ARTICLE IN PRESS

Alexandria Engineering Journal (2016) **xxx**, xxx–xxx

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

The influence of asymmetry in centralizing spring of squeeze film damper on stability and bifurcation of rigid rotor response

Hamidreza Heidari *, **Mohammadreza Ashkooh**

Department of Mechanical Engineering, Malayer University, Malayer, Iran

Received 24 May 2016; revised 4 August 2016; accepted 17 August 2016

KEYWORDS

Stability;
Bifurcation;
Squeeze film damper;
Rigid rotor;
Cavitation

Abstract One of the main challenges in the design of rotating machinery is the occurrence of undesirable vibration. In this paper, stability and bifurcation of the unbalance response of a rigid rotor supported by squeeze film damper with asymmetry in centralizing spring are investigated. The unbalanced rotor response is determined by the shooting method and the stability of these solutions is examined by using the Floquet theorem. Numerical examples are given for both symmetric ($K_x = K_y$) and asymmetry ($K_x \neq K_y$) centralizing springs in **x** or **y** direction. Jump phenomenon and subharmonic and quasi-periodic vibrations are predicted for a range of design and operating parameters such as the unbalancing (U), gravity (W), bearing (B) and spring (K). The results show that increasing the spring stiffness asymmetry parameter in y direction has no influence on the nature of system response and occurrence of bifurcation. But, examining the effect of increase in stiffness parameter in x direction leads to occurrence instability and period-doubling bifurcation in response to the system. Our findings show that this phenomena are due to the weight force in the y direction. Finally, it is shown that the unsymmetrical stiffness of squeeze film dampers in the presence of cavitation promoting the chance of undesirable nonsynchronous vibrations.

1. Introduction

Today, several researchers have extensively focused on the design of rotating machines to enhance the performance and stability of these instruments in the various industries and systems. They also improve rotating machines to provide more space for other components of rotor such as disks, impellers, and blades. Among the various elements of the rotating machine, the shaft of rotors plays a crucial role to achieve a higher level of rotational energy and increase the power generation. In addition, this equipment is a key element of future high speed rotating machines. Hence, extensive efforts are done to decrease unwanted vibrations. Increasing the damping of the system is considered as one of the most common solutions for the reduction in unwanted vibrations of the rotor. Since this type of bearings has a low inherent damping, they are considered for rotating equipments that use rolling element bearings (such as gas turbines of aircrafts). The squeeze film

* Corresponding author.
E-mail addresses: hr.heidari@malayeru.ac.ir (H. Heidari), Ashkooh@rocketmail.com (M. Ashkooh).
Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.08.013
1110-0168

damper is one of the most widely used tools to provide an additional external damping for rotating equipments. In its simplest form, the squeeze film damper consists of an oil-filled annular cavity surrounding the outer race of a rolling element bearing. The outer race of the bearing, which acts as the journal of dampers, is prevented from rotating, but it is allowed to describe whirl motion around its equilibrium position. There are two types of configurations for the use of squeeze film dampers in rotating equipments: dampers with centralizing springs and those without centralizing springs. In the case of damper without centering spring, the journal that lies at the bottom of the clearance circle, is lifted when sufficient lift force is generated. In the case of damper with centralizing spring, the journal is constrained in the center of damper by a centralizing spring. The typical installation of both configurations is illustrated in Fig. 1. Successful use of squeeze film damper in attenuating unwanted vibrations at critical speeds is demonstrated by Kanki et al. [1] and Leader et al. [2]. Despite the positive role of squeeze film damper in the controlling of system vibrations, the response of rotor can present dramatic changes with parameters, even loss stability and give rise to devastation due to the strong nonlinearity of fluid film forces. The main reason for this nonlinear behavior is the interaction between the rotor unbalance force and the oil film force especially when the cavitation is present in the system. The importance of the system analysis in the case of cavitation is mainly for damping capacity reduction due to lower effective volume of lubricant. In addition, this work develops cross coupling forces in the system. Because of the nonlinear relation between cross coupling forces in fluid film and amplitude of system response, reducing the damping of the system by the cavitation eventually leads to occurrence of nonlinear behaviors such as nonsynchronous vibrations, jump phenomena and chaotic motion.

The modeling of the oil film in squeeze film dampers in the presence of cavitation is always one of the challenging problems for researchers. Many researchers [3–5] used the Reynolds equation to calculate the term of pressure distribution within the damper. The integration of the pressure distribution defines the oil film force in squeeze film damper. Although the components of the oil film obtained by this method are reasonably accurate, there are some deficiencies and complexities of the problem. Therefore, searching for efficient ways is persisted to enhance the modeling of the oil film forces.

In this regard, some researchers tried to find a linear stiffness and damping components individually for squeezing film dampers. For example, some scientists [6–8] suggested that the components of stiffness and damping of squeeze film dampers are obtained by stiffness and damping components of the journal bearings while using zero angular velocity. Holmes [6] observed that for the zero angular velocity, squeeze film dampers also have the ability to withstand dynamic load seven in the absence of centralizing spring. Other researchers [7,8] try to find a separate statement stiffness and damping for squeeze film dampers through various methods. Burrows et al. [9] simultaneously used the least squares method and the Reynolds equation to extract the stiffness and damping components for squeeze film dampers in the presence of cavitations. They carefully compared the results with nonlinear model derived from the Reynolds equation for different circumstances. This comparison showed that the results would be acceptable only at low rotational speeds and rotor misalignment.

Theoretical and experimental researches in the field of ethology of rotor-bearing systems with squeeze film dampers indicate that one of the most serious problems in the system is the asynchronous responses and chaotic motion. Chu and Holmes [10] studied the role of squeeze film dampers in controlling vibration and instability of a small centrifugal pump. The theoretical and experimental results showed that dampers play a key role in delaying the occurrence of instability and stabilizing the rotor response after first instability and crossing the first critical speed. Taylor and Kumar [11] studied the steady response of a rigid rotor with squeeze film damper regardless of cavitation and assuming a circular path to the journal. They showed that the system does not present significant nonlinear behavior. Mohan and Hahn [12] confirmed that jump phenomenon occurs in the system response when rotor unbalance

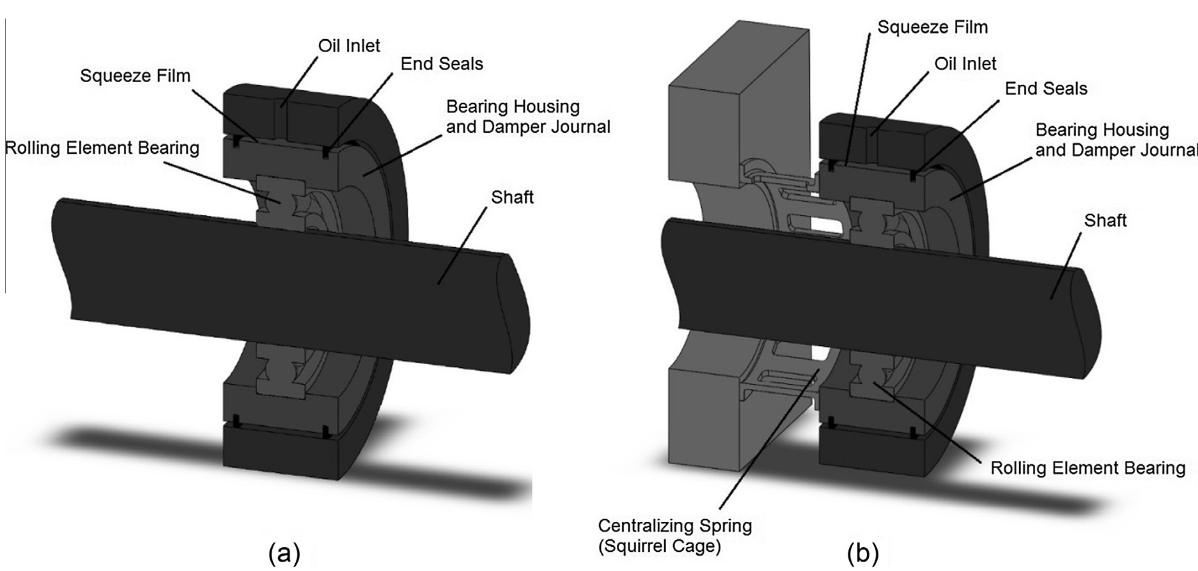

Figure 1 Two types of configuration for the use of squeeze film dampers in rotating equipments: (a) damper without centralizing spring and (b) damper with centralizing spring.

Please cite this article in press as: H. Heidari, M. Ashkooh, The influence of asymmetry in centralizing spring of squeeze film damper on stability and bifurcation of rigid rotor response, Alexandria Eng. J. (2016), http://dx.doi.org/10.1016/j.aej.2016.08.013