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Non-linear dynamic analysis of a flexible rotor supported on porous oil journal bearings

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ABSTRACT

In the present paper, the non-linear dynamic analysis of a flexible rotor with a rigid disk under unbalance excitation mounted on porous oil journal bearings at the two ends is carried out. The system equation of motion is obtained by finite element formulation of Timoshenko beam and the disk. The non-linear oil-film forces are calculated from the solution of the modified Reynolds equation simultaneously with Darcy's equation. The system equation of motion is then solved by the Wilson-θ method. Bifurcation diagrams, Poincaré maps, time response, journal trajectories, FFT-spectrum, etc. are obtained to study the non-linear dynamics of the rotor-bearing system. The effect of various non-dimensional rotor-bearing parameters on the bifurcation characteristics of the system is studied. It is shown that the system undergoes Hopf bifurcation as the speed increases. Further, slenderness ratio, material properties of the rotor, ratio of disk mass to shaft mass and permeability of the porous bush are shown to have profound effect on the bifurcation characteristics of the rotor-bearing system.

1. Introduction

Rotating machineries are one of the most important classes of machineries that are used in diverse engineering fields. The correct prediction of dynamics behaviour is extremely essential when the rotors are made very flexible and a number of complicated accessories are attached to the rotor. Further, the dynamic behaviour of a rotor-bearing system depends on the non-linear characteristics of the fluid-film forces as it can cause self-induced vibrations in the rotor-bearing system, which is popularly known as oil whirl/whip. Because of oil whirl/whip phenomena the rotor vibration is not generally synchronous with the unbalance force. The rotor motion may be in some cases quasi-periodic or chaotic depending upon system parameters.

Myers [1] applied Hopf Bifurcation Theory (HBT) for the stability analysis of a rigid rotor symmetrically supported by two identical, infinitely long journal bearing. Hollis and Taylor [2] also carried out similar type of analysis by using short bearing approximation. Noah and Sundarajan [3] also applied HBT to study subcritical and supercritical bifurcation for rotor-bearing system with finite journal bearing.

Zhao et al. [4] analyzed the stability and response analysis of symmetrical single-disk flexible rotor-bearing system. The threshold speed of the system based on linear oil-film forces had been derived. Non-linear transient simulation and unbalanced responses were investigated. Laha et al. [5] carried out stability analysis of a fully-balanced Timoshenko beam supported on hydrodynamic porous journal bearing using non-linear transient method. The effects of different rotor-bearing parameters on the stability margin of the rotor were investigated.

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Nomenclature

A	cross-sectional area of the rotor, $\pi D^2/4$
C	clearance of the bearing
D	diameter of the rotor
e_d	eccentricity of the disk
E	Young's modulus of the rotor
$\boldsymbol{F}$	force vector
$\bar{F}_r^B$, $\bar{F}_\phi^B$	non-dimensional bearing forces in circumferential and axial direction of the bearing, respectively, $F_r^B C^2/\eta\Omega R^3 L_B$, $F_\phi^B C^2/\eta\Omega R^3 L_B$
$\bar{F}_Y$, $\bar{F}_X$	non-dimensional force component acting on the rotor at the bearing locations in vertical and horizontal directions, respectively
g	acceleration due to gravity
$\bar{\mathbf{G}}^d$	non-dimensional gyroscopic matrix of the disk
$\bar{\mathbf{G}}$	assembled gyroscopic matrix of the system
$\bar{h}$	non-dimensional film thickness, $h/C = 1 + \varepsilon\cos\theta$
H	thickness of the porous bush
K_x, K_y, K_z	permeability of the porous bush in circumferential, radial and axial direction, respectively
$\bar{K}_x$, $\bar{K}_z$	non-dimensional permeability factor of the porous bush in circumferential and axial direction, respectively, K_x/K_y, K_z/K_y
$\bar{\mathbf{K}}$	assembled stiffness matrix of the system
L	length of the rotor
L_B/D	aspect ratio of the bearing
m_d	mass of the disk
$\bar{m}_d$	ratio of disk mass to shaft mass, $m_d/(\rho AL)$
$\bar{m}$	mass parameter, $C\Omega^2/g$
$\bar{\mathbf{M}}^d$	non-dimensional mass matrix of the disk
$\bar{\mathbf{M}}$	assembled mass matrix of the system
$\bar{p}$	non-dimensional pressure in the clearance space of bearing, $pC^2/\eta UR$
$\bar{p}'$	non-dimensional pressure in the porous media of the bearing, $p'C^2/\eta UR$
$\boldsymbol{q}$	displacement vector
R	radius of the rotor
$R/2L$	slenderness ratio of the rotor
R/C	clearance ratio of the bearing
S	Sommerfeld number
$\bar{\mathbf{v}}$, $\bar{\mathbf{w}}$	non-dimensional horizontal and vertical deflection of the rotor, respectively, $\mathbf{v}/C$, $\mathbf{w}/C$
W	load per bearing, $(\rho AL + m_d)g/2$
$\bar{y}$	dimensionless radial coordinate of the bearing, y/H
$\bar{z}$	dimensionless axial coordinate of the bearing, $2z/L_B$
β	bearing feeding parameter, $12K_yR^2/C^3H$
ε	eccentricity ratio of the bearing, e/C
ϕ	attitude Angle
η	viscosity of the lubricant
ω	whirling speed of the rotor
Ω	rotor spin speed
ρ	mass density of the rotor material
θ	dimensionless circumferential coordinate of bearing, x/R
θ_2	circumferential coordinate at which cavitation starts
· (dot)	derivative with respect to time
¯ (bar)	non-dimensional quantity

Adiletta et al. [6] studied the conditions that give rise to chaotic motion in rigid rotor on short journal bearing. Cai-Wan and Chen [7] investigated the dynamic response of a rotor-bearing system with non-linear suspension with the assumptions of the micropolar lubricant together with short bearing approximation. The dynamics of the rotor centre and bearing centre are studied. JianPing et al. [8] also showed that the rotor undergoes Hopf Bifurcation as the rotor speed is increased. Castro et al. [9] showed the effects of unbalance, journal bearing parameters and rotor arrangement (vertical or horizontal) on the bifurcation characteristics of a flexible rotor supported in short journal bearing.

Ruhl and Booker [10] are regarded as the pioneers in the implementation of FEM for rotor systems. However, they considered only elastic bending energy and translational kinetic energy in their finite element formulations. Nelson and McV-