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Design and modeling of a novel active squeeze film damper

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ABSTRACT

Rotating machinery support design with the aim of reducing the amplitude vibration and force transmitted to the foundation has significant importance regarding the various applications of these machineries. In this paper, a theoretical model for an active squeeze film damper (ASFD) is introduced as an option in the vibration control field. The design is based on the SFD with the controllability characteristics of magnetic bearing, which allows the development of a variable force, and a change in fluid film stiffness and damping. It is assumed that the SFD and the AMB are collocated, whether adjacent or integrated in a single unit. Expressions for the oil film forces and magnetic force are obtained. Then, the dynamic equations of the combine both bearings in a single bearing are presented. The vibration control of a rigid rotor is taken as an example of the application of the new design. The possibility of suppressing rotor vibrations and transmitted forces is demonstrated by means of numerical experiments. The simulation shows that in this type of application, good vibration control can be achieved by using new active squeeze-film damper. The potential benefits of varying the magnetic bearing parameters can thus be examined for any given rotor bearing configuration.

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1. Introduction

The use of light high-speed rotors in modern turbo machinery, such as gas turbines, jet engines, and compressors, increases the dynamic problems associated with machines. Squeeze film (SFDs) have been used to overcome vibration problems that cannot be adequately amended by conventional bearings such as ball bearings and journal bearings. Traditional SFDs are generally used to target the vibration problems at the first critical speed. These passive devices are however ineffective if several modes of vibration are excited, and this has led to investigations into the use of active control.

For such systems running super-critical, low damping is desirable above the critical speed to reduce transmitted forces, but high damping is required at the critical speed to allow safe traversing of the critical speed. Therefore, optimum parameter values must be determined to satisfy these two rather conflicting requirements. In addition to the conflicting damping requirements, there exist multiple 'optimal' damping values (one for each vibration mode) in high-speed rotor systems. Thus, it is practically impossible to solve the design challenges with conventional SFDs because they have no control of damping. To cope with these design challenges, controllable SFDs working in active or semi active mode have been studied, and those efforts are still proceeding [1–3]. Several techniques have been adopted by researchers. The semi-active type SFDs using controllable fluids as lubricant also stemmed from such efforts [4].

In recent years some active control techniques for vibration reduction have been developed, and the active squeeze film damper (ASFD) concept was born. The ASFD allows the adjustment of damping during operation, in order to obtain maximum efficiency, according to the different working conditions. Kim et al. developed the design and modeling of a controllable semi-active SFD based on MR fluid [5]. Carmignani et al. evaluated the effect of viscosity, which is one of the key parameters that affect

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the dynamic performance of MR-SFDs. They compared the unbalance vibration control performance of an MR-SFD with four different working fluids [6].

One of the key design features in an SFD configuration is the introduction of support flexibility and damping in the bearing/support structure. This results in lowering the transmitted forces, which increases the bearing life and increasing the stability of the system. Riemann et al. has been stated a methodology for μ synthesis controller design for flexible rotors in hydrodynamic journal bearings, whose dynamics change significantly by the rotational speed, at reasonable design and demonstrated data test rig [7]. The use of squeeze-film dampers to attenuate rotor vibration amplitudes and the forces transmitted to a machine frame is well known [8,9], A. E1-Shafei et al. presented a study of the optimal design of SFDs for multi-mode rotors. The optimal design program obtained the best possible damper parameters for a given rotor to satisfy the minimization requirements for maximum vibration amplitude function [10]. A more versatile approach is to use electromagnetic bearings in which the force can be controlled in closed-loop [11,12]. These devices are now available commercially and where their cost can be justified they represent an attractive solution, although their long-term reliability compared with oil-film bearings must be established. El-Shafei et al. presented a new concept in load carrying and control of rotating machinery. Journal bearings and active magnetic bearings are both excellent bearings for high performance rotating machinery. The load carrying is done by the journal bearings, exploiting their excellent load carrying capabilities, and the JB instability is overcome with the active magnetic bearing (AMB) [13].

In this paper, a novel approach is used to control the SFD that can be considered jump phenomena, non-synchronous motions and high levels of the transmitted forces. It is assumed that the SFD and the AMB are collocated, whether adjacent or integrated in a single unit. Squeeze-film dampers and active magnetic bearings are both excellent bearings for high performance rotating machinery. Actually, SFDs and AMBs are two competing bearings in many markets. SFD manufacturers promote the large load carrying capacity and high damping in SFDs, while AMB manufacturers promote the controllability of the rotor system and the elimination of oil supply. However, both bearings also have their limitations. SFDs are limited by the instability mechanism known as oil whirl and jump phenomena [14,15], while AMBs have lower load capacity and tend to be larger for the same load. Thus it seems natural to try to combine both bearings in a single bearing concept, where the superior load carrying capacity of SFDs is to be exploited along with the controllability characteristics of AMBs that can be used to control the instability and damping of SFDs. This will result in a bearing concept with high load carrying capacity with controlled instability and a smaller magnetic bearing that is not carrying any static load while providing the required control. This concept of a combined SFD/AMB is studied in this paper to illustrate the success of the concept. This work therefore aims to study the effect of control parameters on the unbalance response and transmitted force of a rigid rotor supported by ASFD. In the first step, a nonlinear

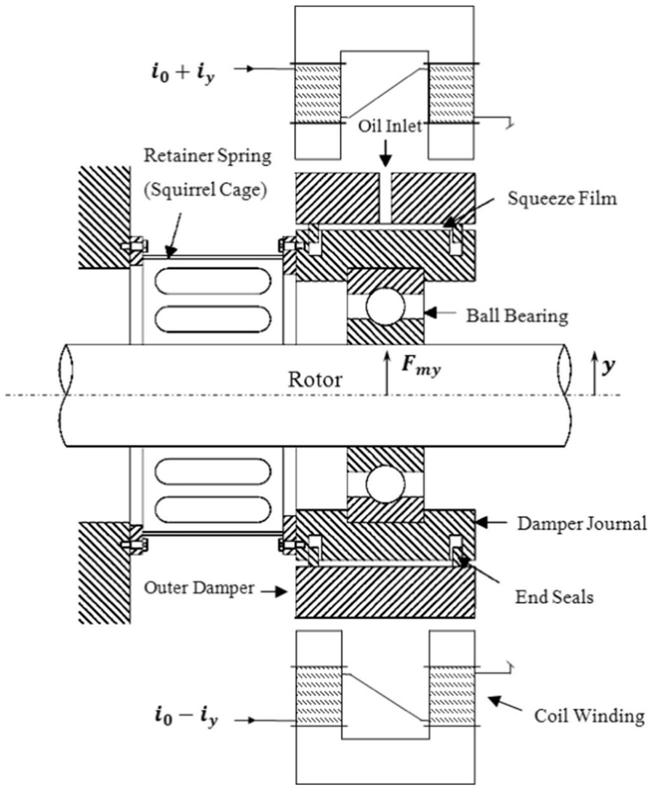

Fig. 1. The proposed active squeeze film damper.

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