BEARINGS
Assessment of Performance

Elaine Pitlik

Bearings: Assessment of Performance

Edited by **Elaine Pitlik**

NY RESEARCH PRESS

New York

Published by NY Research Press,
23 West, 55th Street, Suite 816,
New York, NY 10019, USA
www.nyresearchpress.com

Bearings: Assessment of Performance
Edited by Elaine Pitlik

International Standard Book Number: 978-1-63238-060-9 (Hardback)

Printed in the United States of America.

Bearings: Assessment of Performance

Preface

This book aims to highlight the current researches and provides a platform to further the scope of innovations in this area. This book is a product of the combined efforts of many researchers and scientists, after going through thorough studies and analysis from different parts of the world. The objective of this book is to provide the readers with the latest information of the field.

The performance of bearings has been analysed in this insightful book. Bearings (both plain and rolling material) are significant supporting materials for locating rotating components and confining their motion in the desired direction. In order to ensure their operational reliability and desired life, bearings need to be properly chosen for an application, primarily due to the constantly increasing operational speeds. This requires a careful performance analysis of various types of bearings while considering aspects like thermal stability, lubrication, contaminants in lubricants and controlling mechanism, etc. This book consists of several aspects contributing towards the performance analysis of plain bearings (both journal and thrust), rolling element bearings and magnetic bearings.

I would like to express my sincere thanks to the authors for their dedicated efforts in the completion of this book. I acknowledge the efforts of the publisher for providing constant support. Lastly, I would like to thank my family for their support in all academic endeavors.

Editor

Contents

Section 1

Plain Bearings

Chapter 1

Thermal Studies of Non-Circular Journal Bearing Profiles: Offset-Halves and Elliptical

Amit Chauhan and Rakesh Sehgal

Additional information is available at the end of the chapter

1. Introduction

Hydrodynamic journal bearings are defined as the mechanical components that support the external loads smoothly due to geometry and relative motion of mating surfaces in the presence of a thick film of lubricant. Hydrodynamic journal bearings are extensively used in high speed rotating machines because of their low friction, high load capacity, and good damping characteristics. Such bearings have many different designs to compensate for differing load requirements, machine speeds, cost, and dynamic properties. One unique disadvantage which consumes much time towards the research and experimentation is an instability which manifests itself as oil whip which is a vibration phenomenon. Oil whip is disastrous because the rotor cannot form a stable wedge and consequently this leads to metal to metal contact between the rotor and the bearing surface. Once surface contact exists the rotors begins to precess, in a reverse direction from the actual rotor rotation direction, using the entire bearing clearance. This condition leads to high friction levels which will overheat the bearing metal thus causing rapid destruction of the bearing, rotor journal and machine seals. Fuller [1956] has suggested that the fluid film bearings are probably the most important mechanical components in the recent technological development and are comparable in their significance to the effect of electricity. The development of fluid film lubrication mechanisms has been observed by Petrov [1883] in Russia and Tower [1883] in England. In 1886, Reynolds presented his classical analysis of bearing hydrodynamics, which forms the basis of present days bearing study. The overview of both the circular and non-circular hydrodynamic journal bearings and their design methodologies are discussed as follows:

1.1. Circular journal bearing

The basic configuration of the circular journal bearing consists of a journal which rotates relative to the bearing which is also known as bush (Fig. 1). Efficient operation of such bearing requires the presence of a lubricant in the clearance space between the journal and the bush. In hydrodynamic lubrication it is assumed that the fluid does not slip at the interface with the bearing and journal surface i.e. the fluid in contact with the journal surface moves at the same speed as the journal surface. Over the thickness of the fluid there is a velocity gradient depending on the relative movement of the bearing surfaces. If the bearing surfaces are parallel or concentric, the motion of the lubricant will not result in pressure generation which could support bearing load.

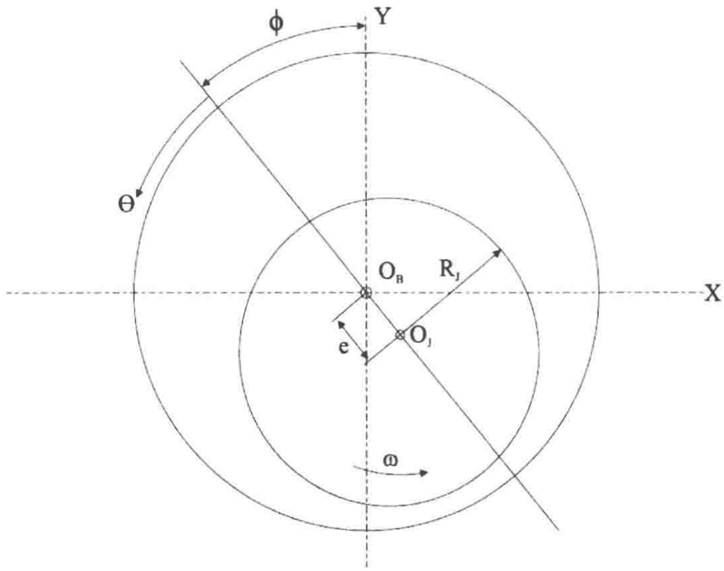

Figure 1. Schematic of circular journal bearing

However, if the surfaces are at a slight angle, the resulting lubrication fluid velocity gradients will be such that generation of pressure results from the wedging action of the bearing surfaces. Hydrodynamic lubrication depends upon this effect. The operation of hydrodynamic lubrication in journal bearings has been illustrated in Fig. 2. Before the rotation commences i.e. at rest the shaft rests on the bearing surface. When the journal starts to rotate, it will climb the bearing surface gradually as the speed is further increased; it will then force the lubricant into the wedge-shaped region. When more and more lubricant is forced into a wedge-shaped clearance space, the shaft moves up the bore until an equilibrium condition is reached and now, the shaft is supported on a wedge of lubricant. The moving surfaces are then held apart by the pressure generated within the fluid film. Journal bearings are designed such that at normal operating conditions the continuously generated fluid pressure supports the load with no contact between the bearing surfaces. This operating condition is known as thick film or fluid film lubrication and results in a very low operating friction. On the other hand if the lubricant film is insufficient between the relatively moving parts, it may lead to surface contact and the phenomenon is normally known as boundary lubrication. This occurs at rotation start-up, a slow speed operation or if the load is too heavy. This regime results in bearing wear and a relatively high friction value. If a bearing is to be operated under boundary lubricating conditions, special lubricants must be used. Amongst hydrodynamic bearings, circular journal bearing is the most familiar and widely used bearing. Simple form of this bearing offers many advantages in its manufacturing as well as in its performance. However, the circular journal bearings operating at high speed encounter instability problems of whirl and whip. Instability may damage not only the bearings but also the complete machine.

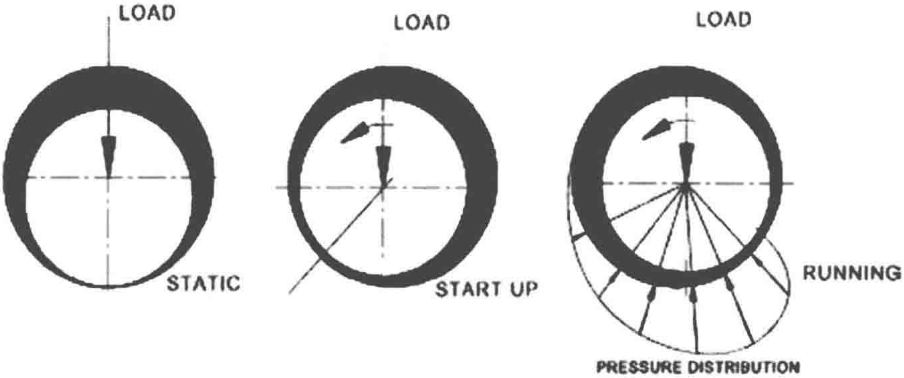

Figure 2. Schematic of operation of hydrodynamic lubrication in journal bearing [W1]

Moreover, these bearings usually experience a considerable variation in temperature due to viscous heat dissipation. This significantly affects the bearing performance as lubricant viscosity is a strong function of temperature. Furthermore, excessive rise in temperature can cause oxidation of the lubricant and, consequently, lead to failure of the bearing. Pressure also influences the viscosity of the lubricant to certain extent. Usually viscosity increases exponentially as the pressure increases which in turn increases the load capacity of the journal bearing. Researchers have studied the behaviour of circular journal bearing by adopting various numerical approaches to simulate the performance in accordance with the real conditions.

1.2. Non-circular journal bearing

It has been reported in the literature that the temperature rise is quite high in circular journal bearings as they operate with single active oil film. This resulted in the development of bearings with non-circular profile which operate with more than one active oil film. This feature accounts for the superior stiffness, damping, and reduced temperature in the oil film as compared to the circular journal bearings. Almost all the non-circular journal bearing geometries enhance the shaft stability and under proper conditions this will also reduce power losses and increase oil flow (as compared to an inscribed circular bearing), thus reducing the oil film temperature. Amongst non-circular journal bearings, offset-halves, elliptical, lemon bore, and three-lobe configurations are the most common.

The offset-halves journal bearing has been commonly used as a lobed bearing in which two lobes are obtained by orthogonally displacing the two halves of a cylindrical bearing. Offset-halves journal bearings (Fig. 3) are frequently used in gear boxes connecting turbine and generator for the power generation industries. These also find applications where primary directions of force, constant direction of rotation are found or high bearing load capacity, long service life, high stiffness, and damping values are the main characteristics under consideration. If the equipment is operated at full power, these requirements can be met by lemon bore bearings. Lemon bore bearing is a variation on the plain bearing where the bearing clearance is reduced in one direction and this bearing has a lower load carrying capacity than the plain bearings, but is more susceptible to oil whirl at high speeds [W2]. However, equipment must often be operated at lower performance levels, particularly in the times of reduced current needs. It is precisely under these conditions that lemon bore bearings may provide unstable conditions, which may require equipment shut down to avoid damage. Offset-halves journal bearings have the durability equal to lemon bore bearings while these show stiffness and damping properties which permit light loads at high rotational speeds. It also offers the advantage of a long, minimally convergent inlet gap, resulting in high load carrying capacity. At the same time, the externally applied force and the compression resulting from the horizontal displacement of the bearing halves accurately holds the shaft in the lubricant film. This effect produces excellent hydrodynamic characteristics, such as elastic rigidity and damping by the oil film. Thus, the offset-halves journal bearings prove to be technical alternative to conventional lemon bore bearings [Chauhan and Sehgal: 2008].

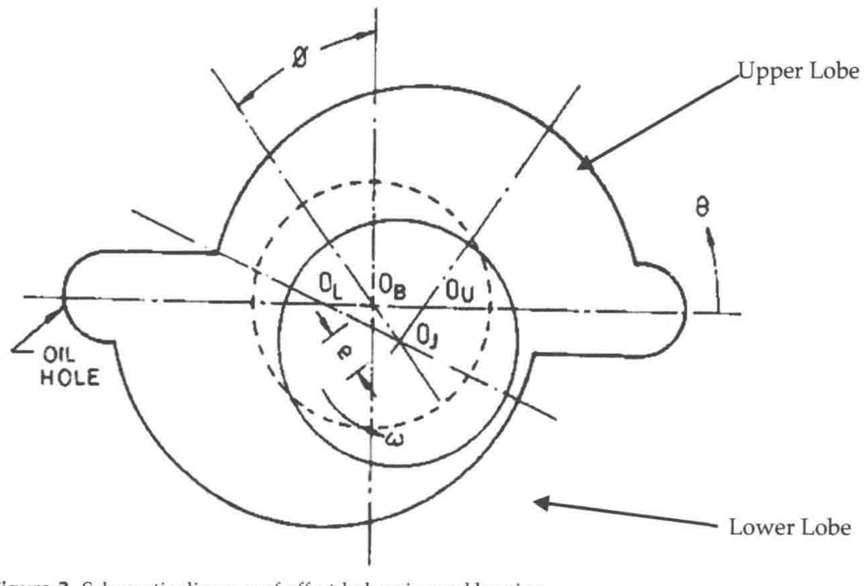

Figure 3. Schematic diagram of offset-halves journal bearing

The elliptical journal bearings (Fig. 4) are commonly used in turbo-sets of small and medium ratings, steam turbines, and generators. The so-called elliptical journal bearing is actually not elliptic in cross section but is usually made up of two circular arcs whose centers are displaced along a common vertical straight line from the centre of the bearing. The bearing so produced has a large clearance in the horizontal or split direction and a smaller clearance in the vertical direction. Elliptical journal bearings are slightly more stable toward the oil whip than the cylindrical bearings. In addition to this elliptical journal bearing runs cooler than a cylindrical bearing because of the larger horizontal clearance for the same vertical clearance.

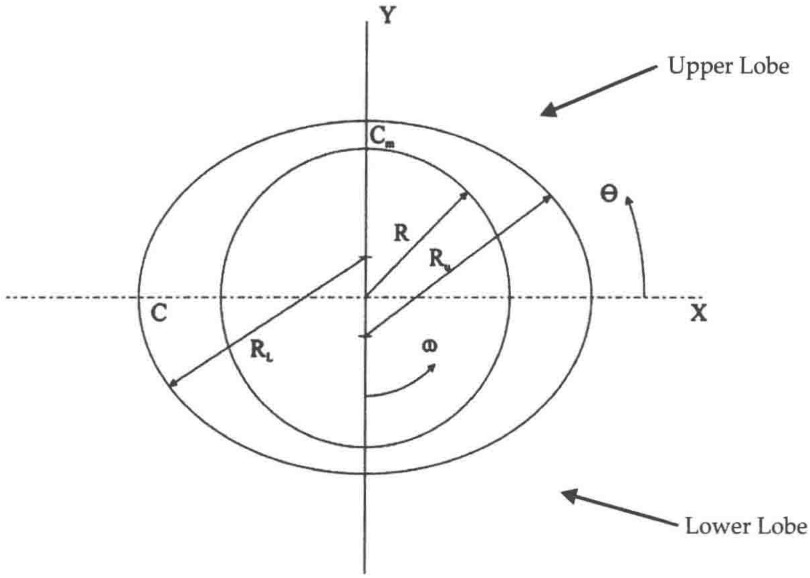

Figure 4. Schematic diagram of elliptical journal bearing

2. Literature review

This section of the chapter provides details of research carried out on hydrodynamic bearings in general and, offset-halves and elliptical journal bearings in particular. There is enormous information available on the theoretical and experimental work related to the circular journal bearings. However, such work pertaining to non-circular journal bearings especially offset-halves and elliptical journal bearings are limited and hence, the theoretical and experimental works pertaining to non-circular journal bearings have been summarized:

Pinkus and Lynn [1956] have presented an analysis of elliptical journal bearings based on the numerical solution of Reynolds equation for finite bearings with the assumption that there is no heat loss to the surroundings. They have supplemented the solution of differential equation by additional work on the nature of the oil flow, power loss, and eccentricity in elliptical journal bearings. Wilcock [1961] has worked towards the possibility of displacing the lobe centers of two-lobe journal bearings orthogonally with respect to the mid-radius of the lobe. The author shows that when the lobe displacement is in a direction opposite to the shaft surface motion, and the bearing is centrally loaded, shaft stiffness orthogonal to the load vector is substantially increased. At the same time, vertical stiffness essentially remains unchanged and minimum film thickness is decreased; particularly at low loads, while oil flow is increased. Author also carried out an analysis for a bearing having in cross-section two arcs (each subtending an angle of 150^0), L/D=1/2, and with the arc centers each displaced from the geometric center by half the radial clearance. Singh et al. [1977] have reported that non-circular bearings are finding extensive use in high speed machinery as they enhance shaft stability, reduce power losses and increase oil flow (as compared to circular bearings), thus reducing bearing temperature. The authors had presented a solution to analyze the elliptical bearings, using a variational approach. Crosby [1980] has solved full journal bearing of finite length for thermohydrodynamic case in which the energy transmitted by conduction is included. The effect of temperature variation across the film thickness on bearing performance is investigated by the author. Singh and Gupta [1982] have considered the stability limits of elliptical journal bearings supporting flexible rotors. The Reynolds equation was solved numerically for several values of the eccentricity ratio, the L/D ratio and the dimensionless velocity of the journal centre. The authors observed that the operating load, ellipticity, L/D ratio and shaft flexibility significantly affect the limit of stable operation. The authors also reported that elliptical bearings are suitable for stiff and moderately flexible rotors. Tayal et al. [1982] have investigated the effect of non-linear behavior of additive-fortified lubricants which behave as non-Newtonian fluid on the performance characteristics of the finite width elliptical journal bearing. The finite element method with Galerkin's technique was used to solve the Navier-Stokes equations in cylindrical co-ordinates that represent the flow field in the clearance space of a bearing using Newtonian fluids, and then the non-Newtonian effect was introduced by modifying the viscosity term for the model in the iterations. Booker and Chandra et al. [1983] have compared the performance of different bearing configurations namely offset-halves, lemon-bore, three-lobe and four-lobe bearing at the same load capacity and speed. During the comparison, the authors have considered the steady state and stability characteristics. Govindachar [1984] have suggested that Novel 'offset' designs offer attractive possibilities in several applications for which conventional journal bearings are only marginally satisfactory. They considered one such prototypical problem in rotating machinery (the support of a rigid rotor turning at high speed under gravity). The problem has been studied by the authors through a numerical example for both dimensional and non-dimensional parametric studies. The authors show that the stability of full journal bearing system is significantly improved by moderate offset and is fairly insensitive to small departures from optimal design values. Singh and Gupta [1984] have theoretically predicted the stability of a hybrid two-lobe bearing which is obtained by displacing the lobe centers of an elliptical bearing. It has been found that an orthogonally displaced bearing is more stable than the conventional bearings. Mehta and Singh [1986] have analytically analyzed the dynamic behaviour of a cylindrical pressure dam bearing in which centers of both halves are displaced. Authors observed that the stabilities of a cylindrical pressure dam bearing can be