Mechanical Systems and Signal Processing 52-53 (2015) 506–528

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

A journal bearing with variable geometry for the suppression of vibrations in rotating shafts: Simulation, design, construction and experiment

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ARTICLE INFO

Article history:
Received 17 December 2013
Received in revised form
13 June 2014
Accepted 4 July 2014
Available online 24 July 2014

Keywords:
Journal bearing
Variable geometry
Vibration quenching
Passive control

ABSTRACT

The idea for a journal bearing with variable geometry was formerly developed and investigated on its principles of operation giving very optimistic theoretical results for the vibration quenching of simple and more complicated rotor bearing systems during the passage through the first critical speed. The journal bearing with variable geometry is presented in this paper in its final form with the detailed design procedure. The current journal bearing was constructed in order to be applied in a simple real rotor bearing system that already exists as an experimental facility. The current paper presents details on the manufactured prototype bearing as an experimental continuation of previous works that presented the simulation of the operating principle of this journal bearing. The design parameters are discussed thoroughly under the numerical simulation for the fluid film pressure in dependency of the variable fluid film thickness during the operation conditions. The implementation of the variable geometry bearing in an experimental rotor bearing system is outlined. Various measurements highlight the efficiency of the proposed bearing element in vibration quenching during the passage through resonance. The inspiration for the current idea is based on the fact that the alteration of the fluid film characteristics of stiffness and damping during the passage through resonance results in vibration quenching. This alteration of the bearing characteristics is achieved by the introduction of an additional fluid film thickness using the passive displacement of the lower half-bearing part.

1. Introduction

A number of initiatives have been launched in the field of lubrication as potential sources of improvements in energy efficiency in a wide range of engineering products, plant and processes. Attention is being focused on bearings to improve both performance and efficiency in fields such as automotive, machine tools, industrial and power generation plant. The demands for vibration control in rotating machinery motivated the development and application of journal bearings with

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http://dx.doi.org/10.1016/j.ymssp.2014.07.002
0888-3270/

adjustable/controllable properties within the last 20 years. The reduction of vibrations through the application of adjustable/controllable journal bearings has been proven to be beneficial in many variants of rotating machinery. Through the concept of adjustable properties of journal bearings it is possible to increase the stability of the rotor-bearing system, to enlarge its operational frequency range, to suppress vibration amplitude, to reposition journal center of rotation whilst in operation, to suppress journal orbits for a range of loads, and to provide reduced oil temperature rises compared to the conventional bearing. Theoretical modeling and practical tests have demonstrated clear improvements over conventional fluid film bearings, along with a number of other characteristics offering benefits that may be of interest to designers and operators of such bearings.

In general, several methods have been presented in order to dissipate the vibration energy and to keep low vibration levels in rotating machines. Among these mechanisms are seal dampers (Vance and Li, [1]) squeeze-film dampers (San Andre´s and Lubell [2]), and hybrid squeeze-film dampers (El-Shafei and Hathout [3]). Mechanisms that incorporate active adjustment of journal bearing properties have been proposed since the last 20 years; among them the hydraulic active chamber systems (Ulbrich and Althaus [4], Althaus et al. [5,6], and Santos [7]), and the variable impedance hydrodynamic journal bearings (Goodwin et al. [8]). The magnetized journal bearings lubricated with ferrofluids (Osman et al. [9]) offer also the benefit of controlling the fluid film properties because of their controllability by an external magnetic force.

If a part of the hydrostatic pressure is dynamically modified by means of hydraulic control systems, one refers to the active lubrication. The concepts of actively lubricated bearings (Santos [10], Santos and Russo [11], Santos and Nicoletti [12], and Santos and Scalabrin [13]) and of active-control applied in fluid bearings (Bently et al. [14]) have met also wide interest in research and remains still under promising investigation. By employing of electronics, control design, and hydraulics, the active lubrication simultaneously allows the reduction of wear between rotating and nonrotating parts of the machinery and, in addition, the attenuation of rotor vibrations. Recent theoretical (Santos and Nicoletti [15], and Nicoletti and Santos [16]) and experimental (Santos and Scalabrin [17]) investigations related to active lubrication showed the feasibility of attenuating rotor vibrations in test rigs with rigid rotors. The use of active lubrication in tilting-pad journal bearings (TPJB) has the strong advantage of bearing characteristics with negligible cross-coupling effects. However, this kind of active strategy can also be applied to hydrostatic (Bently et al. [12]) and to multi-lobed bearings (Santos et al. [17]).

On the concept of introducing the variable geometry of a journal bearing in order to adjust its properties there are several contributions with various methods for the adjustment of the clearances through the deformation of the bearing pads; among them a novel adjustable multi-lobe hydrodynamic journal bearing was designed, manufactured, fitted and experimentally tested by Martin and Parkins [18] and Martin [19] replacing a conventional bearing in a large marine gearbox. The novel bearing demonstrated the ability to suppress journal orbits and to translate the journal orbit in a controlled manner by an amount exceeding double the clearance of the conventional bearing. A novel tight-tolerance tilt-pad journal bearing that provides increased stability in high speed turbomachinery was analyzed and measured by Bischof and Zhou [20]. On a similar way, an active journal bearing with a flexible sleeve that is deformed under controlled pressure of a hydraulic chamber has been developed by Krodkiewski and Sun [21] and Krodkiewski [22] as a method to control the stability of rotor-bearing systems.

Unlike most works documented in literature that incorporated various mechanisms for active control of the lubrication pressure or the bearing deformation (geometry), the current paper introduces an entirely passive mechanism without any additional component needed to support its operation. The present paper presents in detail the design and the construction process of a journal bearing with variable geometry [23,24] that has been theoretically applied in a large scale rotor bearing system [25] before its commercial expose in industries related with the manufacturing of journal bearings. The operation principle is based on the combination of the vibration suppression utilizing discontinuous spring characteristics (Ishida and Liu [26]) and the variation of bearing properties due to an additional fluid film (Papadopoulos et. al [27] and Chasalevris et. al [28]) with the passive radial displacement of the half-ring of the bearing to happen when the fluid film forces exceed certain limits. The movable semi-bearing part is mounted on an adjustable damper and two adjustable springs of certain stiffness according to the application. The adjustable damper has been proved not to contribute on the dissipation of the vibration energy of the rotor-bearing system [23] but only on the motion of the bearing moving part.

The present paper incorporates all the detailed conception of this recent idea of a journal bearing that is capable of suppressing the developed vibration amplitude during the passage through the critical speed. A simple experimental rotor bearing system is the test rig in which the Variable Geometry Journal Bearing (VGJB from now and on) will be applied in order to measure and notify the ability of the current element in vibration suppression. Under this consideration of application the VGJB was designed with its main dimensions already defined. The entire project of simulation, design and construction of the VGJB was executed in the Institute for Structural Dynamics at the Technical University of Darmstadt.

The current paper is structured into four main sections:

a) *Section 1*: the conception of the journal bearing with variable geometry. In correspondence to [23–25] and under the theoretical background gained during the last two years by theoretical applications of the VGJB in rotor systems, the bearing under construction is simulated in order to cover the demands of vibration quenching of a predefined rotor-bearing system that will be constructed and tested as well. The simulation of a the experimental rotor bearing system yields the two basic values for the properties of the external damping and stiffness that are incorporated in the mechanism of VGJB, together with all the rest design parameters of a normal journal bearing (clearance, viscosity, length, diameter, load, rotational speed).