Created in COMSOL Multiphysics 6.2

Vibration Control in a Motor Drive Using an Active Magnetic Bearing

Introduction

Active magnetic bearings (AMBs) are used for controlling the vibration in mechanical systems by using a feedback control. In this model, we consider a motor driven assembly in which the speed of the system is gradually increased. As the speed of the system increases, it crosses through many critical speeds. Vibrations in the system due to existing imbalances are amplified when the speed of the rotor is near critical speed.

Two different time dependent studies are performed on the system with the objective of studying the influence of the active magnetic bearings on the overall vibration of the system. The first study excludes the active magnetic bearing to get the vibration levels in the system without any control. In the second study, an AMB is switched on when the vibration in the system is high due to resonance. Subsequently, the system responds to the additional control forces from the AMB. The response of the system including the AMB is compared with the response excluding the AMB.

The results include the vibration at different locations in the system as well as stress and control currents.

Model Definition

The model consists of a rotor driven by a motor. The rotor is supported by two journal bearings along its length. Two additional bearings are located inside the motor. A fan is also located inside the motor, outside the two bearings. The whole assembly is mounted on a foundation through a motor pedestal and bearing housings. In the model, the rotor speed is gradually increased to simulate the run-up of the system. During the run-up, the system crosses through critical speeds. As a result, high-amplitude vibrations are observed in the system. The system also has an electromagnetic bearing, placed between the two journal bearings on the rotor, to control the vibrations during resonance.

Figure 1 shows a schematic representation of the system, while Figure 2 shows an inside view of the motor to highlight the rotor components inside the motor.

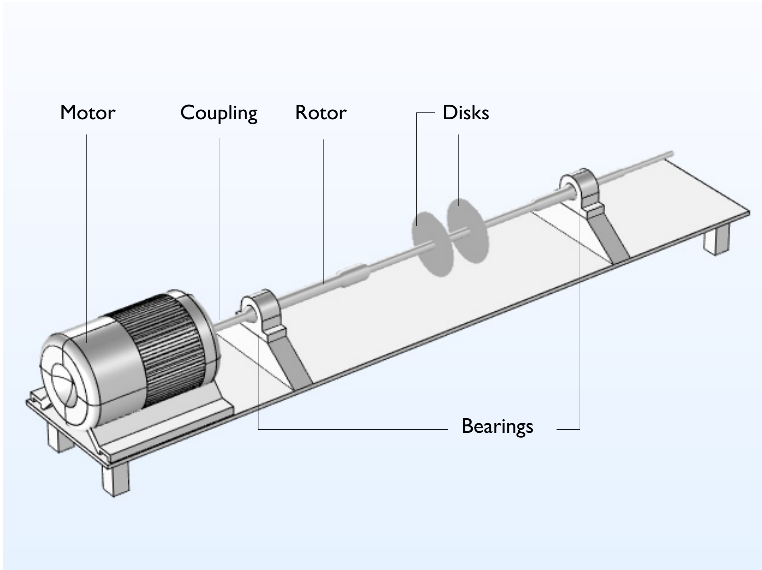

Figure 1: Motor-driven rotor assembly.

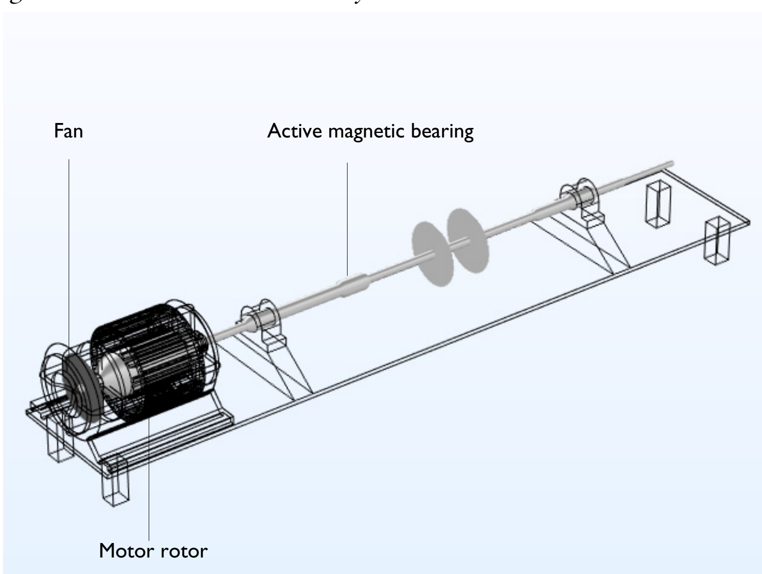

Figure 2: Inside view of the motor.

The motor and the foundation are modeled using a Solid Mechanics interface. The rotor (inside and outside of the motor) is modeled using a Beam Rotor interface. The rotor inside the motor is connected to the rotor outside the motor through a rigid coupling. Rayleigh damping is added to both rotors to dampen out vibrations. Hence, the coupling is not modeled, rather the whole rotor is considered as a single entity.

The two disks on the rotor and the fan inside the motor are modeled using the **Disk** feature in the Beam Rotor interface. Both bearings inside the motor and the two external journal bearings are modeled using a lumped approximation with equivalent stiffness and damping coefficients. The electromagnetic bearing is modeled using the **Active Magnetic Bearing** feature in the Beam Rotor interface. The rotors are connected to the static structure through **Attachments** on the static structure as a foundation in the bearing nodes. The electromagnetic interaction between the stator and the rotor in the motor is neglected in this study. The properties of the rotor are given in Table 1, and the length and diameter between different stations are given in Table 2. Lastly, the properties of the bearings are given in Table 3.

Two *Time Dependent* studies are performed on the system:

1. Excluding the active magnetic bearing to observe the vibration amplitudes without any control.
2. Including the active magnetic bearing and switching it on when the resonance is about to occur.

The results are then compared to analyze the effectiveness of the control mechanism.

TABLE 1: ROTOR PROPERTIES.

Parameter	**Value**
Young's modulus of the rotor, E	211 GPa
Poisson's ratio of the rotor, ν	0.3
Density of the rotor, ρ	7850 kg/m^3
Mass damping parameter of the rotor, α_{dM}	7.0 1/s
Stiffness damping parameter, β_{dK}	$3.2\cdot10^{-5}$ s
Length of the rotor in motor, L_m	0.343 m
Length of the rotor outside motor, L_e	1.3 m
Location of the first bearing in motor (Station 2)	0.0467 m
Location of the second bearing in motor (Station 5)	0.2933 m
Location of the coupling (Station 6)	0.343 m
Location of the first external bearing (Station 8)	0.4683 m

TABLE 1: ROTOR PROPERTIES.

Parameter	Value
Location of the second external bearing (Station 17)	1.3683 m
Location of the active magnetic bearing (Station 11)	0.7183 m
Location of the first disk (Station 13)	0.9433 m
Location of the second disk (Station 14)	1.0433 m
Mass of the fan, m_{f}	5.0 kg
Transverse moment of inertia of the fan, I_{df}	0.0079 kg·m^2
Polar moment of inertia of the fan, I_{pf}	0.0154 kg·m^2
Mass of the external disks, m	3.9 kg
Transverse moment of inertia of the external disks, I_{d}	0.0057 kg·m^2
Polar moment of inertia of the external disks, I_{p}	0.0113 kg·m^2
Eccentricity in the first disk in local y direction	73 µm
Eccentricity in the second disk in local z direction	222 µm

TABLE 2: GEOMETRIC PROPERTIES OF THE ROTOR

Rotor segment	Length (m)	Diameter (m)
Station 1-2	0.0467	0.02
Station 2-3	0.0467	0.02
Station 3-4	0.15	0.1
Station 4-5	0.05	0.02
Station 5-6	0.05	0.02
Station 6-7	0.1	0.02
Station 7-8	0.025	0.04
Station 8-9	0.025	0.04
Station 9-10	0.2	0.03
Station 10-11	0.025	0.04
Station 11-12	0.025	0.04
Station 12-13	0.2	0.02
Station 13-14	0.1	0.02
Station 14-15	0.2	0.02
Station 15-16	0.1	0.03
Station 16-17	0.025	0.04
Station 17-18	0.025	0.04

TABLE 2: GEOMETRIC PROPERTIES OF THE ROTOR

Rotor segment	**Length (m)**	**Diameter (m)**
Station 18-19	0.1	0.02
Station 19-20	0.15	0.015

TABLE 3: BEARING PROPERTIES.

Parameter	**Value**
Bearing stiffness, k_b	357 MN/m
Bearing damping coefficient, c_b	130 kN·s/m
AMB gap, h	2 mm
Bias current positive axis, i_{bp}	1 A
Bias current negative axis, i_{bn}	1 A
Maximum current, i_{max}	5 A
Proportional gain, K_p	$2(i^2_{bp} + i^2_{bn})/((i_{bp} + i_{bn})h)$
Integral gain, K_i	$K_p/0.001$
Derivative gain, K_d	$0.005\ K_p$
Force constant, F_c	20

Results and Discussion

The stress in the assembly without the AMB is shown in Figure 3. The maximum stress occurs in the central region of the rotor. The eccentricity of the disks cause the rotor to bend between the bearings, thus stressing the rotor. Moreover, the diameter of the rotor is smaller close to the disks and, as a result, the maximum stress is observed in this part of the rotor. The figure also shows that the foundation is primarily deformed in the first bending mode.

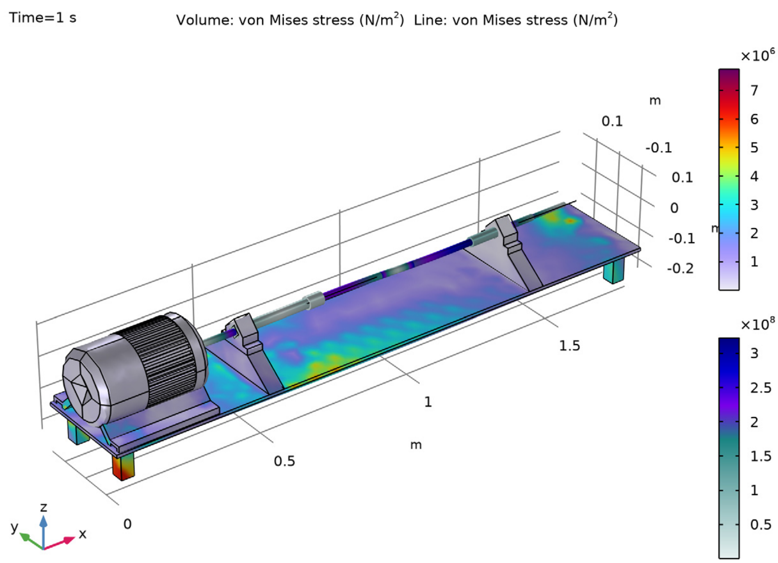

Figure 3: Stress in the system without the AMB at 1 s.

The stress profile in the assembly with the AMB active is shown in Figure 4. Again, we observe higher stresses in the part of the rotor near the disks. In this case, the deformation of the foundation is likewise dominated by the first bending mode. The rotor is found to deform in a higher bending mode.

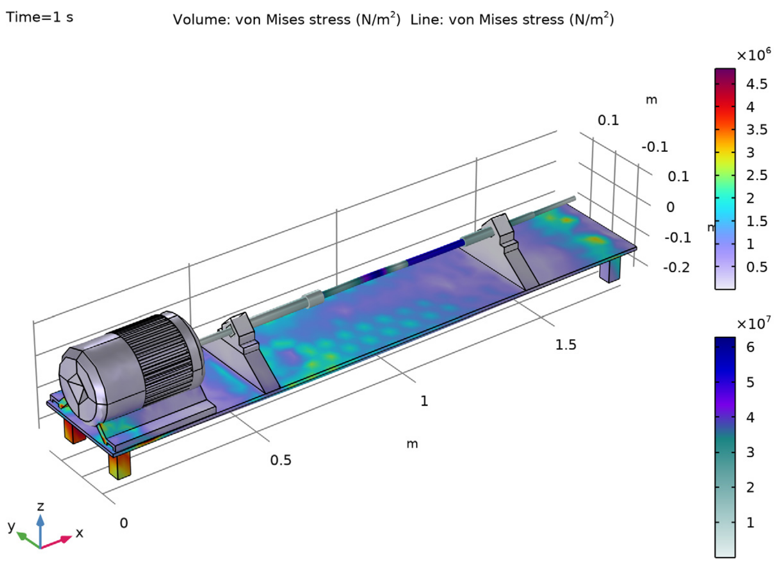

Figure 4: Stress in the system with the AMB at 1 s.

The vertical displacement of the rotor at the coupling location is compared in Figure 5. It is found that the system without the AMB undergoes multiple resonances during the run-up. In the presence of the AMB in the system, the vibration levels during resonance have decreased significantly. To analyze it further, a comparison of the vibrations near the AMB itself is conducted. The associated plot is shown in Figure 6. In the figure, it is clear that any vibrations after the activation of the AMB are suppressed. Thus, the AMB helps in isolating any vibrations caused by imbalances in the rotor and prevents them from propagating to the motor.

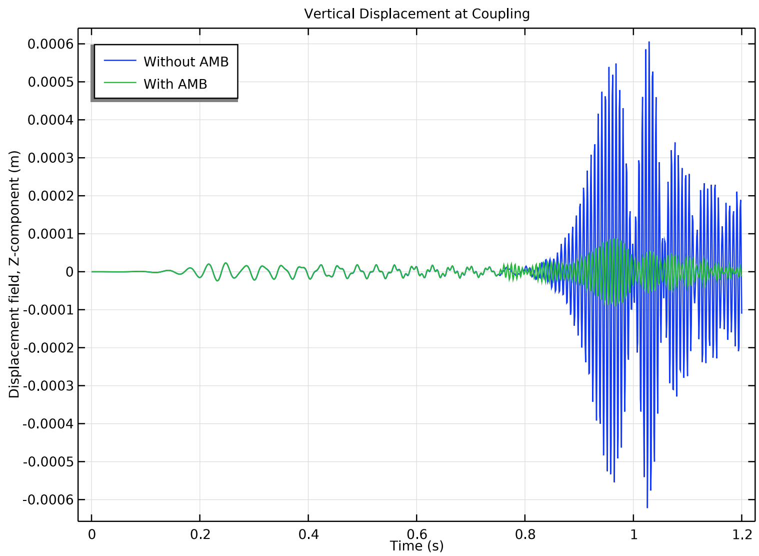

Figure 5: Vertical displacement at coupling.

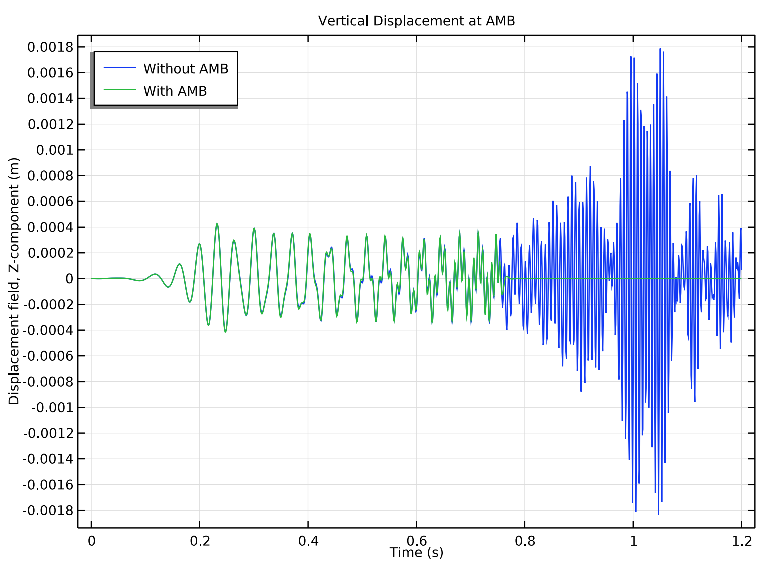

Figure 6: Vertical displacement at active magnetic bearing.

The variation in the control current in the AMB in both transverse directions is shown in Figure 7. Since a step function is used to switch the bearing forces on, the control current in the bearing still responds to the displacement variations before the AMB is switched on. After the bearing is switched on, it quickly suppresses the vibration level in the system. Consequently, the required control current also decreases.

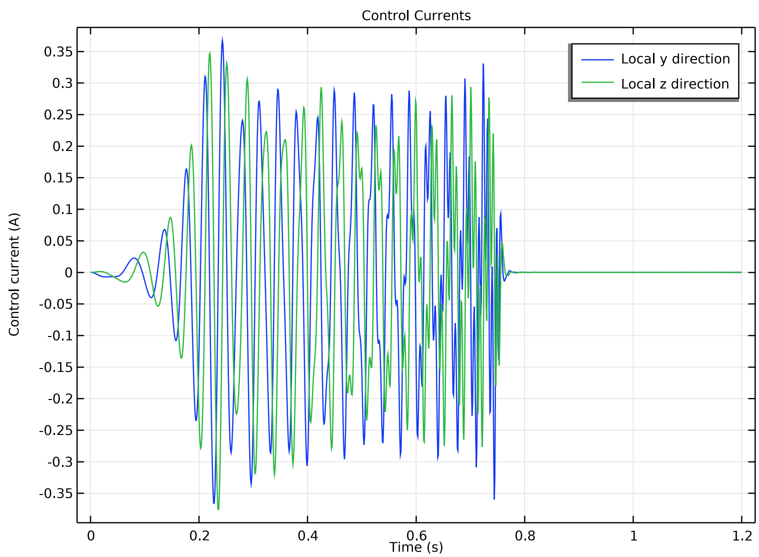

Figure 7: Variation of the control current.

The force in the AMB in the transverse directions is shown in Figure 8. Before the bearing is switched on, the force remains zero. In the later part, when the AMB is active, we can clearly see significant variation in the control forces, even though the variation in the control currents is small.

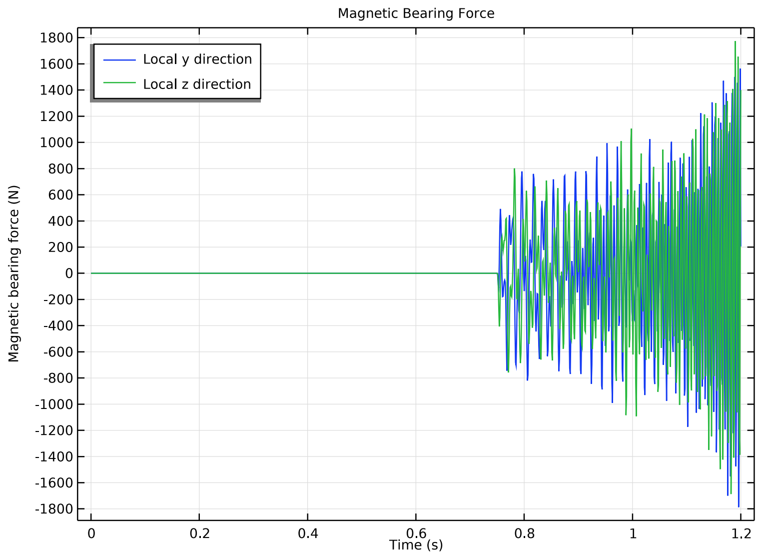

Figure 8: Force in the electromagnetic bearing.

Application Library path: `Rotordynamics_Module/Tutorials/vibration_control_with_amb`

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>Solid Mechanics (solid)** and **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**.

GEOMETRY 1

Import the geometry of a rotor-stator assembly.

Import 1 (imp1)

1 In the **Home** toolbar, click **Import**.

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

3 Click **Browse**.

4 Browse to the model's Application Libraries folder and double-click the file `vibration_control_with_amb.mphbin`.

5 Click **Import**.

Import the rotor and bearing parameters.

GLOBAL DEFINITIONS

Parameters: Rotor

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

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

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `vibration_control_with_amb_rotor.txt`.

5 In the **Label** text field, type `Parameters: Rotor`.

Parameters: Bearing

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

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

3 Click **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `vibration_control_with_amb_bearing.txt`.

5 In the **Label** text field, type `Parameters: Bearing`.

Create some selections for later use.

DEFINITIONS

Motor Bearing 1

1 In the **Definitions** toolbar, click **Explicit**.
2 In the **Settings** window for **Explicit**, type `Motor Bearing 1` in the **Label** text field.
3 Locate the **Input Entities** section. From the **Geometric entity level** list, choose **Boundary**.
4 Select the **Group by continuous tangent** check box.
5 Select Boundaries 85, 86, 89, and 91 only.
6 Right-click **Motor Bearing 1** and choose **Duplicate**.

Motor Bearing 2

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections** click **Motor Bearing 1.1**.
2 In the **Settings** window for **Explicit**, type `Motor Bearing 2` in the **Label** text field.
3 Locate the **Input Entities** section. Click **Clear Selection**.
4 Select Boundaries 485, 486, 490, 493, 505, 506, 510, 513, 524, 525, 529, 532, 541, 542, 546, and 549 only.
5 Right-click **Motor Bearing 2** and choose **Duplicate**.

External Bearing 1

1 In the **Model Builder** window, click **Motor Bearing 2.1**.
2 In the **Settings** window for **Explicit**, locate the **Input Entities** section.
3 Click **Clear Selection**.
4 Select Boundaries 565–568 only.
5 In the **Label** text field, type `External Bearing 1`.
6 Right-click **External Bearing 1** and choose **Duplicate**.

External Bearing 2

1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions>Selections** click **External Bearing 1.1**.
2 In the **Settings** window for **Explicit**, type `External Bearing 2` in the **Label** text field.
3 Locate the **Input Entities** section. Click **Clear Selection**.
4 Select Boundaries 586–589 only.

Rotor

1 In the **Definitions** toolbar, click **Explicit**.

2 In the **Settings** window for **Explicit**, locate the **Input Entities** section.

3 From the **Geometric entity level** list, choose **Edge**.

4 Select Edge 1341 only.

5 Select the **Group by continuous tangent** check box.

6 In the **Label** text field, type `Rotor`.

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 **Add to Global Materials** in the window toolbar.

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

MATERIALS

Material Link 1 (matlnk1)

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

2 Right-click **Material Link 1 (matlnk1)** and choose **Duplicate**.

Material Link 2 (matlnk2)

1 In the **Model Builder** window, click **Material Link 2 (matlnk2)**.

2 In the **Settings** window for **Material Link**, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Edge**.

4 From the **Selection** list, choose **Rotor**.

SOLID MECHANICS (SOLID)

Change the discretization to linear to reduce the model size and the computational time. If you want to capture the stresses accurately, you can continue with the default discretization.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Solid Mechanics (solid)**.

2 In the **Settings** window for **Solid Mechanics**, click to expand the **Discretization** section.

3 From the **Displacement field** list, choose **Linear**.

Fixed Constraint 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Fixed Constraint**.

2. Select Boundaries 71, 76, 600, and 605 only.

Attachment: Motor Bearing 1

1. In the **Physics** toolbar, click **Boundaries** and choose **Attachment**.
2. In the **Settings** window for **Attachment**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Motor Bearing 1**.
4. In the **Label** text field, type `Attachment: Motor Bearing 1`.
5. Right-click **Attachment: Motor Bearing 1** and choose **Duplicate**.

Attachment: Motor Bearing 2

1. In the **Model Builder** window, click **Attachment: Motor Bearing 1.1**.
2. In the **Settings** window for **Attachment**, locate the **Boundary Selection** section.
3. From the **Selection** list, choose **Motor Bearing 2**.
4. In the **Label** text field, type `Attachment: Motor Bearing 2`.
5. Right-click **Attachment: Motor Bearing 2** and choose **Duplicate**.

Attachment: External Bearing 1

1. In the **Model Builder** window, under **Component 1 (comp1)>Solid Mechanics (solid)** click **Attachment: Motor Bearing 2.1**.
2. In the **Settings** window for **Attachment**, type `Attachment: External Bearing 1` in the **Label** text field.
3. Locate the **Boundary Selection** section. From the **Selection** list, choose **External Bearing 1**.
4. Right-click **Attachment: External Bearing 1** and choose **Duplicate**.

Attachment: External Bearing 2

1. In the **Model Builder** window, under **Component 1 (comp1)>Solid Mechanics (solid)** click **Attachment: External Bearing 1.1**.
2. In the **Settings** window for **Attachment**, type `Attachment: External Bearing 2` in the **Label** text field.
3. Locate the **Boundary Selection** section. From the **Selection** list, choose **External Bearing 2**.

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 **Edge Selection** section.
3. From the **Selection** list, choose **Rotor**.
4. Locate the **Rotor Speed** section. In the text field, type `10000[rpm/s]*t`.

Linear Elastic Material 1

In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** 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 `7`.

4 In the β_{dK} text field, type `3.2e-5`.

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_0 text field, type `ds1`.

4 Right-click **Component 1 (comp1)>Beam Rotor (rotbm)>Rotor Cross Section 1** and choose **Duplicate**.

Rotor Cross Section 2

1 In the **Model Builder** window, click **Rotor Cross Section 2**.

2 In the **Settings** window for **Rotor Cross Section**, locate the **Edge Selection** section.

3 Click **Clear Selection**.

4 Select Edge 492 only.

5 Locate the **Cross-Section Definition** section. In the d_0 text field, type `dR`.

6 Right-click **Rotor Cross Section 2** and choose **Duplicate**.

Rotor Cross Section 3

1 In the **Model Builder** window, click **Rotor Cross Section 3**.

2 In the **Settings** window for **Rotor Cross Section**, locate the **Edge Selection** section.

3 Click **Clear Selection**.

4 Select Edges 1301, 1316, 1336, 1337, 1359, and 1374 only.

5 Locate the **Cross-Section Definition** section. In the d_0 text field, type `ds2`.

6 Right-click **Rotor Cross Section 3** and choose **Duplicate**.

Rotor Cross Section 4

1 In the **Model Builder** window, click **Rotor Cross Section 4**.

2 In the **Settings** window for **Rotor Cross Section**, locate the **Edge Selection** section.

3 Click **Clear Selection**.

4 Select Edges 1328 and 1341 only.

5 Locate the **Cross-Section Definition** section. In the d_o text field, type `ds3`.

6 Right-click **Rotor Cross Section 4** and choose **Duplicate**.

Rotor Cross Section 5

1 In the **Model Builder** window, click **Rotor Cross Section 5**.

2 In the **Settings** window for **Rotor Cross Section**, locate the **Edge Selection** section.

3 Click **Clear Selection**.

4 Select Edge 1394 only.

5 Locate the **Cross-Section Definition** section. In the d_o text field, type `ds11`.

Disk: Motor Fan

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

2 Select Point 63 only.

3 In the **Settings** window for **Disk**, type `Disk: Motor Fan` in the **Label** text field.

4 Locate the **Disk Properties** section. In the m text field, type `mf`.

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

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

Disk 1: Rotor

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

2 In the **Settings** window for **Disk**, type `Disk 1: Rotor` in the **Label** text field.

3 Select Point 785 only.

4 Locate the **Disk Properties** section. From the **Center of mass** list, choose **Offset from selected points**.

5 In the z_r text field, type `e1`.

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

7 In the I_p text field, type `Ip`.

8 In the I_d text field, type `Id`.

9 Right-click **Disk 1: Rotor** and choose **Duplicate**.

Disk 2: Rotor

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

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

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

4 Select Point 786 only.

5 Locate the **Disk Properties** section. In the z_r text field, type `e2`.

6 In the ϕ text field, type `pi/2`.

Journal Bearing 1 (Motor)

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

2 Select Point 88 only.

3 In the **Settings** window for **Journal Bearing**, type `Journal Bearing 1 (Motor)` in the **Label** text field.

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

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

kb	0
0	kb

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

cb	0
0	cb

7 Locate the **Foundation Properties** section. From the list, choose **Attachment: Motor Bearing 1 (solid)**.

8 Right-click **Journal Bearing 1 (Motor)** and choose **Duplicate**.

Journal Bearing 2 (Motor)

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

2 In the **Settings** window for **Journal Bearing**, type `Journal Bearing 2 (Motor)` in the **Label** text field.

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

4 Select Point 721 only.

5 Locate the **Foundation Properties** section. From the list, choose **Attachment: Motor Bearing 2 (solid)**.

6 Right-click **Journal Bearing 2 (Motor)** and choose **Duplicate**.

Journal Bearing 3 (External)

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** click **Journal Bearing 2 (Motor) 1**.

2 In the **Settings** window for **Journal Bearing**, type `Journal Bearing 3 (External)` in the **Label** text field.

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

4 Select Point 765 only.

5 Locate the **Foundation Properties** section. From the list, choose **Attachment: External Bearing 1 (solid)**.

6 Right-click **Journal Bearing 3 (External)** and choose **Duplicate**.

Journal Bearing 4 (External)

1 In the **Model Builder** window, under **Component 1 (comp1)>Beam Rotor (rotbm)** click **Journal Bearing 3 (External) 1**.

2 In the **Settings** window for **Journal Bearing**, type `Journal Bearing 4 (External)` in the **Label** text field.

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

4 Select Point 804 only.

5 Locate the **Foundation Properties** section. From the list, choose **Attachment: External Bearing 2 (solid)**.

MESH 1

Create a coarser mesh to reduce the problem size and the computational time. For better accuracy you can continue with the normal mesh.

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Coarser**.

STUDY 1

Step 1: Time Dependent

1 In the **Model Builder** window, under **Study 1** 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(0,1e-3,1.2)`.

Add a fully coupled solver and set the Newton solver to **Automatic Newton**.

Solution 1 (sol1)

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

2 In the **Model Builder** window, expand the **Solution 1 (sol1)** node.

3 In the **Model Builder** window, under **Study 1>Solver Configurations>Solution 1 (sol1)** click **Time-Dependent Solver 1**.

4 In the **Settings** window for **Time-Dependent Solver**, click to expand the **Time Stepping** section.

5 Right-click **Study 1>Solver Configurations>Solution 1 (sol1)>Time-Dependent Solver 1** and choose **Fully Coupled**.

6 In the **Settings** window for **Fully Coupled**, click to expand the **Method and Termination** section.

7 From the **Nonlinear method** list, choose **Automatic (Newton)**.

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

9 In the **Settings** window for **Study**, type `Study: Without AMB` in the **Label** text field.

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

Stress in the solid rotor and beam rotor are the default plots. Follow the instructions below to combine both the plots together as shown in Figure 3.

RESULTS

Line 1

1 In the **Model Builder** window, expand the **Results>Stress (rotbm)** node.

2 Right-click **Line 1** and choose **Copy**.

Stress (solid)

In the **Model Builder** window, under **Results** right-click **Stress (solid)** and choose **Paste Line**.

Line 1

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

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

3 Select the **Radius scale factor** check box. In the associated text field, type `1`.

4 Click **Change Color Table**.

5 In the **Color Table** dialog box, select **Aurora>AuroraAustralisDark** in the tree.

6 Click **OK**.

Deformation

1. In the **Model Builder** window, expand the **Line 1** node, then click **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 `10`.
4. In the **Stress (solid)** toolbar, click **Plot**.

Volume 1

The stator part is solved using linear elements. Thus, stresses within the elements are constant. Change the **Smoothing Threshold** to **None** to smoothen the stress.

1. In the **Model Builder** window, under **Results>Stress (solid)** click **Volume 1**.
2. In the **Settings** window for **Volume**, click to expand the **Quality** section.
3. From the **Smoothing threshold** list, choose **None**.

Deformation

1. In the **Model Builder** window, expand the **Volume 1** node, then click **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 `150`.

Stress (solid)

1. In the **Model Builder** window, under **Results** click **Stress (solid)**.
2. In the **Settings** window for **3D Plot Group**, locate the **Color Legend** section.
3. From the **Position** list, choose **Right double**.
4. Locate the **Data** section. From the **Time (s)** list, choose **1**.
5. Click the **Go to Default View** button in the **Graphics** toolbar.
6. Click the **Zoom Extents** button in the **Graphics** toolbar.
7. In the **Stress (solid)** toolbar, click **Plot**.

Plot the vertical displacement of the rotor at the coupling location using the instructions below.

Vertical Displacement at Coupling

1. In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.
2. In the **Settings** window for **1D Plot Group**, type `Vertical Displacement at Coupling` in the **Label** text field.
3. Click to expand the **Title** section. From the **Title type** list, choose **Label**.
4. Locate the **Legend** section. From the **Position** list, choose **Upper left**.

Point Graph 1

1 Right-click **Vertical Displacement at Coupling** and choose **Point Graph**.

2 Select Point 748 only.

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

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

Create a legend for the plot. This will later help in comparing this result with the result including active magnetic bearing.

5 Click to expand the **Legends** section. Select the **Show legends** check box.

6 From the **Legends** list, choose **Manual**.

7 In the table, enter the following settings:

Legends
`Without AMB`

Now add an active magnetic bearing in the model to control the resonant vibrations in the system. Start by creating a step function to activate the bearing just before the resonance.

DEFINITIONS

Step 1 (step1)

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

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

3 In the **Location** text field, type `0.8[s]`.

BEAM ROTOR (ROTBM)

Active Magnetic Bearing 1

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

2 Select Point 783 only.

3 In the **Settings** window for **Active Magnetic Bearing**, locate the **Air Gap** section.

4 In the h table, enter the following settings:

`gap`
`gap`

5 Locate the **Control Parameters** section. In the K_p table, enter the following settings:

Kp	0
0	Kp

6 In the K_i table, enter the following settings:

Ki	0
0	Ki

7 In the K_d table, enter the following settings:

Kd	0
0	Kd

8 In the F_c table, enter the following settings:

Fc*step1(t)	0
0	Fc*step1(t)

9 Locate the **Currents** section. In the $i_{b,p}$ table, enter the following settings:

ibp	0
0	ibp

10 In the $i_{b,n}$ table, enter the following settings:

ibn	0
0	ibn

11 In the i_{max} table, enter the following settings:

imax	0
0	imax

Add a new study to study the vibration response with active magnetic bearing. Use the same solver settings as in the first study.

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 **General Studies> Time Dependent**.

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

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

STUDY 2

Step 1: Time Dependent

1 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.

2 In the **Output times** text field, type `range(0,1e-3,1.2)`.

Solution 2 (sol2)

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

Change the scaling of the control current variable in **Active Magnetic Bearing**.

2 In the **Model Builder** window, expand the **Solution 2 (sol2)** node.

3 In the **Model Builder** window, expand the **Study 2>Solver Configurations> Solution 2 (sol2)>Dependent Variables 1** node, then click **Control current (comp1.rotbm.amb1.ic)**.

4 In the **Settings** window for **Field**, locate the **Scaling** section.

5 From the **Method** list, choose **Manual**.

6 In the **Scale** text field, type `10`.

7 In the **Model Builder** window, expand the **Study 2>Solver Configurations> Solution 2 (sol2)>Time-Dependent Solver 1** node.

8 Right-click **Study 2>Solver Configurations>Solution 2 (sol2)>Time-Dependent Solver 1** and choose **Fully Coupled**.

9 In the **Settings** window for **Fully Coupled**, locate the **Method and Termination** section.

10 From the **Nonlinear method** list, choose **Automatic (Newton)**.

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

12 In the **Settings** window for **Study**, type `Study: With AMB` in the **Label** text field.

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

Follow the similar instructions again to combine the stress results from solid rotor and beam rotor for the second study. This plot is shown in Figure 4.

RESULTS

Line 1

1 In the **Model Builder** window, expand the **Results>Stress (rotbm) 1** node.

2 Right-click **Line 1** and choose **Copy**.

Stress (solid) 1

In the **Model Builder** window, under **Results** right-click **Stress (solid) 1** and choose **Paste Line**.

Line 1

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

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

3 Select the **Radius scale factor** check box. In the associated text field, type `1`.

4 Click **Change Color Table**.

5 In the **Color Table** dialog box, select **Aurora>AuroraAustralisDark** in the tree.

6 Click **OK**.

Deformation

1 In the **Model Builder** window, expand the **Line 1** node, then click **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 `10`.

Volume 1

1 In the **Model Builder** window, under **Results>Stress (solid) 1** click **Volume 1**.

2 In the **Settings** window for **Volume**, click to expand the **Quality** section.

3 From the **Smoothing threshold** list, choose **None**.

Deformation

1 In the **Model Builder** window, expand the **Volume 1** node, then click **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 `150`.

Stress (solid) 1

1 In the **Model Builder** window, under **Results** click **Stress (solid) 1**.

2 In the **Settings** window for **3D Plot Group**, locate the **Color Legend** section.

3 From the **Position** list, choose **Right double**.

4 Locate the **Data** section. From the **Time (s)** list, choose **1**.

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

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

7 In the **Stress (solid) 1** toolbar, click **Plot**.

Now you will compare the vibrations response with active magnetic bearing at the coupling location with the one without it. Start by duplicating the **Point Graph 1** in the **Vertical Displacement at Coupling** node and changing the solution and legend. The resulting plot is shown in Figure 5.

Point Graph 1

1 In the **Model Builder** window, expand the **Results>Vertical Displacement at Coupling** node.

2 Right-click **Point Graph 1** and choose **Duplicate**.

Point Graph 2

1 In the **Model Builder** window, click **Point Graph 2**.

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

3 From the **Dataset** list, choose **Study: With AMB/Solution 2 (sol2)**.

4 Locate the **Legends** section. In the table, enter the following settings:

Legends
`With AMB`

5 In the **Vertical Displacement at Coupling** toolbar, click **Plot**.

Duplicate the current plot and change the selection to compare the rotor displacement at the active magnetic bearing as shown in Figure 6.

Vertical Displacement at Coupling

In the **Model Builder** window, right-click **Vertical Displacement at Coupling** and choose **Duplicate**.

Vertical Displacement at AMB

1 In the **Model Builder** window, expand the **Results>Vertical Displacement at Coupling 1** node, then click **Vertical Displacement at Coupling 1**.

2 In the **Settings** window for **1D Plot Group**, type `Vertical Displacement at AMB` in the **Label** text field.

Point Graph 1

1 In the **Model Builder** window, click **Point Graph 1**.

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

3 Click to select the **Activate Selection** toggle button.

4 Click **Clear Selection**.

5 Select Point 783 only.

Point Graph 2

1 In the **Model Builder** window, click **Point Graph 2**.

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

3 Click **Clear Selection**.

4 Select Point 783 only.

5 In the **Vertical Displacement at AMB** toolbar, click **Plot**.

Follow the instructions below to plot the control current variation in the bearing as shown in Figure 7.

Control Currents

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: With AMB/Solution 2 (sol2)**.

4 In the **Label** text field, type `Control Currents`.

5 Locate the **Title** section. From the **Title type** list, choose **Label**.

6 Locate the **Plot Settings** section.

7 Select the **y-axis label** check box. In the associated text field, type `Control current (A)`.

Point Graph 1

1 Right-click **Control Currents** and choose **Point Graph**.

2 Select Point 783 only.

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

4 In the **Expression** text field, type `rotbm.amb1.ic1`.

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

6 From the **Legends** list, choose **Manual**.

7 In the table, enter the following settings:

Legends
`Local y direction`

8 Right-click **Point Graph 1** and choose **Duplicate**.

Point Graph 2

1 In the **Model Builder** window, click **Point Graph 2**.
2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
3 In the **Expression** text field, type `rotbm.amb1.ic2`.
4 Locate the **Legends** section. In the table, enter the following settings:

Legends
`Local z direction`

5 In the **Control Currents** toolbar, click **Plot**.

Duplicate the **Control Currents** plot and follow the instructions below to plot the forces in the electromagnetic bearing as shown in Figure 8.

Control Currents

In the **Model Builder** window, right-click **Control Currents** and choose **Duplicate**.

Magnetic Bearing Force

1 In the **Model Builder** window, expand the **Results>Control Currents 1** node, then click **Control Currents 1**.
2 In the **Settings** window for **1D Plot Group**, type `Magnetic Bearing Force` in the **Label** text field.
3 Locate the **Plot Settings** section. In the **y-axis label** text field, type `Magnetic bearing force (N)`.
4 Locate the **Legend** section. From the **Position** list, choose **Upper left**.

Point Graph 1

1 In the **Model Builder** window, click **Point Graph 1**.
2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
3 In the **Expression** text field, type `rotbm.amb1.F2`.

Point Graph 2

1 In the **Model Builder** window, click **Point Graph 2**.
2 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
3 In the **Expression** text field, type `rotbm.amb1.F3`.
4 In the **Magnetic Bearing Force** toolbar, click **Plot**.

Finally, create an animation of the stress variation in the system for the second study using the following instructions.

Animation 1

1 In the **Results** toolbar, click **Animation** and choose **Player**.

2 In the **Settings** window for **Animation**, locate the **Scene** section.

3 From the **Subject** list, choose **Stress (solid) 1**.

4 Locate the **Animation Editing** section. From the **Time selection** list, choose **Manual**.

5 In the **Time indices (1-1201)** text field, type `range(1100,1,1201)`.

6 Locate the **Frames** section. In the **Number of frames** text field, type `50`.

7 Click the **Play** button in the **Graphics** toolbar.

Disable the **Active Magnetic Bearing** in the first study to make sure that results in this study are not influenced by it even after rerunning the study.

STUDY: WITHOUT AMB

Step 1: Time Dependent

1 In the **Model Builder** window, expand the **Study: Without AMB** node, then click **Step 1: Time Dependent**.

2 In the **Settings** window for **Time Dependent**, locate the **Physics and Variables Selection** section.

3 Select the **Modify model configuration for study step** check box.

4 In the tree, select **Component 1 (comp1)>Beam Rotor (rotbm)>Active Magnetic Bearing 1**.

5 Right-click and choose **Disable**.