Application of a Finite Element Package for Modeling Rotating Machinery Vibrations

Farouk O. Hamdoon*

Received on: 26/11/2008
Accepted on : 2 /4 /2009

Abstract

ANSYS has no module to analyze dynamics of rotor-bearing systems, 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, rotating disks and bearings. Some ideas are presented to deal with critical speeds calculation using ANSYS. The accuracy of the model and the solution technique have been demonstrated by comparison with results of previous publications. Very good agreement has been obtained.

Keywords: Finite element model , Rotor- bearing system , Critical speeds.

الخلاصة

لا يمتلك برنامج (ANSYS) وحده برمجيه نسقيه لتحليل الاهتزاز لنظـام عمـود دوار – كرسي تحميل وخاصة لحساب السرع الحرجة . تم في هذا البحث اسـتخدام عنـصر (BEAM4) وعنصر (MATRIX27) الموجودين في برنامج (ANSYS) في تمثيل العمود الدوار والأقـراص الدوارة وكراسي التحميل لغرض بناء أنموذج رياضي لتحليل الاهتزاز لأنظمة عمود دوار – كرسي تحميل , كما و تم تقديم بعض الأفكار لحساب السرع الحرجة لهذه الانظمه باستخدام برنـامج (ANSYS).وللتأكد من دقة الأنموذج الرياضي وصحة طريقة الحل فقد تم عمل مقارنه مـع نتـائج البحوث المنشورة مسبقا. ولقد أظهرت نتائج المقارنة تطابقا جيدا جدا.

* Mechanical Engineering Department, College of Engineering, Wassit University /Wassit

https://doi.org/10.30684/etj.27.12.3
2412-0758/University of Technology-Iraq, Baghdad, Iraq

1.Introduction

ANSYS is a common tool for finite element analyses and it is widely used in research and development of rotating machinery. It has rotating beam elements such as BEAM4 element and PIPE16 element which can be used to model the shaft. For a rotating beam element, the gyroscopic effect can be taken into consideration. Also, the effects of rotary inertia , shear deformation , axial load and internal damping can be included. However, this package like most others doesn't set specific elements for modeling rotating disks and bearings .Also, it has no module to analyze dynamics of rotating machinery, especially to calculate critical speeds. Therefore, some efforts have to be made.

This paper shows how MATRIX27 element is used to model rotating disks and bearings. The geometry of this arbitrary element is undefined ,but its mechanism can be specified by stiffness , damping or mass matrix. Specifications for the elements, descriptions and examples of the critical speed calculations of rotor-bearing system are also included in this paper.

2. Element Selections

In critical speed calculations of rotor-bearing systems,BEAM4 and MATRIX27 elements are adopted.

2.1 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 nodal x,y and z axes.

Its Real Constants include: AREA ,IZZ , IYY ,TKY , IXX ,SPIN , ADDMAS. According to different Real Constant options, the BEAM4 element may model beams with different section shapes. As section shape of shaft is 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.

2.2 Matrix27

MATRIX27 represents an arbitrary element whose geometry is undefined but whose mechanism can be specified by stiffness ,damping , or mass matrix 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 cross coupling bearing characteristics and gyroscopic damping matrix for rotating disks.

3.Methods Of Critical Speed Calculations

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

3.1 Critical Map Method

The natural frequencies of a rotor-bearing system are commonly called the whirl speeds. These whirl speeds generally change magnitude as the shaft rotating speed changes because of the gyroscopic effects of the rotating shaft and disks. Whenever the rotating speed coincides with one of the natural frequencies of whirl, a resonant condition is introduced, and the rotating speed is called critical speed.

The Modal Analysis module of ANSYS is applied to calculate all natural frequencies of the rotor-bearing 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. When the BW frequency (backward precession) or the FW frequency (forward precession) equal the spin speed Ω, indicated by the intersections A and B with the synchronous spin speed line, the response of the rotor may show a peak. This represents a critical speed.

3.2 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. For rotating machinery, 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 rotor-bearing system, and a Bode plot can be obtained .From the Bode plot, rotating speeds with peak vibration are defined as critical speeds.

4. Numerical Examples

In order to illustrate the application and the accuracy of finite element model, a typical rotor –bearing system which was first used by Nelson et al [5] is analyzed to determine its whirl speeds and unbalance response. A density of $7806\,kg/m^3$ and elastic modulus $2.078*10^{11}\,N/m^2$ were used for the distributed rotor and a concentrated disk with a mass of 1.401 kg , polar inertia $0.002 kg.m^2$ and diametral inertia $0.00136 kg.m^2$ was located at station five. The distributed rotor was modeled as eighteen elements shown in figure(3).The data of these elements is listed in Table(1). Two identical bearings, idealized as undamped and linear ,were located at stations eleven and fifteen. The following two cases of bearing stiffness were analyzed:

4.1case(A) Isotropic Bearings

The shaft is supported by identical bearings with the following data:

$$k_{yy} = k_{zz} = 4.378 * 10^7\ N/m$$

$$k_{yz} = k_{zy} = 0$$

An analysis was performed to determine the whirl frequencies, the results are compared to that published by Nelson et al[5] for a rotating speed 70000 rpm in Table(2).Very Good agreement is obtained. This close agreement demonstrates the accuracy of the model for calculating the eignvalues.

4.2case(B) Orthotropic Bearings

The undamped whirl speeds were computed for several rotating speeds for the shaft supported by bearings with the following data:

$$k_{yy} = k_{zz} = 3.503*10^7\ N/m$$

$$k_{yz} = k_{zy} = -8.756*10^6\ N/m$$

The numerical results of the first three whirl speeds are well compared to those published by [5]. Very good agreement is obtained as shown in

figure(4) which represents whirl speeds map for finding critical speeds.
The unbalance response for a disk mass center eccentricity of 0.0635cm at station five was also determined for speed range 0-30000 rpm and is plotted in Fig.(5). The first critical speed is found around 235 Hz ,while the second is approximately 275 Hz which are identical to those obtained from the whirl speeds map. This can also be another verification for the validity of the model and the technique presented in this paper to calculate critical speeds using ANSYS.

5.Conclusions

A finite element model of multi bearing rotor system using ANSYS is presented. The effects of rotary inertia ,gyroscopic moments, internal viscous and hysteretic damping, and shear deformation can be included. The characteristic of the fluid film bearing can be represented by eight stiffness and damping coefficients. Some ideas are presented to determine forward and backward whirl speeds, critical speeds and unbalance response of rotor-bearing systems. The accuracy of the model and the technique have been demonstrated by comparison with the results of previous publications. The results obtained from comparison showed that by defining proper elements types and options, ANSYS is also a powerful tool of rotating machinery vibration analysis.

References

[1]ANSYS 10.0 help document.
[2]Maurice,L.A,ROTATING MACHINERY VIBRATION, Marcel Dekker,2001.
[3]Rao, J. S., ROTOR DYNAMICS, New Age International (p) LTD,1996.
[4]Erik S. et al "A Practical Review of Rotating Machinery Critical Speeds and Modes" Journal of Sound and Vibration, May 2005.
www.sandv.com
[5]Nelson, H.D. et al "The Dynamics of Rotor Bearing System Using Finite Elements" " ASME Journal of Engineering
For Industry Vol.98,No.2,PP.593-600,1976.

Table (1) Geometric Data of Rotor-Bearing Elements

Element Node No.	Node Location (cm)	Bearing & disk	Inner Diameter (cm)	Outer Diameter (cm)
1	0.0		0.0	0.51
2	1.27		0.0	1.02
3	5.08		0.0	0.76
4	7.62		0.0	2.03
5	8.89	Disk	0.0	2.03
6	10.16		0.0	3.30
7	10.67		1.52	3.30
8	11.43		1.78	2.54
9	12.70		0.0	2.54
10	13.46		0.0	1.27
11	16.51	Bearing	0.0	1.27
12	19.05		0.0	1.52
13	22.86		0.0	1.52
14	26.67		0.0	1.27
15	28.70	Bearing	0.0	1.27
16	30.48		0.0	3.81
17	31.50		0.0	2.03
18	34.54		1.52	2.03

Table (2) Whirl Speeds (rpm) for Case (A) at Rotating Speed of 70000 rpm.

Mode No.	Ref.[5]	Present Work	Ratio
1BW	12815	12904.343	1.006
1FW	19838	19705.265	0.993
2BW	45599	45666.437	1.001
2FW	50555	50620.981	1.001
3BW	63990	64623.893	1.009
3FW	91320	91421.884	1.001

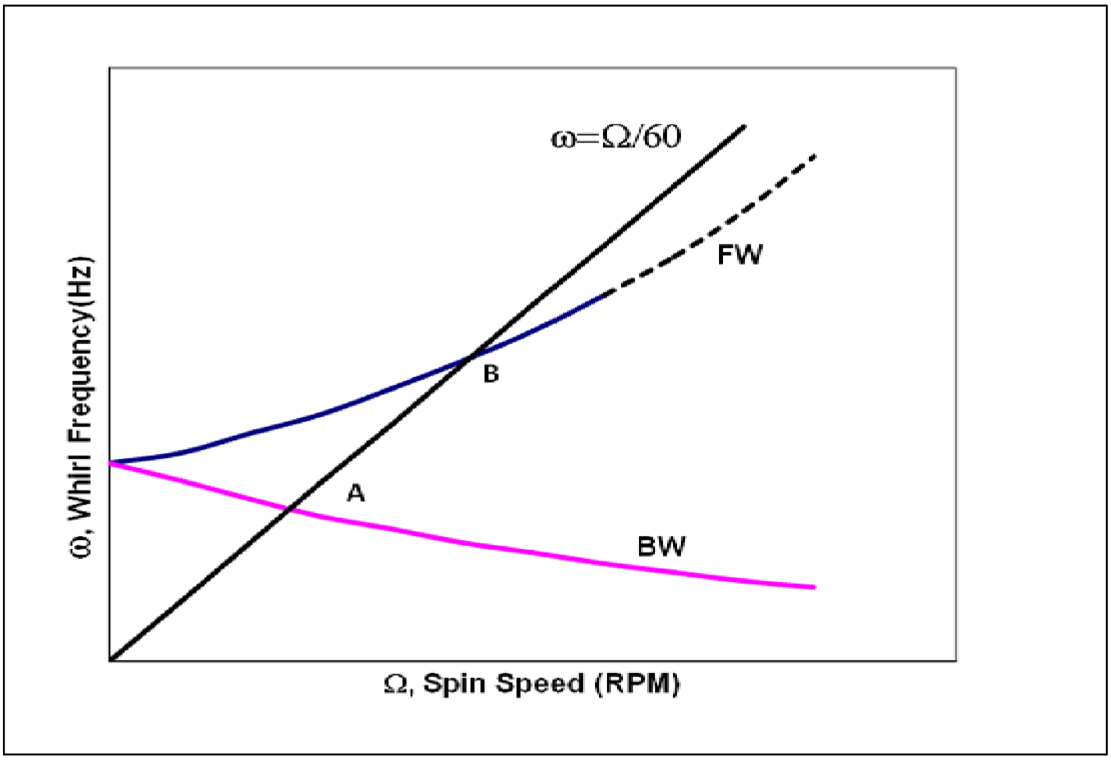

Fig.(1) Campbell Diagram

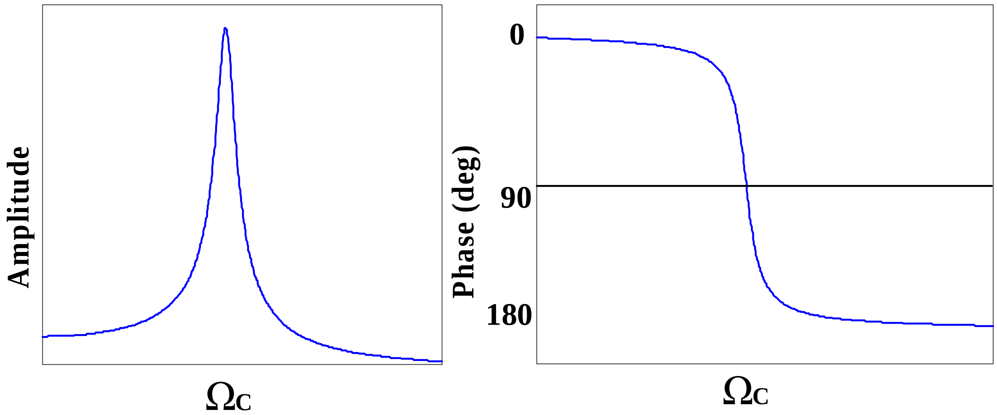

Fig.(2) Synchronous Response Diagram.

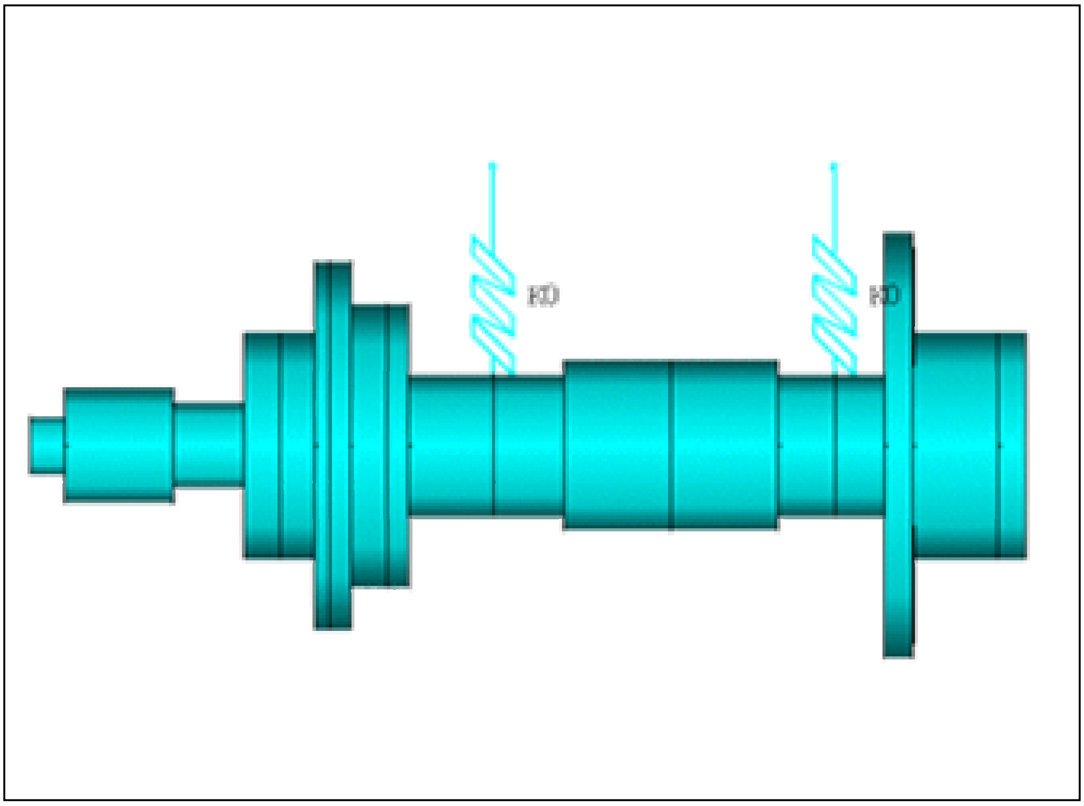

Fig.(3) Rotor- Bearing Configuration.

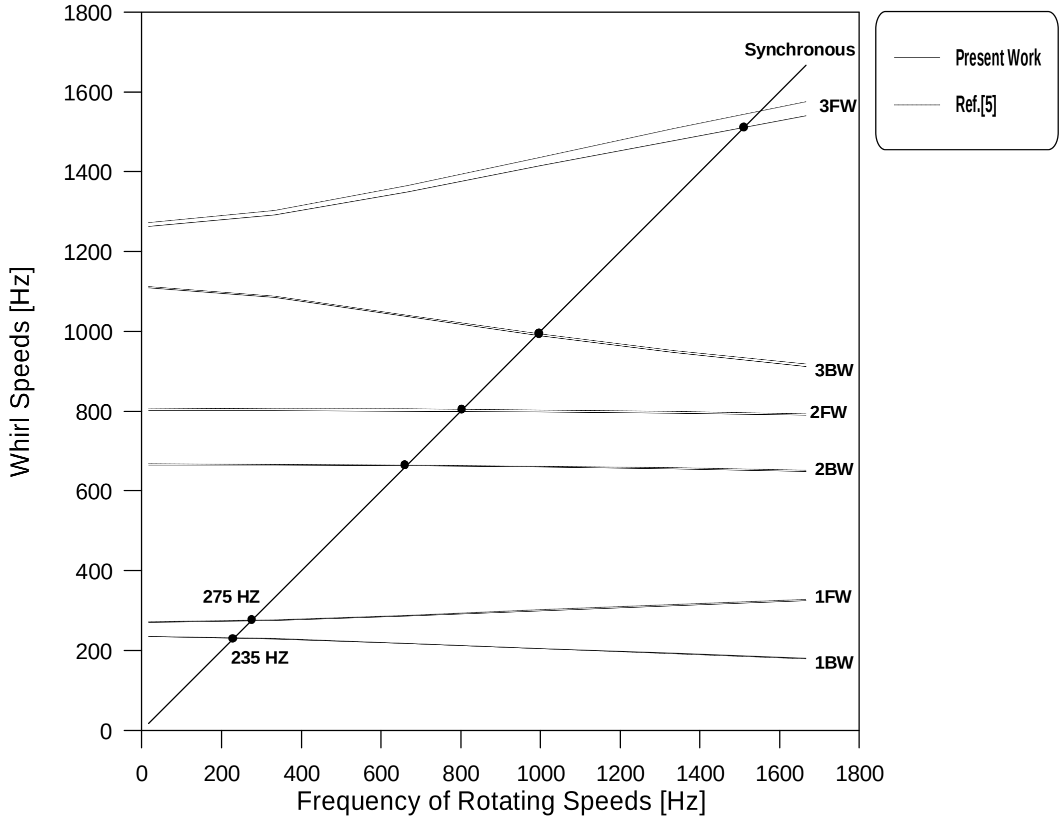

Fig.(4) System Whirl Speeds Map.

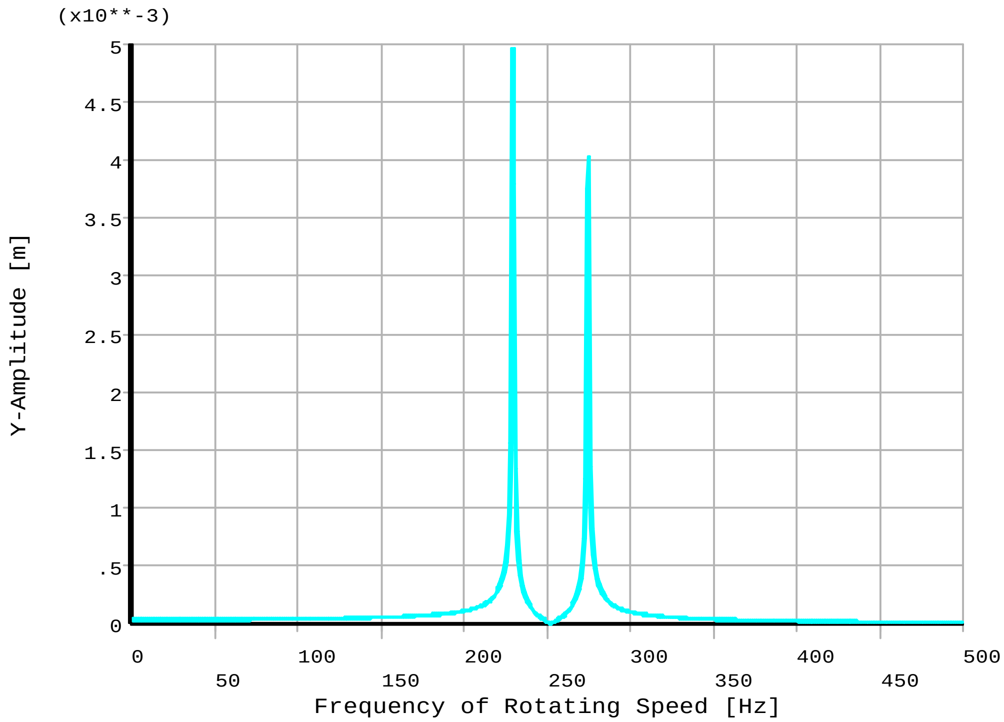

Fig.(5) System Unbalance Response at Station Five .