CHAOTIC DYNAMICS OF ROTOR SUPPORTED ON TILTING-PAD JOURNAL BEARING (TPJB); A REVIEW AND CURRENT WORK

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ABSTRACT

The use of tilting-pad journal bearing (TPJB) has increased in the recent past due to their stability effects on the rotor bearing system. The first part of this paper presents a review of the state of the art work on rotor response when supported on TPJB. Only few published work presented results relating to the strongly nonlinear behavior, especially chaos, resulting from the use of these types of bearings. In the second part of this paper, three loading mechanisms capable of producing instabilities in terms of sub-harmonic and chaotic motions are suggested. The first one is that of a centrally loaded pad with small rotor unbalance excitations. The second one is when the load is applied between two pads. And, the third represents a concentric rotor (zero static load) acted upon by centering springs and unbalance excitation. After a quite extensive numerical experimentation, the resulting response shows, for certain parameters, sub-harmonic, quasi-periodic and chaotic motions.

INTRODUCTION

Tilting-pad journal bearings (TPJB) are, increasingly, being used due to their stabilizing effects on the rotor bearing system. Examples of their use are in large turbine sets, generators, and pumps. The TPJB has frequently been used successfully to replace traditional fixed geometry journal bearings in installations where rotor instabilities have existed. In spite of this, TPJB are still susceptible to inducing instabilities, especially of the fractional-frequency type. There are only few studies that focused on predicting bearing stability and the non-synchronous responses of TPJB. Elwell and Findlay [1], pointed out that shaft journal eccentricity will always be higher when the load direction is between pivots rather than in line with one particular pivot. Fractional-frequency whirl, not of a serious nature, has been observed by Orcutt [2] in the unpreloaded 4-pad tilting-pad bearing at high speeds and very light loads. Adams and McCloskey [3] studied the problem of sub-harmonic resonances in turbine generators. They stated that TPJB can protect against the possibility of catastrophic levels of vibration with large unbalance for large units marginally below oil whip threshold speed. Love [4] studied non-synchronous response of a pivoted-pad gas bearing. He showed that if the pivot clearance is made too small in the presence of a large journal orbit, all pads will tend to become resonant simultaneously. Adams and Payandeh [5] stated that statically unloaded pads can exhibit a strong sub-synchronous (below half the rotational speed) self-excited vibration. Brancati et al. [6] obtained the limit curves separating the stable synchronous motion and unstable (1/2 rotor speed) one using a variational non-linear stability analysis of a symmetrical rigid rotor mounted on 2-pad TPJB.

THREE-PAD TPJB

Figure 1(a) presents a simplified model for a 3-pad TPJB. The rotor has two degrees of freedom. Each pad is allowed to pitch about its pivot point adding one D.O.F. for each pad. The integration technique for the pad motion under the fluid film pressure pitching moment follows the details in [5]. Stability of the TPJB depends on the pads being able to track the motions of the rotor axis. During operation, each pad will assume an inclination such that the resultant of the fluid film forces passes through the pivot point. The effective radial stiffness, of the pad's hydrodynamic oil film, increases nonlinearly with load. A multi-pad bearing can be represented as a system of nonlinear radial springs supporting the journal. The rotor shaft is considered as a single mass supported on two equal (symmetrical) springs with no damping. The rotor equations of motion are given by.
\[m\ddot{X} + \ddot{K}X = me_\mu \Omega^2 \cos(\eta\Omega t) + \ddot{F}_x,
\]

\[m\ddot{Y} + \ddot{K}Y = me_\mu \Omega^2 \sin(\eta\Omega t) + \ddot{F}_y,\]

where, \(X\) and \(Y\) are inertial co-ordinates of the rotor center, \(\ddot{K}\) is rotor stiffness, \(m\) is rotor mass, \(e_\mu\) is unbalance eccentricity, \(\ddot{F}_x, \ddot{F}_y\) are components of the resultant fluid film forces, \(\Omega\) is the speed of rotor in (radians/sec.), and \(\eta\) is the Rotor speed ratio. Equation (1) is solved for the rotor displacement and velocity at each time step using the predictor-corrector Euler-Newmark technique [7].

Figure 1. (a) 3-Pad TPJB model, (b) and (c) centrally loaded pad, and (d) loading between pads.

As presented in Figures (1) and (2), the TPJB, because of their geometrical and nonlinear fluid film characteristics, show great potential for the possibility of the onset of chaos. In Figures 1(b) and 1(c), a synchronous response catastrophically changes into a horizontally oriented chaotic one by reducing the excitation unbalance \(\delta\) for light bearing load \(\Gamma = 1/S\), where \(S\) is the Sommerfeld number. Figure 1(d) presents a situation in which a heavy loading is 30° offset from the pivot of the lower pad. The rotor jumps erratically over this pad.

A large subharmonic period-3 motion is depicted in Figure 2(a). Upon halving the rotor non-dimensional stiffness \(K\) [7], a large symmetrical quazi-periodic orbit is obtained for the concentric (zero deadweight \(\Gamma = 0.0\), Figure 2(b)). Also, by slightly increasing the unbalance and decreasing the rotor stiffness \(K\), a chaotic motion is obtained as shown in Figure 2(c). Figures 2(d),(e), and (f) illustrate three cases of lightly centrally loaded pad for fixed unbalance \(\delta=0.164\), but decreasing loading \(\Gamma\). A period-3 sub-synchronous motion, finally gives birth to a chaotic motion. It is noted that because of the central pad loading, the horizontally extended chaotic orbit still persists similar to the case in Figure 1(c).

Figure 2. (a) Subharmonic period 3, (b), Quasiperiodic, and (c) Chaos, for concentric (or vertical) rotor \(\Gamma = 0.0\).

(d), (e), and (f) \(\delta = 0.164\).

REFERENCES