Rotor Dynamics Analysis of An Electric Machine

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Abstract

ANSYS has no module to analyze dynamics of electric machine rotor, especially to calculate critical speeds. But it has element types, such as beam element and matrix27 element, which can be modeled as stiffness, damping and mass matrix. In this paper, Beam4 element and matrix27 element are adopted to model the shaft and bearings, respectively. Some ideas are presented to deal with critical speeds calculation using ANSYS. To verify the validity of the method, an example is given to show the procedure of critical speeds calculation. Also, the analysis results obtained from ANSYS reach a good agreement with those calculated by DyRoBeS software and testing results.

Introduction

ANSYS software is a powerful tool widely used in research and development of electric machines. It has element types, such as beam element and matrix27 element, which can be modeled as stiffness, damping and mass matrix. However, ANSYS has no module to analyze dynamics of an electric machine rotor, especially to calculate critical speeds. Therefore, some efforts have to be made. This paper shows how elements BEAM4 and MATRIX27 are used to model the shaft and bearings, respectively. Included are specifications for the elements, descriptions and an example of the critical speed calculations, and the conclusion resulting from the calculations. Supporting figures are also included

1. Element Selections

In critical speed calculations, beam4 and matrix27 elements are adopted.

1.1 Beam4

BEAM4 is a uniaxial element with tension, compression, torsion, and bending capabilities. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Since critical speeds are in the horizontal and vertical directions, degree of freedom in the axial direction is always ignored.

Its Real Constants include: AREA, IZZ, IYY, TKZ, TKY, IXX, SPIN, ADDMAS. According to different Real Constants options, the beam4 element may model beams with different section shapes. As section shape of shaft is always circular, IZZ is equal to IYY, also TKZ is equal to TKY. SPIN is an important item in the critical speed calculations, which defines the rotational speed of the shaft. ADDMAS defines added masses along the shaft, such as fans and rotor core.

1.2 Matrix27

MATRIX27 represents an arbitrary element whose geometry is undefined but whose elastic kinematic response can be specified by coefficients. The matrix is assumed to relate two nodes, each with six degrees of freedom per node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. There are three options to use the MATRIX27 to define coefficients, which is very useful to model linear bearing characteristics, i.e. eight stiffness and damping coefficients.

2. Two Methods of Critical Speed Calculations

Two methods are always used to calculate critical speed: critical map and synchronous response.

2.1 Critical Map Method

Often, rotor critical speeds correspond to natural frequencies of the system. Electric machine rotor is supported by two sleeve or ball/roller bearings. Typically, stiffness and damping coefficients of the sleeve bearing are varied with rotating speed, and in this case, natural frequencies of the electric machine system are varied. When a natural frequency equals to the rotating speed, the rotating speed is called critical speed. The Modal Analysis module of ANSYS can be applied to calculate all natural frequencies of the electric machine system with different rotating speeds, and then a Campbell diagram is obtained as figure 1 shows. It is easy to locate the critical speeds of the system. Noted that critical speeds refer to synchronous forward precession.

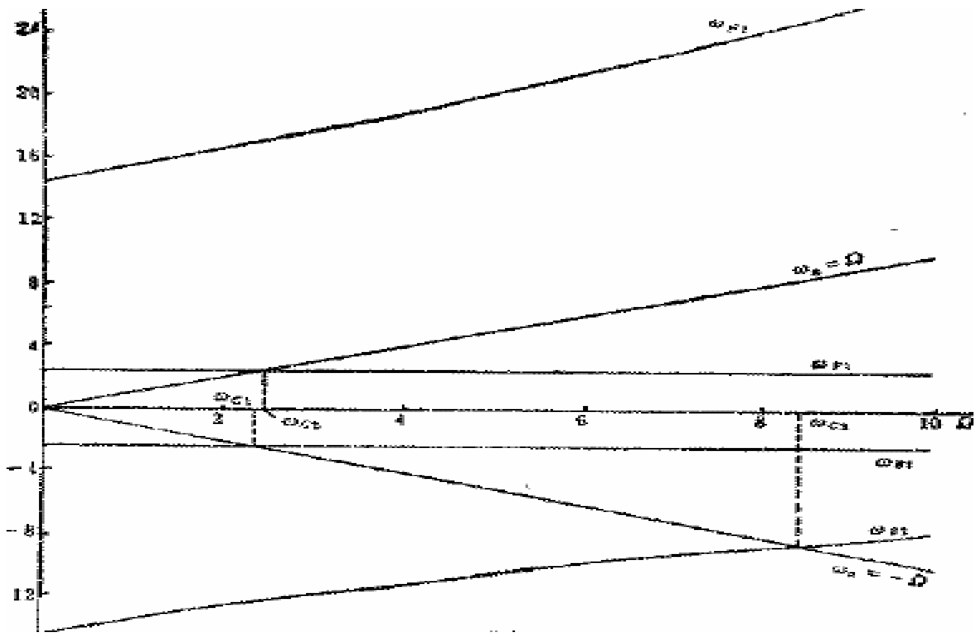

Figure 1. Campbell Diagram [2]

2.2 Synchronous Response Method

In general, any rotating critical speed is associated with high vibration amplitude. When the rotating speed is close to or away from a critical speed, vibration amplitude increases or decreases abruptly and phase becomes unsteady as figure 2 shows.

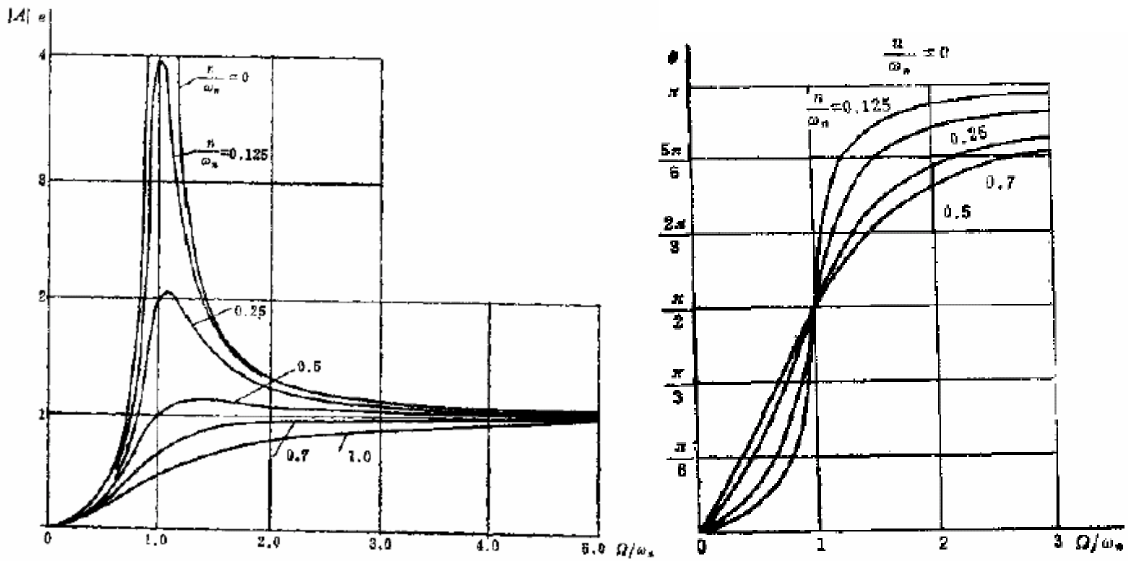

Figure 2. Synchronous Response Diagram [2]

For electric machine system, rotor unbalance mass is a kind of synchronous excitation, and induces vibration. The Harmonic Response Analysis module of ANSYS is applied to calculate unbalance synchronous response of the electric machine system, and a Bode plot can be obtained. From the Bode plot, rotating speeds with peak vibration are defined as critical speeds.

3. An Example of Critical Speed Calculations

In the following, rotor critical speeds of an electric machine are calculated as an example showing the procedure using ANSYS. Only the synchronous response method is adopted. Figure 3 shows the FEA model of the electric machine rotor.

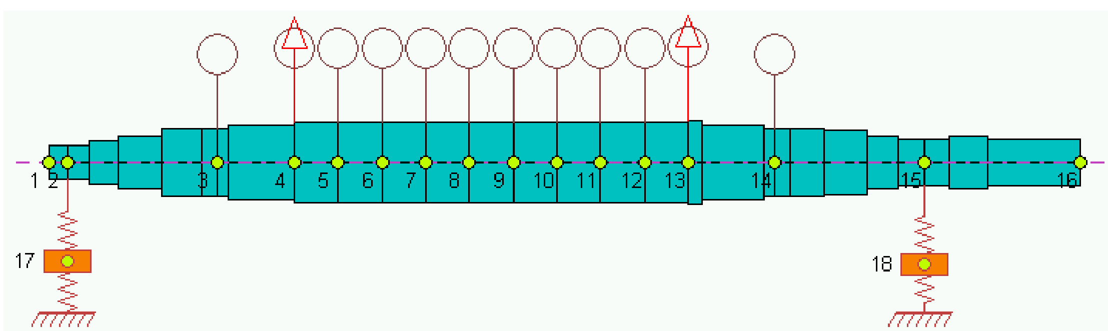

Figure 3. FEA Model

3.1 Define FEA model

All the shaft segments and bearings are modeled as line by connecting keypoints defined on the working plane. APDL can be employed to finish this work.

3.2 Define elements and real constants

Three elements with specified options are defined as the following.

```
ET, 1, BEAM4
KEYOPT, 1, 6, 1
KEYOPT, 1, 7, 1
ET, 2, MATRIX27, , ,4
KEYOPT, 2, 2, 1
ET, 3, MATRIX27, , ,5
KEYOPT, 3, 2, 1
```

For BEAM4 with keyopt(7) equal to 1, real constant SPIN must be greater than zero, and IYY must equal IZZ. ADDMAS defines added masses on the shaft, such as fans and rotor core.

For MATRIX27 with keyopt(2) equal to 1, matrices are un-symmetric. Stiffness and damping coefficients of sleeve bearings with different rotating speeds are stored in a formatted file, which are ready to fill the matrices during calculations.

3.3 Meshing and Solving

After meshing the above FEA model by specifying element type, real constants, material property and element size, loads and constraints can be applied using the following APDL.

```
D,…,…
F, … ,FY, …
HARFRQ, 0, w
NSUBST, 1
```

Where D command is used to apply boundary conditions to nodes of the model, F command defines the unbalance mass, HARFRQ command defines the solver for a harmonic response analysis, w is the rotor rotating speed. Noted that NSUBST must be equal to 1.

Then, Harmonic Response Analysis is carried out to calculate the unbalance response at a rotating speed. All the unbalance response at a rotating speed region can be obtained using a loop block

3.4 Postprocessor

Amplitude and phase of the unbalance response can be got from ANSYS result file using APDL, and a Bode diagram is plotted as figure 4 using Octave (a GNU free software).

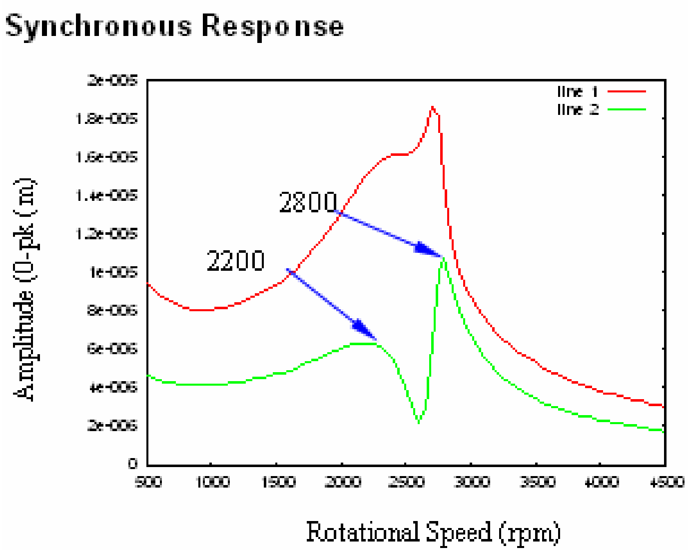

Figure 4. Unbalance Synchronous Response

4. Conclusion

The critical speeds of the electric machine are also calculated using DyRoBeS software, which is a professional tool of rotor-dynamic analysis. Figure 5 shows the Bode plot. Figure 6 shows the test result.

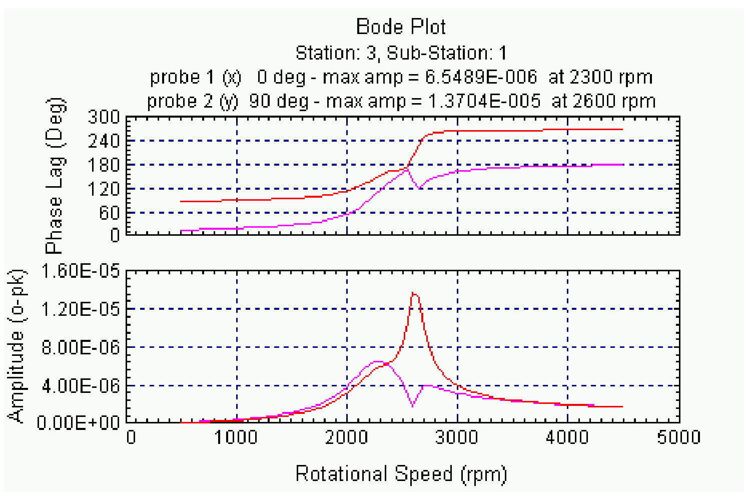

Figure 5. Bode Plot

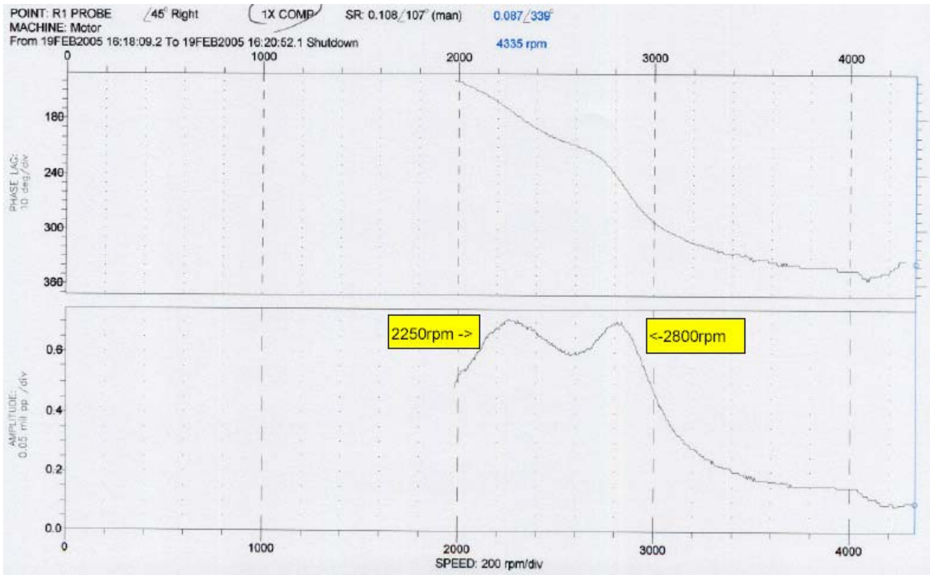

Figure 6. Test Results

Table 1 Result Comparisons

Tool	Critical Speeds (rpm)		Difference between Calculation and Testing (%)	
	Horizontal	Vertical	Horizontal	Vertical
ANSYS	2200	2800	-2.2	0
DyRoBeS	2300	2600	2.2	-7.1
Testing	2250	2800		

From the above table, it is found the results calculated by ANSYS are even more accurate than those by DyRoBeS.

Therefore, by defining proper element types and options, ANSYS is also a powerful tool of rotor-dynamic analysis.

Acknowledgement

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References

1.ANSYS Help Document

2. Yie Zhong, Zheng Wang, etc. 1987. *Rotor Dynamics*, Tsinghua University Press: Beijing (Chinese).