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Analysis Of Hydrodynamic Journal Bearing: A Review

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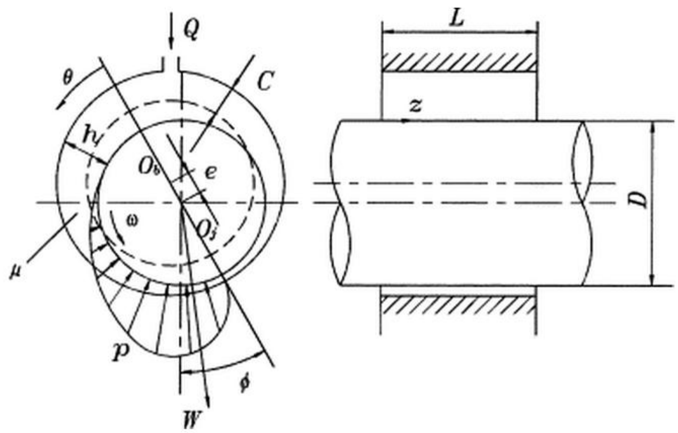
Abstract

This paper presents a survey of important papers pertaining to analysis of various types of methods, equations and theories used for the determination of load carrying capacity, minimum oil film thickness, friction loss, and temperature distribution of hydrodynamic journal bearing. Predictions of these parameters are the very important aspects in the design of hydrodynamic journal bearings. The present study mainly focuses on various types of factors which tremendously affect the performance of hydrodynamic journal bearing.

Keywords: Load Carrying Capacity, Minimum Oil Film Thickness, Friction Loss, Temperature Rise, Reynolds Equation, Navier-Stokes Equation, Finite Elements Method and Runge-Kutta Method.

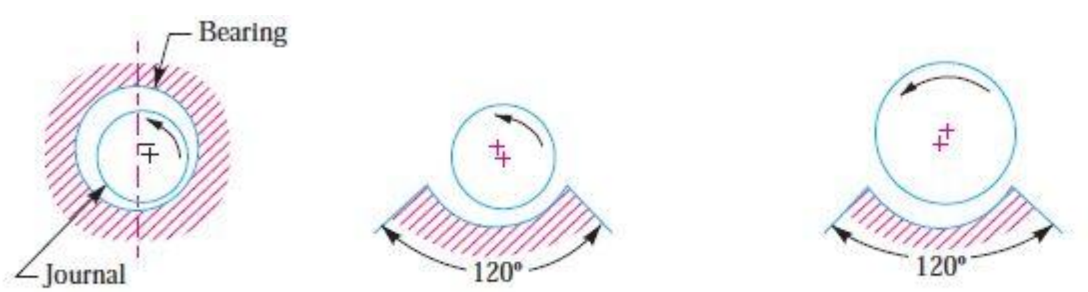
Introduction

Hydrodynamic journal bearings are commonly used in various rotating machines such as pumps, compressors, fans, turbines and generators are widely used in industries. A journal bearing is the most common hydrodynamic bearing in which, a circular shaft, called the journal, is made to rotate in a fixed sleeve is called the bearing. The bearing and the journal operates with a small radial clearance of the order of $1/1000^{th}$ of the journal radius. The clearance space between the journal and the bearing is assumed to be full of the lubricant. The radial load squeezes out the oil from the journal and bearing face and metal-to-metal contact is established. When the journal begins to rotate inside the bearing, it will climb the bearing surface and as journal speed is further increased; it will force the fluid into the wedge-shaped region. Since more and more fluid is forced into the wedge-shaped clearance space, which begins to exert pressure with increasing journal speed. At a particular speed, the pressure becomes enough to support the load and the closest approach between journal and bearing where the oil film thickness is the minimum. A condition of perfect lubrication will exit when minimum oil film thickness is greater than the quantity dependent on the nature of the irregularities of the contacting surfaces. The value of minimum oil film thickness, the angle between the line of center with the vertical is called the attitude angle and the location of the maximum film pressure is important considerations in journal bearing lubrication [17]. In this type of bearing, it is not necessary to supply the lubricant under pressure and the only requirement is sufficient and continuous supply of the lubricant [20].



The journal bearing can be classified in to three types according to the angle of the contact between the journal and the bearing as the follows:

- **Full journal bearings:** When the angle of contact of the bearing with journal is 360^0. It is used in industrial machine so that it can accommodate radial load in any direction.
- **Partial journal bearings:** When the angle of the contact of the bearing with the journal is 120^0 but the diameter of the journal not equal to the bearing diameter. Partial journal bearings are used only to accommodate one radial direction and are used in rail road car axles. This type of bearing bear less friction due to small angle of contact.
- **Fitted journal bearings:** When the angle of the contact of the bearing with the journal is 120^0 but the diameter of the journal is equal to the bearing diameter.



(*a*) Full journal bearing. (*b*) Partial journal bearing. (*c*) Fitted journal bearing.

Literature Review

The effects of bearing and housing elasticity on the stress fields, which could result in surface fatigue in journal bearings, have been investigated. The parameters such as pressure gradient, presence of oil grooves, flexibilities of backing and housing materials, non-uniform housing supports and non-uniform temperature distributions have been individually considered as the sources of stresses in journal bearings. The combination of these stress sources may cause surface fatigue in journal bearings. Two-dimensional and three-dimensional bearing have been modeled by using finite element modeling [16]. Consider the flexibility of porous bearings, the Brinkman model to predict the influences of viscous shear stresses on the bearing characteristics of long, flexible, porous journal bearings. The oil film pressure is numerically calculated by the Fourth Runge-Kutta method and this pressure is utilized to evaluate the load carrying capacity and the friction parameter. A comparison of the results between the Darcy model and Brinkman model is made to show the viscous shear effects provide an increase in the load capacity, as well as a decrease in the friction parameter [9]. Water-based fluid can reduce the fire risks in areas such as hot rolling mills, underground mining, die casting, steel and plastic industries, etc. A binary fluid mixture is used with different viscosity ratio, namely two, ten, twenty five, hundred and their inverse. By solving Navier-Stokes equation with the aid of the Simpson rule, calculated the pressures, drags and load carrying capacities and predict their comparison at different viscosity ratio [11]. A theoretical study of the effects of circumferential, axial and combined surface waviness on the performance of the hydrodynamic journal bearings is presented. When waviness number is approximately below nine, then circumferential waviness increases the load carrying capacity and decreases the friction variable. But the axial waviness is to always have an opposite effect on the load carrying capacity and friction variable. The combined waviness increases the load carrying capacity and friction variable when the circumferential and axial waviness numbers are kept approximately below nine and two respectively. Reynolds equation has been used for Newtonian isoviscous lubricant [7]. The effect of isotropic roughness on the steady-state characteristics of hydrodynamic journal bearings is analyzed. The steady-state characteristics of a hydrodynamic journal bearing in terms of load capacity, attitude angle, end leakage flow rate, misalignment moment and friction coefficient are estimated for different values of roughness parameter, eccentricity ratio and degree of misalignment at unit slenderness ratio. The steady-state oil film pressures are obtained by using Reynolds equation with the help of finite difference method [18]. The effects of circumferential groove on the minimum oil film thickness in engine bearings are presented. Infinitely short bearing theory is used to calculate the oil film pressure for the convenience of analysis. Mobility method is used for journal locus analysis. A comparison of results of minimum oil film thickness (MOFT) of grooved and un-grooved bearing is made. It is observed that the circumferential 360^0 groove only decreases the magnitude of the MOFT, but 180^0 half groove affects the shape and position of the MOFT [12]. New design of the journal bearing with two-component surface layer is analyzed and experimentally proved its usefulness in the case, where oil is contaminated by hard particles.

Helical grooves are made on the bearing journal surface that should enable to eliminating contaminants from the frictional contact zone. In addition, if the soft material is placed in the immediate vicinity of the grooves it will restrict the hard particles driving into the bearing surface. This type of bearing design provides about one-fifth times lower sensitivity to the contamination than conventional bearing design [8]. Acoustical properties of hydrodynamic journal bearing are investigated through frequency analysis of pressure fluctuation of the lubricant film calculated from nonlinear analysis. The universal Reynolds equation is solved at each step of time using the finite difference method and the nonlinear transient motion of the journal centre is obtained by numerical integration of its acceleration using fourth order Runge-Kutta method. The acoustical frequency spectra of the lubricant film are pure tone spectra, having the frequency of the shaft rotation and its super-harmonics sound pressure level of fluid film could be enlarged to predict noise of bearing [4]. The effects of design parameters on the noise of rotor-bearing system supported by oil lubricated journal bearing are investigated. The Reynolds equation for finite width bearing under unsteady condition is applied for calculating pressure. Finite Difference Method, along with the column method is also used for the analysis. The graphs of the A-weighted sound pressure level of the bearing for various speeds of rotation of the rotor are presented. It is observed that the radial clearance, mass eccentricity of the rotor and the width of the bearing considerably affect the A-weighted sound pressure level of the bearing [3]. Wall slip in journal bearing increases the journal instability, vibration and oil film collapse. Wall slip problem is studied by parametric quadratic programming method and finally a generalized form of Reynolds equation with wall slip for two-dimensional flow is found. It is observed that if both surfaces have same adhesion property with a lubricant then wall slip will decrease the oil film load support capacity. On the other side, if both surfaces have different adhesion properties, then effect of wall slip is more complex. To avoid the wall slip, the limiting shear stress at the bearing surface should be more than that at the journal surface [5]. Shaft misalignment in bearing system is the most common cause of wear. The bearing is assumed to operate in the hydrodynamic region, at high eccentricities, wear depths, and angular misalignment. The relationship among the friction force, wear depth and misalignment angles is found out by developing an analytical model. The Reynolds equation is used to calculate the friction force in the equilibrium condition. The friction coefficient is presented versus misalignment angles and wear depths for different Sommerfeld numbers, hence friction function dependent on wear and misalignment of the bearing [14]. The performance characteristics and the core formation of a hydrodynamic journal bearing lubricated with a Bingham fluid are derived by means of three-dimensional computational fluid dynamics analysis. The Navier–Stokes equations are solved using the FLUENT. Three-dimensional computational fluid dynamics model are found to be in very good agreement with experimental and analytical data from previous investigations on Bingham fluids. The validated Computational Fluid Dynamics (CFD) model is used to extract a series of diagrams in the form of the Raimondi and Boyd graphs and can be use in the smart bearing design [10]. Steady-state thermodynamic analysis of an axial groove bearing is performed theoretically. This requires simultaneous solution of

Reynolds equation, energy equation and heat conduction equation with appropriate boundary conditions in the journal bearing. It is studied that the fluid film temperature increases due to frictional heat resulting viscosity, load carrying capacity decreases. Single axial groove geometry on the performance of the journal bearing is very important. It is observed that groove angle of 36^0 and groove length (Half of the bearing length) promoted to decrease the maximum temperature and increase the load carrying capacity [19]. A mathematical optimization procedure is presented to find the optimal film height distribution for a hydrodynamic bearing. Optimal is defined as the film height distribution that is able to carry a prescribed load with maintaining a maximum separation between the bearing surfaces. Firstly this methodology is applied for a bearing with constant load and sliding speed. Then subsequently applied for a bearing with periodic load and sliding speed. Slider bearings with different shapes, loads and speeds are analyzed by new heuristic load optimization procedure along with Reynolds equation which is more efficient than general purpose optimization routine [15]. The structure of lubricant film is modified by using double layer of lubricant in to clearance space of bearing surfaces in place of single layer of lubricant. The composite-film bearing combines the advantages of high-viscosity with the low-viscosity lubricant. The low-viscosity lubricant will be to reduce viscous dissipation, while the high-viscosity lubricants maintain the desirable thickness to separate out the bearing surfaces. The basic Reynolds equation is used for composite films under the restrictive assumptions by applying boundary conditions. On comparing the performance of four bearings, which are lubricated, respectively, by a homogeneous film of ISO50 oil, a composite film of ISO130 oil+water, a composite film of ISO500 oil+water, and a composite film of ISO1000 oil+water with identical dimensions and the operating parameters of bearing. Composite-film bearings have considerably lower frictional losses in comparison to traditional bearings [2]. Hydrodynamic bearings are known for initial wear due to direct contact between bearing surfaces. This problem is overcome by assembling hydrodynamic bearing with rolling bearing, separated by a fixed clearance to form a Journal-Rolling Hybrid Bearing (JRHB). The journal is supported by the rolling bearing, under the condition of insufficient hydrodynamic pressure (IHP) so to protect the hydrodynamic bearing from metal to metal contact while under the working condition the journal is supported by hydrodynamic bearing alone. Designing and fabricating a test rig to investigate the stability nature of the JRHB have been carried out to demonstrate its feasibility. Experimentally a series of tests it measured the clearance circles of the hybrid bearing, shaft orbit and the load sharing of the rolling bearing. It is found that the rolling bearing plays a protective role under IHP condition [6]. The influence of roughness on the hydrodynamic journal bearing performance is very important. The use of different shapes of textures and at different locations of the texture zone can be an effective approach to improve the performance of the bearings. A numerical model based on finite difference method by using Reynolds equation is developed to study the cylindrical textures shape effect on the performance of hydrodynamic journal bearing. Twenty five cases according to the geometric arrangement of textures on the bearing surface have been considered. The texture configuration twenty five gives the best result compared with all the other cases, the minimum oil film thickness increased approximately by 1.8% and friction torque is decreased approximately by 1.0% [13]. To design the proper bearing in order to eliminate the deviation of the final product in extrusion process, a general methodology has been developed. Three smooth curved dies with non-symmetric T-shaped sections at different off-centricities have been taken and for each die proper bearing has designed. Bezier curve is used to determine the exit velocity profile with aid of Chitkara corrective function. Physical and numerical modeling has been performed to validate the bearing design. It is seen that the deviation of the final product is eliminated to a great extent [1].

Conclusions

The stress types, magnitudes and distributions in journal bearings are affected by the geometrical and physical properties of the bearing system. Brinkman model (BM) significant improves the lubrication performance of long, flexible, porous journal bearings in comparison with Darcy model. The load carrying capacity and misalignment moment decrease with an increase in the roughness for all values of the eccentricity ratio while attitude angle and end leakage flow increase with the roughness parameter. The frictional coefficient increases with the degree of misalignment at lower values of the eccentricity ratio. The circumferential 360^0 groove only decreases the magnitude of the minimum oil film thickness, but 180^0 half groove affects the shape and position of minimum oil film thickness. The noise of the bearing decreases as the mass eccentricity of the rotor decreases, the lubricant viscosity increases, the width of the bearing increases, and the radial clearance of the bearing decreases. The friction coefficient is increased, with increasing wear depth as well as misalignment and Sommerfeld number. The friction coefficient and consequently the power loss are strongly dependent upon the misalignment angle and wear depth.

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