 ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

Modal and Transient Analysis of a Single Disc Rotor System

[1]V. Jangde, [2]M. Chouksey, [3]J. Patil, [4]V. Jain
[1,2,3,4]Research Scholar, SGSITS, Indore, Madhya Pradesh, India

Abstract
Applications of rotating machinery ranges from house hold appliances to turbines, aeroplanes etc. In rotor systems, it is important to predict the characteristics of the systems like critical speed, natural frequency and stability. These characteristics can easily be found out by using finite element method e.g. by using ANSYS software. Modal analysis and transient analysis has been carried out on a single disc rotor system using finite element method. Such results can be helpful in dynamic design of the rotor systems.

Keywords
Campbell Diagram , Stability Analysis , Mode Shape , Stability Plot, Mode Orbit Plot

I. Introduction

Modal analysis of structures gives information about their dynamic characteristics i.e. natural frequencies, modal damping factors and mode shapes ([4]; [9], [11], [12]). Simple models can be used for this purpose. However, it may be difficult sometimes to model complex structural systems using simple models. The alternatives to this may be in the form of use of finite element models. Finite element method is widely used for this purpose ([1]; [13]). Readily available software packages e.g. ANSYS can be used reliably for this purpose ([2]). ANSYS Multiphysics software has inbuilt capabilities for dynamic analysis. Applications of rotating machinery ranges from house hold appliances to turbines, aeroplanes etc. The modelling of rotating machines is not as simple and direct and that of non- spinning structures. This is due to the presence of many spin-speed dependent forces associated with rotor system, e.g. tangential forces, circulatory forces, gyroscopic forces etc.

A. Campbell Diagram and Stability Analysis

Critical speed and stability limit speed are two important parameters for rotor systems. Critical speed of rotor systems can be found out with the help of Campbell diagrams ([5]; [10]). In Campbell diagrams, the variation of natural frequencies is plotted against spin speed of rotation. The intersection of excitation order lines with these natural frequency lines gives the locations of critical speeds. Unbalance is the primary source of excitation in rotor systems. The excitation order line for unbalance bears a ratio one to the spin speed frequency. Stability of rotor systems can be judged by studying the modal damping factors or real part of eigenvalues or logarithmic decrement. The estimation of critical speed or stability limit speed of rotors calls for their modal analysis. There are many studies which deal with variation of natural frequencies or modal damping factors for rotor systems using simple models ([10]; [8]). Finite element methods are widely used for structural analysis including rotor systems. This gives not only natural frequencies or modal damping factors but spatial modal pattern also. This work reports modal analysis studies for a single disc rotor system to predict its critical speed and stability limit speed. The single disc rotor system is considered to be supported on rolling element bearings and the effect of shaft material damping is included in the model.

B. Transient Analysis

Transient analysis is an analysis where dynamic response of the system is investigated under transient time- varying load. The time frame for this type of analysis is such that inertia or damping effects of the rotor system are considered to be important. Loading conditions considered is step or impulse loading, for example, where there is a sharp load change in a fraction of time. If inertia effects are negligible for the loading conditions being considered, a static analysis may be used instead. Transient analysis of rotating structures is also very important as it reveals the response of the structures to any transient excitations. There may be many agents present in rotor systems which may make the rotor system unstable, e.g. journal bearings, shaft material damping, nonaxisymmetric rotor etc. This work investigates the transient analysis of the single disc rotor system under the i nfluence of shaft material damping. Shaft material damping has been modelled using internal viscous damping. Stiffness matrix multiplier β is used to form the viscous damping matrix [C] = β [K], where [K] is the stiffness matrix. Values of β may also be input as a material property (use the BETD label on the MP command). The transient analysis of the rotor system has been carried out below and above the stability limit speed of the rotor system.

II. Theory

The finite element method has been used in the present work as is available in ANSYS software. The effects of shear deformation, rotary inertia and tangential forces are considered in the model. Rolling element bearings are considered to provide both stiffness and damping to the system. Nonproportional damping model has been used to model damping. The references ([6], [8]) may be referred to study the mathematical equations or the theory of modal analysis.

III. Numerical Example

Here a single disk rotor is considered for the transient analysis after following [12]. Model as shown in Figure 1 is used for transient analysis in ANSYS. The coefficient of shaft material damping is considered as 0.0002 s. And bearing stiffness and damping coefficient are taken as K_{yy}=K_{zz}=1.75e7 N/m and C_{yy}=C_{zz}=0 Nsec/m respectively at both the ends.

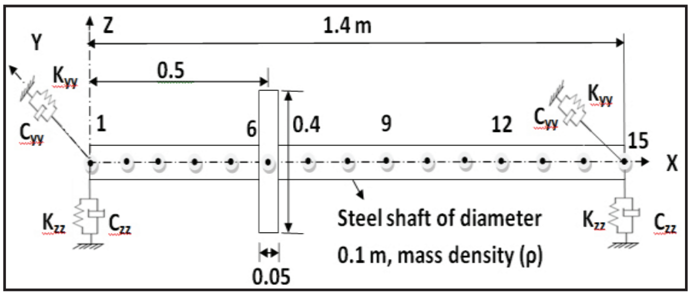


Fig. 1: Single Disc Rotor System

A. Modeling of Single Rotor System

Firstly above rotor system is modelled in ANSYS. While modelling of this single disc rotor system beam188 element for the shaft, mass21 element for the disc and combin14 element for the bearing properties have been considered.

IV. Results and conclusion

A. Campbell Diagram

For the Campbell diagram and stability plot, modal analysis of the rotor system has been carried out by considering internal viscous damping for shaft material. Campbell diagram is the plot between rotational speed and natural frequency. It is shown in fig. 2.

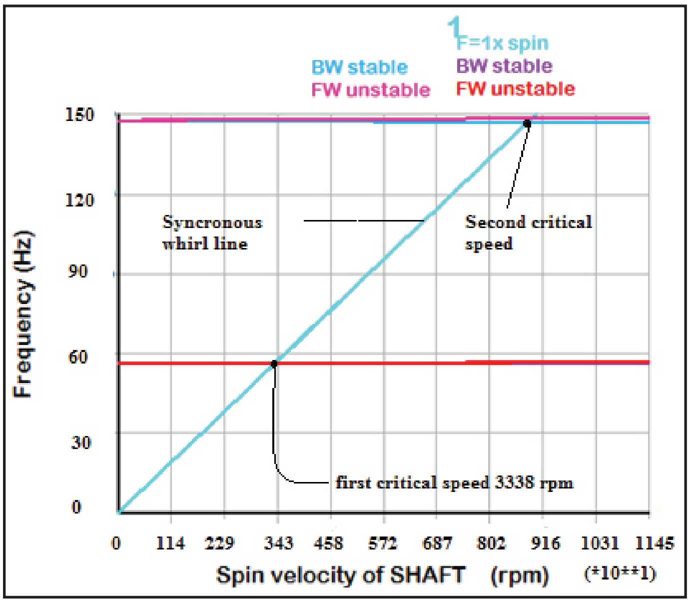


Fig. 2: Campbell Diagram

B. Stability Plot

Stability diagram is the plot between modal damping factor or logarithmic decrement or real part of eigenvalues against rotational speed. It shows the variation of these quantities with the rotational speed in backward and forward modes. When modal damping factor changes its sign for any mode then rotor gets unstable in that mode. By the study of the stability diagram it can be seen that rotor gets unstable due to material damping at a particular speed and this speed is called stability limit speed. The value of stability limit speed decreases as the material damping goes on increasing. Stability diagram for the rotor system is shown in fig. 3 In the plot the real part of eigenvalues in various modes in Hz, called as stability values, are plotted. It shows the Stability Limit Speed (SLS) for the rotor system is 3338 rpm.

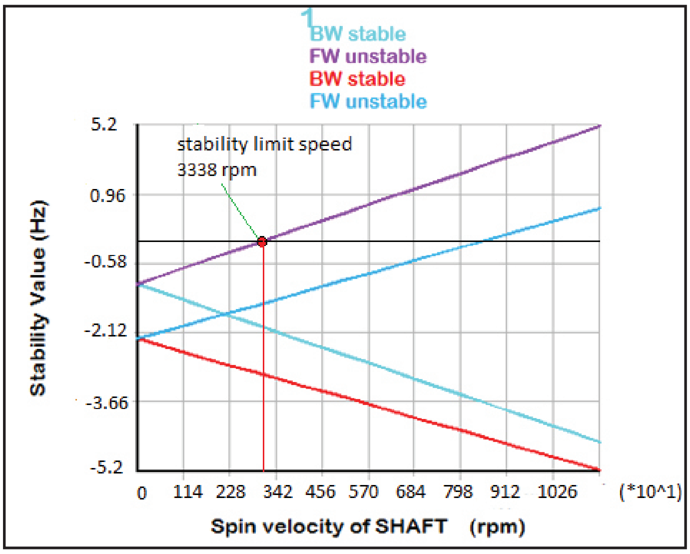
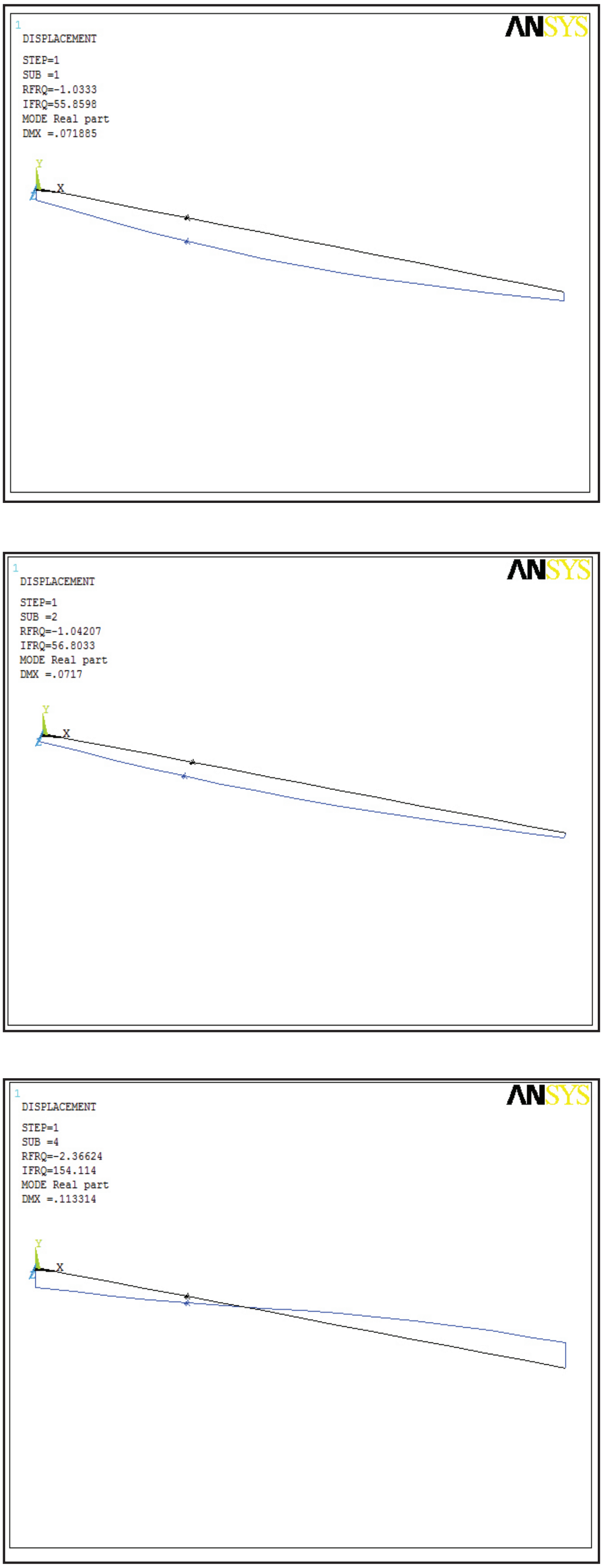


Fig. 3: Stability Diagram

C. Mode Shapes

Mode shapes of any structure show the displacement pattern for the system at any mode. Such information may be helpful in the design of a system. Initial four mode shapes of the rotor system are shown in the fig. 4.



 ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

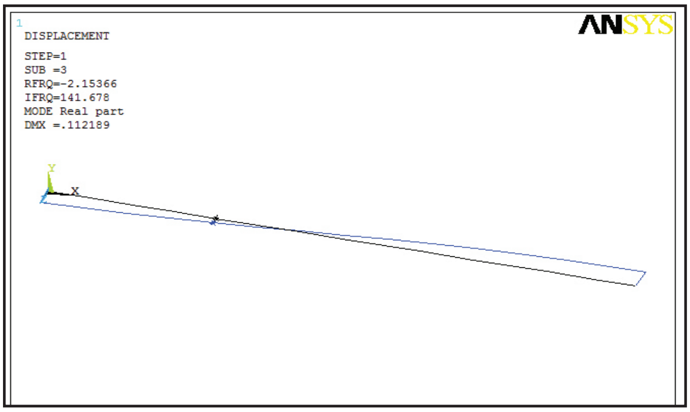


Fig. 4: Mode Shapes in xy, xz Plane for Two Modes (a) First Mode; (b) Second Mode; (c) Third Mode; (d) Fourth Mode

D. Mode Orbit Plot

Mode orbit plots are used to study the rotor response under a natural frequency. Mode orbit plot shows whirl of the mode. This is plotted against the natural frequency 147 Hz. It is shown below in fig. 5.

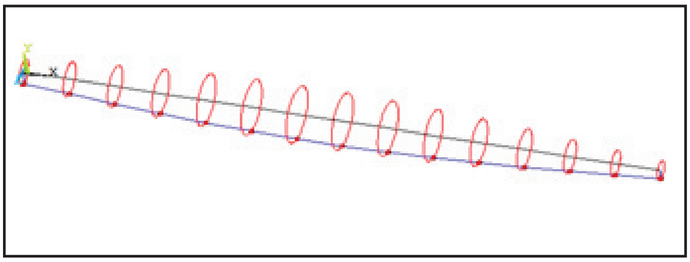


Fig. 5: Mode Orbit Plot

E. Transient Response

Transient analysis of the rotor system has been predicted on node 4 by applying transient force on node 4 by considering the speed of 2000 rpm which is below the stability limit speed. If this rotor rotates below SLS then response of the system is decreasing and if this rotor rotates above SLS then response of the system is increasing. It has been shown that the transient response decays out with time if the operating speed is below the stability limit speed which for the case considered is 3338 rpm. Figure 6 shows the transient response of the rotor system at node 4, when transient excitation is applied at node 4.

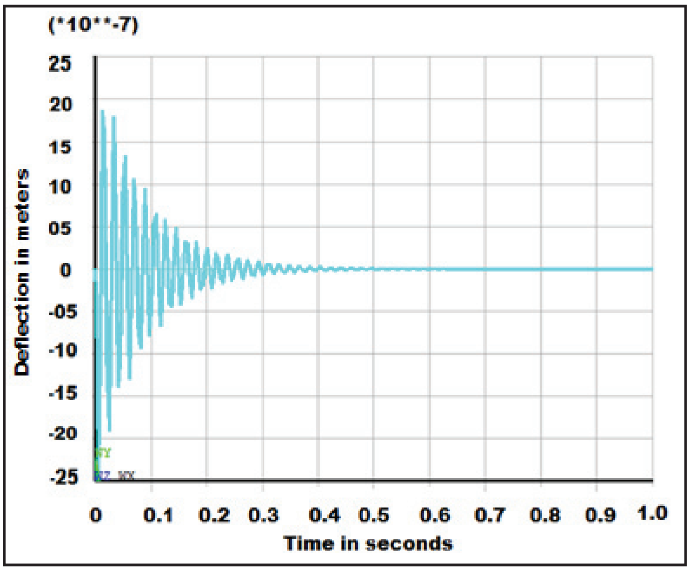


Fig. 6: Response Before Stability Limit Speed

Considering the speed of 4000 rpm which is above the stability limit speed. On this speed, response of the rotor increases exponentially. Fig. 7 shows the transient response of the rotor system at node 7, when excitation is there at node 7.

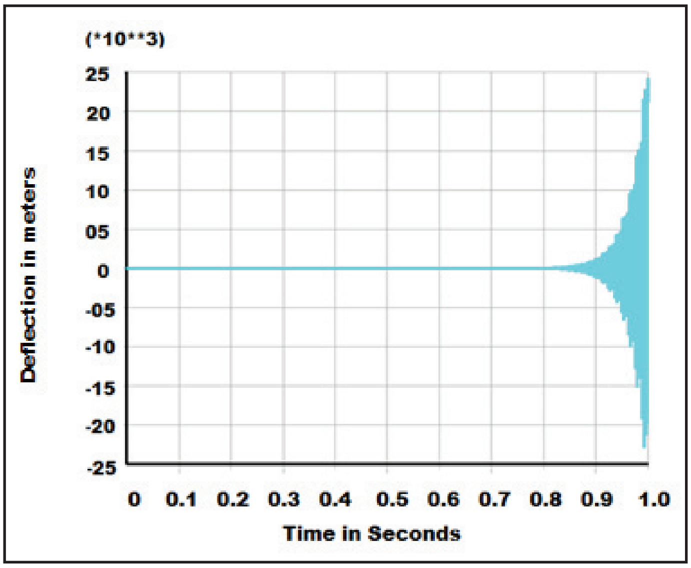


Fig. 7: Response After Stability Limit Speed

V. Conclusion

In this chapter a single disc rotor system is modelled considering the rotor dynamic properties such as stiffness, external damping coefficient, material damping etc. Modal analysis has been carried out and Campbell diagram and stability diagram are plotted. Stability plot gives the value of stability limit speed which is the limit of the speed for stable operation of the rotor system. Response of the rotor system is seen under and beyond the stability limit speed. It has been shown that the transient response decays out with time if the operating speed is below the stability limit speed. On the other hand it has been shown that the transient response increases exponentially if the operating speed is above the stability limit speed.

References

[1] K. J. Bathe,"Finite Element Procedures in Engineering Analysis", Prentice-Hall, 1982.

[2] R. Bedri, M. O. Al-Nais,"Prestressed Modal Analysis Using Finite Element Package ANSYS (2005)".

[3] Z. Li, L. Vulkov, J. Waśniewski,"Numerical Analysis and Its Applications", Springer Berlin Heidelberg. 3401, pp. 171-178.

[4] I. Bucher, D. J. Ewins,"Modal analysis and testing of rotating structures", Phil. Trans. R. Soc. London 359, pp. 61-96, 2001.

[5] W. E. Campbell,"The Protection of Steam Turbine Disk Wheels From Axial Vibration", J. Appl. Mech.-T. ASME 46: pp. 31-160, pp. 1924.

[6] D. J. Ewins,"Basics and state-of-the-art of modal testing", Sadhana 25(3), pp. 207-220, 2000.

[7] D. J. Ewins,"Modal testing: Theory, practice and application, Research Studies Press, Baldock, Hertfordshire, England, 2000.

[8] M. I Friswell, J. E. T. Penny, et al.,"Dynamics of Rotating Machines", Cambridge University Press, 2010.

[9] J. He, Fu, Z.-F.,"Modal Analysis", Butterworth-Heinemann, 2001.

[10] C. W. Lee, Y. H. Seo,"Enhanced Campbell Diagram with the Concept of H infinity in Rotating Machinery: Lee Diagram", Journal of Applied Mechanics 77(2), pp. 1-12, 2010.
[11] C. W. Lee,"A complex modal testing theory for rotating machinery", Mech. Syst. Sig. Process. 5(2), pp. 119-137, 1991.
[12] M. Chouksey, S. V. M., J. K. Dutt,"Influence of rotorshaft material damping on modal and directional frequency response characteristics", PROCEEDINGS OF ISMA 2010. INCLUDING USD 2010.
[13] C. R. M. Rao, G. Muthuveerappan,"Finite element modelling and stress analysis of helical gear teeth", Computers & Structures 49(6), pp. 1095-1106, 1993.