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Nonlinear Frequencies and Unbalanced Response Analysis of High Speed Rotor-Bearing Systems

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Abstract

This paper describes a step forward in calculating the nonlinear frequencies and resultant dynamic behavior of high speed rotor bearing system with mass unbalance. Nonlinear strongly coupled equations of motion has been formulated based on strain energy and kinetic energy equations for shaft, disk and unbalance mass with shaft undergoing large bending deformations. Here gyroscopic effects of disk as well as mass unbalance are also considered while vibration effect along the shaft axis is ignored. Time history and FFT analysis for finding the fundamental frequencies for the rotating are portrayed under variation of shaft diameter, frequency of the shaft speed, geometric nonlinearity and disk location. The present research shows an interesting development that the initial conditions are playing an important role in finding the nonlinear frequencies and this variation is strongly due to the presence of nonlinear geometric coupling. In addition, response analysis of the system has been developed due to mass unbalanced using time history. This paper enables an understanding and realization of operating zones of rotational speed of the shaft by which the excessive vibration can easily be avoided due to the resonant conditions occurred as the natural frequencies come closer to the frequency of the rotational speed.

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Keywords: Shaft-disk; Higher order deformation; Inextensible condition; Method of multiple scales; Free vibration analysis; Critical speeds;

1. Introduction

Rotor dynamics being appealing subset of vibration due to its varied applications as well as vast opportunities to explore the subject in multiple dimensions. Rotating machines exist in many high end engineering applications such as jet engines, helicopter rotors, turbines, compressors and the spindles of machine tools as well as routine applications such as pump, fan, blower, IC engine etc. which makes rotor dynamics an important field of study. Kinetic energy always exist in forms the internal energy of the system because of connection to the driving

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system. Hence, the rotating elements possess enormous amount of operating energy which can be converted into vibrations due to which the prediction and analysis of the rotor system becomes essential.

Mass unbalance is very commonly observed in industrial application due to reasons such as material characteristic, machine design, non-uniform wear or corrosion, sticking of external particles etc. As the speed of rotation increases the impact of mass unbalance increases significantly and if not predicted and controlled may result in catastrophic failure occurs thus disrupting the smooth functioning of the same. Dynamics of rotating shafts is therefore necessary for an accurate design. Free vibration analysis is one of the vital steps for analysis in rotor dynamics. Over years, research on rotor dynamics is being carried on. For the instances, the effect of shear deformation and rotary inertia of a rotor on its critical speeds was studied by R. Grybos [1]. Choi et al [2] displayed the consistent derivation of a set of governing differential equations describing the flexural and the torsional vibrations of a rotating shaft where a constant compressive axial load was acted on it. Using the beam and shell theory, Singh and Gupta [3] investigated free damped flexural vibrations analysis of composite cylindrical tubes. Almasi [6] developed a model considering large deformations of a rotor based on virtual work theory. Chang and Cheng [7] studied the instability and nonlinear dynamics of a slender. Villa et al. [8] used invariant manifold approach to numerically investigate the responses of a nonlinear rotor-bearing system. Shabaneh and Zu [9] investigated the dynamic analysis of a single-rotor shaft system with nonlinear elastic bearings at the ends mounted on visco-elastic suspension.

In general linear analysis is done as it is easy. But there demand for more accurate and refined solution, consideration of nonlinearities has become important and that result into tedious process. Nonlinearities in the rotating system can be in the form of higher order large deformations in bending, geometric and inertial nonlinearities, gyroscopic effect, etc. A better result can be obtained considering the nonlinearities mentioned. Hosseni and Khadem [4] analyzed the free and forced vibration of nonlinear rotor-bearing systems by means of multiple scales method. Rizwan et al. [5] derived the mathematical modeling and investigated that nonlinear phenomenon of nonlinear rotor dynamics due to higher order deformations in bending considering geometric nonlinearity and gyroscopic effect.

2. Mathematical Modeling And Approaches

The geometry of the rotor system considered for this work has been shown in Fig.1 where the shaft, considered being a beam of circular cross section of length L and radius R_s has been modeled by its kinetic and strain energies.

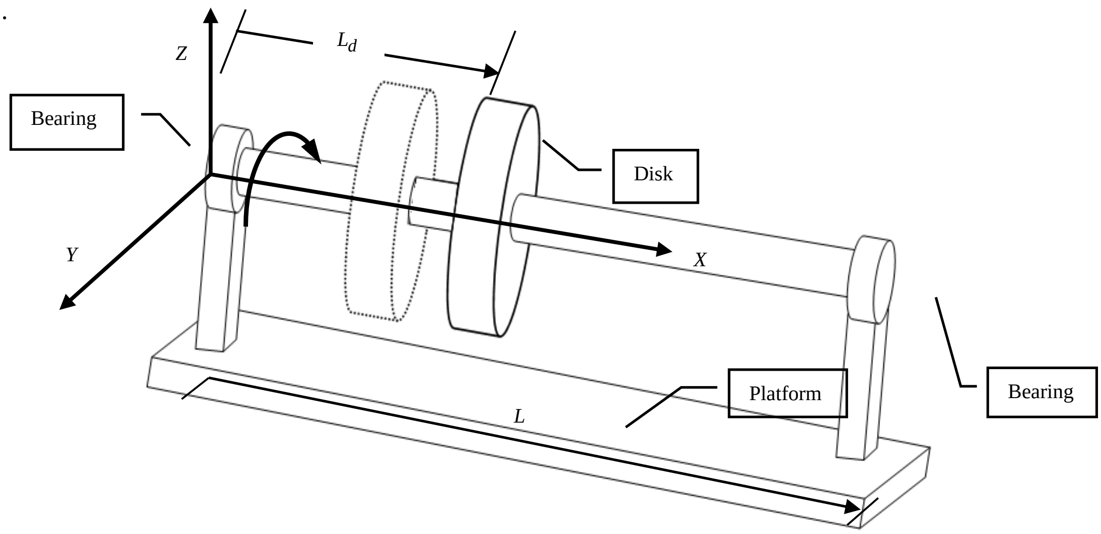

Figure 1: Rotor System with shaft and disk