluid Properties** section. From the μ list, choose **User defined**. In the associated text field, type `mu0`.
12 From the ρ list, choose **User defined**. In the associated text field, type `rho0`.

Use a mapped mesh to resolve the pressure.

MESH 1

Mapped 1

1 In the **Mesh** toolbar, click **More Generators** and choose **Mapped**.

2 In the **Settings** window for **Mapped**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **All boundaries**.

Distribution 1

1 Right-click **Mapped 1** and choose **Distribution**.

2 Select Edges 1, 2, 4, and 6 only.

3 In the **Settings** window for **Distribution**, locate the **Distribution** section.

4 In the **Number of elements** text field, type 50.

Distribution 2

1 In the **Model Builder** window, right-click **Mapped 1** and choose **Distribution**.

2 Select Edge 3 only.

3 In the **Settings** window for **Distribution**, click **Build All**.

STUDY 1

Step 1: Stationary

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

2 In the **Settings** window for **Stationary**, click to expand the **Study Extensions** section.

3 Select the **Auxiliary sweep** check box.

4 Click **Add**.

5 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
e (Eccentricity)	range(0.02,0.02,0.96)	

6 In the table, click to select the cell at row number 1 and column number 3.

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

RESULTS

Fluid Pressure (hdb)

1 In the **Fluid Pressure (hdb)** toolbar, click **Plot**.

Pressure in the damper is the default plot. Follow the below instructions to compare the computed and the analytical values of the dimensionless damping for the damper as shown in Figure 1.

Damping coefficients (Dimensionless)

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

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

Global 1

1 Right-click **Damping coefficients (Dimensionless)** 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)> Hydrodynamic Bearing>Dynamic coefficients>hdb.sfd1.c22 - Bearing damping coefficient, local yy-component - N·s/m**.

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

Expression	Unit	Description
hdb.sfd1.c22/c0	1	c₂₂, COMSOL
-hdb.sfd1.c23/c0	1	-c₂₃, COMSOL
-hdb.sfd1.c32/c0	1	-c₃₂, COMSOL
hdb.sfd1.c33/c0	1	c₃₃, COMSOL

4 Click to expand the **Coloring and Style** section. From the **Width** list, choose **2**.

Global 2

1 In the **Model Builder** window, right-click **Damping coefficients (Dimensionless)** and choose **Global**.

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

3 In the table, enter the following settings:

Expression	Unit	Description
c_22		c₂₂, Analytical
-c_23		-c₂₃, Analytical
-c_32		-c₃₂, Analytical
c_33		c₃₃, Analytical

4 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **None**.

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

Damping coefficients (Dimensionless)

1 In the **Model Builder** window, click **Damping coefficients (Dimensionless)**.

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

3 Select the **x-axis label** check box. In the associated text field, type `Relative eccentricity (e)`.

4 Select the **y-axis label** check box. In the associated text field, type `Dimensionless damping coefficients`.

5 Click to expand the **Title** section. From the **Title type** list, choose **None**.

6 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

7 Click the **y-Axis Log Scale** button in the **Graphics** toolbar.

8 In the **Damping coefficients (Dimensionless)** toolbar, click **Plot**.