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Vibrations Analysis of a Rotor Supported by Tilting-Pad Journal Bearings with Considering of Geometric Nonlinearity

S.A.A. Hosseini*, A. Tamadon, M. Zamaniani

Department of Mechanical Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran

ABSTRACT: Vibrations of a continuous rotor with uniform circular cross section supported by two tilting-pad journal bearings at both ends are analyzed. Since the shaft is slender, shear deformation is neglected, but, gyroscopic effect is considered (Rayleigh beam theory). In addition, geometric nonlinearity due to large deformation of the rotor is considered. Based on short bearing assumption, an analytical model of a tilting-pad journal bearing with laminar and turbulence flows has been derived. Galerkin method is applied to discretize differential equations of motion. By solving discrete rotor-bearing system equations, the response is obtained. For further investigation, responses of rotor-bearing system in different situations are presented. Comparing the responses of the linear and nonlinear rotor with two tilting-pad journal bearings at both ends shows that the nonlinear rotor has less amplitude than linear rotor and nonlinear rotor is closer to reality. In addition, nonlinear model has a larger natural frequency in comparison to the linear rotor. Using turbulence flow makes the bearing stiffer and have less amplitude than laminar flow. Reducing viscosity of lubricant leads to increase of amplitude of response and shows that higher viscosity make the bearing stiffer.

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1- Introduction

Hydrodynamic lubrication is applied in most rotating machinery. Tilting-Pad Journal Bearing (TPJB) is used as a foundation and source of damping and stiffness in rotors. This type of bearings have usually four or five pads. Each pad can rotate freely around a pivot. As a result the forces that are causing instability greatly reduced or eliminated. This feature considers TPJB as a standard bearing fluid film bearings for high speed machines. Sometimes a continuous model whose mass is distributed along the rotor is used as an analytical model for a practical rotor. Usually slender beam theory and geometric type nonlinearity is used in modelling of the rotor. Analysis of these type of rotors is based on the theory of classic beam theory [1]. Ocvirk [2] provided an analytical method based on Reynolds equation which is known as short-bearing equation. Lund [3] obtained stiffness and damping coefficients of TPJB. Orcutt [4] followed the same basic approach as Lund by developing a partial arc bearing solution. He accounted turbulence effects in the lubricating film using the Ng and Pan [5] analysis. Ishida et al. [6] studied nonlinear vibrations of rotating continuous shaft systems. Hosseini and coworkers [7-9] studied different aspects of vibrations of a spinning beam in several articles.

The analysis of nonlinear flexible shaft with TPJB is the subject of this article. Feature of this study is that the two types of modeling has been used. In the first model, the equations of shaft and bearings were solved simultaneously. In fact, the effects of nonlinearity of the shaft and bearings have been considered. In the second, the linear equivalent stiffness and damping of bearings intended, and the results were compared with previous solutions.

2- Methodology

In order to calculate the hydrodynamic forces of the lubricant fluid Reynolds equations is used. Then the forces exerted on the rotor due to bearings can be calculated.

To model the shaft, a slender spinning beam supported with TPJB is considered. Rayleigh beam theory is used in modelling the rotor. Therefore, shear deformation is neglected but rotary inertia and gyroscopic effect are considered. Nonlinearity due to large deformation of the shaft is considered. This model leads to stretching type nonlinearity. To model the exerted force from bearings, Dirac delta function is used. To solve the equations of motion, the partial differential equations must be discretized with a suitable method. Here, Galerkin method is applied with one-mode term. Then the discretized equations are solved with numerical method.

3- Results and Discussion

In order to verify the results obtained, the equivalent stiffness and damping coefficients of TPJB are extracted from reference [10]. The equivalent stiffness of TPJB versus rotational velocity can be calculated. Also the equivalent damping of TPJB versus rotational velocity is computed.

It is found from calculations that at a certain rotational speed, stiffness becomes minimize. Damping is reduced versus rotational speed and then in high speed, its value becomes constant.

In order to verify the results, the responses of linear

*Corresponding author's email: ali.hosseini@khu.ac.ir

rotor-TPJB with linear rotor-stiffness-damping of TPJB are compared. Response of nonlinear rotor-TPJB with nonlinear rotor-stiffness-damping of TPJB are also compared.

The analysis shows that the difference between responses of rotor-TPJB system and equivalent rotor-stiffness-damping system is negligible. This shows the validity of the results. It is found from the analysis that the nonlinear response in both models has smaller peak in comparison to linear one.

4- Conclusions

In this paper, first, the hydrodynamic forces and moments from TPJB acting on the rotor were calculated. Then the equations of motion of continuous rotor were derived. In order to solve the resulting equations, the equations of motion were discretized using the Galerkin method and then the obtained ordinary differential equations were solved by numerical methods.

The results can be presented as follows:

- The response of nonlinear model has a smaller amplitude in comparison to linear one. Also, the natural frequency in nonlinear model is larger.
- In the case of turbulent flow, the amplitude of response is smaller. But the natural frequencies for both laminar and turbulent flows are not so different; i.e. the type of flow is effective on peak of the domain, but does not create a significant difference in the natural frequency of the rotor.
- Change in dynamic viscosity causes variation in the natural frequency and the response amplitude. When the viscosity increases, the natural frequency becomes bigger and the amplitude reduces.

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