# A Technical Review on Design & Thermal Behavior of Non-circular Hydrodynamic Journal Bearing using CFD Technique

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***Abstract* – The revolutionary changes have taken place in the field of hydrostatic and hybrid journal bearing from very slow speed radar to very high speed turbo machinery. These find application in ultra precision machine tools requiring high stiffness to improve accuracy. The growing demands from industries for higher speed applications and ability of hybrid journal bearing to support heavy loads have necessitated studying the performance of bearings in detail under more realistic conditions. However, the high speed operation of bearings results in higher operating temperature of both lubricant and bearing surface. Increase in bearing temperature poses a danger to bearing liner as well as to lubricant. It not only degrades the performance of a bearing but also of machine itself. Also, an increase in lubricant temperature reduces its viscosity and thereby changes the fluid-film profile**

***Keywords* – Hydrodynamic Journal Bearing, Thermo-hydrodynamic Analysis, lubricant temperature, viscosity.**

## I. INTRODUCTION

Hydrodynamic bearings are common components of rotating machinery. They are frequently used in applications involving high loads and/or high speeds between two surfaces that have relative motion. Journal bearings are specific to surfaces that mate cylindrically with the applied load in the radial direction. In the study of journal bearings many aspects of engineering are present. Stress analysis, fluid dynamics, instrumentation, vibration, material properties, thermodynamics, and heat transfer are some of the common subjects encountered in understanding hydrodynamic bearings. Bearings are used to prevent friction between parts during relative movement. In machinery they fall into two primary categories: anti-friction or rolling element bearings and hydrodynamic journal bearings. The primary function of a bearing is to carry load between a rotor and the case with as little wear as possible. This bearing function exists in almost every occurrence of daily life from the watch on your wrist to the automobile you drive to the disk drive in your computer. In industry, the use of journal bearings is specialized for rotating machinery both low and high speed. This paper will present an introduction to journal bearings and lubrication. Lubrication technology goes hand-in-hand with Understanding journal bearings and is integral to bearing design and application.

Hydrodynamic bearings are common components of rotating machinery. They are frequently used in applications involving high loads and/or high speeds between two surfaces that have relative motion. Journal bearings are specific to surfaces that mate cylindrically with the applied load in the radial direction. In the study of journal bearings many aspects of engineering are present. Stress analysis, fluid dynamics, instrumentation, vibration, material properties, thermodynamics, and heat transfer are some of the common subjects encountered in understanding hydrodynamic bearings. Since they have significant damping fluid film journal bearings have a strong impact on the vibration characteristics of machinery. The types of machinery we are concerned with range from small high speed spindles to motors, blowers, compressors, fans, and pumps to large turbines and generators to some paper mill rolls and other large slow speed rotors. 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 process, 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. 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. Plain Journal*

The plain journal bearing is the most basic of fluid-film bearings, shown in figure 1, and involves a shaft which spins within the circumference of a single, continuous outer bearing surface, suspended by a thin film of lubricating oil. The simplicity of this bearing type renders it relatively inexpensive; however, the low cost comes at the price of high destabilizing forces. The continuous, uninterrupted fluid film undergoes whirling creating cross-coupled forces, which continue to grow with increased speeds. In addition to high cross-couple forces, the plain journal bearing has relatively low damping compared to other options, leaving it susceptible to self-excited rotor instabilities.

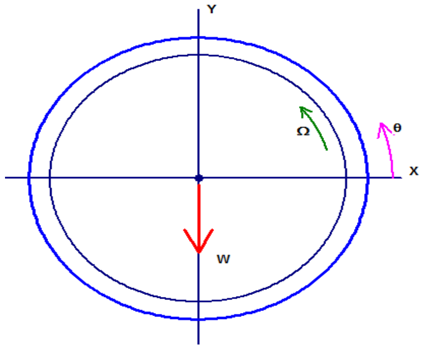


Fig. 1. Typical Plain Journal Bearing

*1.2. Axial Groove*

Although similar to the plain journal bearing, the axial groove bearing differs in that it has length-wise grooves cut in the outer bearing surface, parallel to the axial length of the journal, seen in figure 2. These grooves allow for greater oil supply, which helps to reduce (but not eliminate) the self-induced instabilities found in the plain journal bearing. The cost of the axial groove bearing is slightly higher than that of the plain journal bearing due to the added machining required to create the grooves.

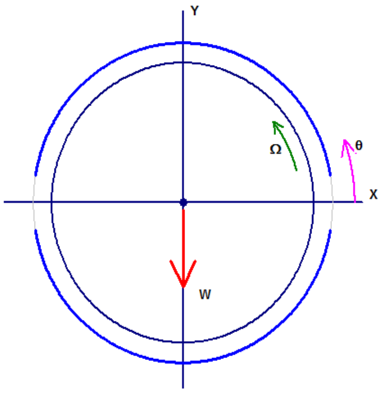


Fig. 2. Typical Axial Groove Journal Bearing

*1.3. Elliptical*

The elliptical or lemon-bore bearing, seen in figure 3, has a lemon-shaped profile, that is, the bore of the bearing is oblong with grooves machined at the ends of the bore. Oil is supplied in the grooves and is picked up by the rotating shaft. The converging clearance between shaft and bearing creates a pressure gradient which tends to somewhat reduce shaft instabilities such as whirl, but still introduces cross-coupling instabilities. The elliptical bearing is still relatively inexpensive, but more costly than the axial groove bearing.

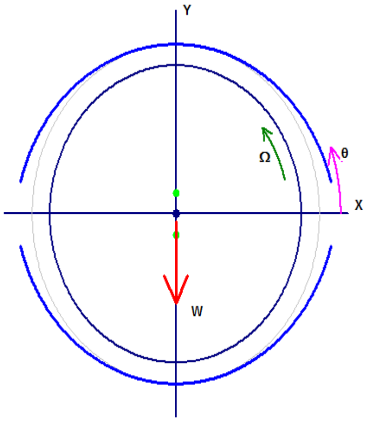


Fig. 3. Typical Elliptical Journal Bearing

*1.4. Offset Half*

The offset half bearing is similar to an elliptical journal bearing, cut in half (upper and lower, for example). The halves are staggered, as seen in figure 4, by approximately half the clearance radius. Similar to the elliptical bearing, this creates a pressure gradient which reduces the whirl of the shaft; although, cross-coupling is still present as a result of the bearing. The improved stability comes at an additional cost in that the stagger of the halves yields the bearing effective in only one direction of motion & the converging surfaces do result in power losses.

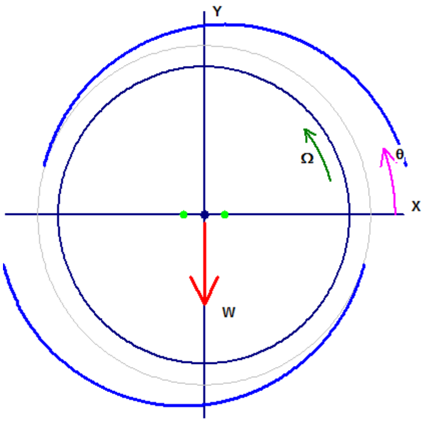


Fig. 4. Typical Offset Half Journal Bearing

*1.5. Multi-lobe*

The outer surface of multi-lobe bearing is made up of a series of individual segments ("lobes" or "pads") separated by axial grooves which provide an oil supply to the bearing as seen in figure 5, similar to the axial groove bearing. This scheme generates a series of converging surfaces, creating pressure gradients as are visible in Figure 5; note that the more heavily loaded lobes, where clearances become tighter, create higher pressures, as expected. While this concept provides a greatly improved damping (stabilizing) effect over plain journal bearings, it comes at a higher manufacturing cost, as well as the robbing of power from the system in which it serves due to the multiple converging surfaces.

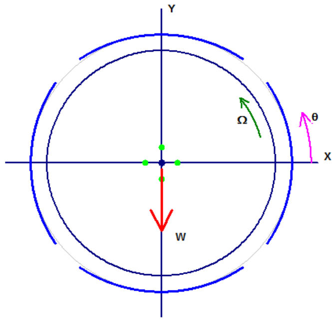


Fig. 5. Typical Multilobe Journal Bearing

*1.6. Pressure Dam*

The pressure dam bearing is similar to an axial groove bearing with one key difference. A relief pocket is milled into the bearing surface, as seen in figure 6. The relief begins gradually and ends abruptly; this sharp edge is the "dam" which results a pressure spike of the lubricating oil (hence "pressure dam"). This increased pressure, usually located on the top of the bearing, applies an artificial downward force on the shaft to greatly reduce instabilities. A relief is sometimes included over the entire radius of the loaded half of the bearing to increase the effects of the artificial loading of the pressure dam, further lessening instabilities induced by oil whirl. The artificial forces result in significant power losses, and the precise machining involved to fabricate this bearing is also significant.

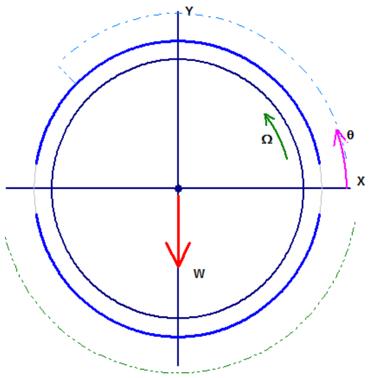


Fig. 6. Typical Pressure Dam Journal Bearing

## II. LITERATURE REVIEW

Ram et al. [1] presented a study on the performance of an orifice compensated sym- metric hole-entry hybrid journal bearing operating with micro- polar lubricant has. On the basis of numerically simulated results presented in this paper. Lin et al. [2] develoed a suitable and effective computational approach for transient analysis on the fluid/structure interaction in a rotor- bearing system by combining CFD and FSI techniques. Gertzos et al. [3] examined the performance characteristics and the core formation in a hydrodynamic journal bearing lubricated with a Bingham fluid. The load carrying capacity, the film pressure, and the frictional force of a Bingham solid are larger than those of a Newtonian fluid. Deligant et al. [4] conluded that the bearing cooling mostly occurs by conduction throughout the bearing and convection inside the outer clearance. The friction torque is not a linear function of speed. The slope of friction torque may decrease with speed for low oil temperature. Bompos et al. [5] presented an integrated simulation study, of a magnetorheological (MRF) fluid journal bearing, via computational fluid dynamics (CFD) and finite element method (FEM). The journal bearing characteristics such as, eccentricity, attitude angle, oil flow and friction coefficients are calculated and presented as functions of the magnetic field, and L/D bearing ratios. Chasalevris et al. [6] carried out a very recent analysis of the exact analytical solution of the Reynolds equation for the lubrication of the plain journal bearing with finite length in order to evaluate the impedance forces of the fluid film and define them in closed form analytical expressions. Brito et al. [7] proved based on the present investigation, that the twin groove journal bearing might be problematic under combinations of high eccentricity and low feeding pressure. Papadopoulos et al. [8] demonstrated the possibility of clearance defect identification due to wear, in a system of a flexible rotor supported on two journal bearings by response measurement at any arbitrarily point. The stability of a rotating system with worn clearances is also examined, indicating the future stable or unstable operation of the system. Sharma et al. [9] proved that, a slot-entry hybrid journal bearing operating with micropolar lubricant shows an increase in the value of minimum fluid film thickness and a reduction in the value of coefficient of friction as compared to a corresponding similar slot-entry hybrid journal bearing operating with Newtonian lubricant. Prasad et al. [10] analyzed the system with non-Newtonian incompressible power law lubricants where the consistency of the lubricant varies with pressure and temperature. Also there is significant change in pressure and temperature while non-Newtonian fluid is considered. Montazeri [11] showed that compared with Newtonian fluids, that micro polar fluids exhibit the increase in load capacity and temperature, but the decrease in coefficient of friction and side leakage flow. in the full film region, micro polar fluids increase the values of nondimensional density, while in the cavitated region, both micro polar fluids and Newtonian fluids yield the same values of the fractional film content Ouadoud et al. [12] suggested that, the distortion field due to pressure plays an important role in predicting the behaviour of the bearing, particularly on the pressure and the maximum temperature that is lower than that obtained with the "THD" lubrication and a rigid pad. Panday et al. [13] mentioned that, the maximum pressure, the bearing can withstand is increasing with increase in L/D ratio. The maximum pressure is noted at minimum oil film thickness. Turbulent viscosity of the lubricant increases with increase in L/D ratio and the level of turbulence at the minimum oil film thickness is low. Boubendir et al. [14] showed theoretically that, the temperature influence on the journal bearings performance is important in some operating cases, and that a progressive reduction in the pressure distribution, in the load capacity and attitude angle is a consequence of the increasing permeability. Nicodemus et al. [15] solved the modified Reynolds equation for micropolar lubricant using FEM and the Newton–Raphson method along with appropriate boundary conditions. The influence of micropolar effect of lubricant on bearing performance is predominantly affected by the geometric shape of recess and restrictor design parameter. Rahmatabadi et al. [16] recommended Generalized differential quadrature (GDQ) method is a simple, efficient and high order numerical technique used for the solution of modified Reynolds equation to obtain the performance of micropolar lubricated hydrodynamic circular and noncircular lobed journal bearings. Garg et al. [17] used FEM to solve the Reynolds equation governing flow of lubricant in bearing clearance space along with restrictor flow equation, energy equation and conduction equation using suitable iterative technique . Variation of viscosity due to temperature rise and non-Newtonian behavior of lubricant affects the bearing performance quite significantly. Bhaskar et al. [18] used Flow factor method in the analysis to evaluate the roughness terms and the finite difference method is used to find the pressure distribution over the bearing surface. The load carrying capacity is increased by 52.57% compared with the bearing having zero surface roughness. Mongkolwongrojn et al. [19] presented that, stability of the bearing system deteriorates with decreasing both the power law exponent and the elastic modulus of bearing liner material. The rough surface journal bearing with transverse pattern under TEHL regime exhibits better stability when compared with the rough surface journal bearing with longitudinal pattern. Nair et al. [20] used Finite element technique to solve the modified Reynold's equation governing the flow of micropolar lubricant in the clearance space of the journal bearing and the three-dimensional elasticity equations governing the displacement field in the bearing shell. Sharma et al. [21] reported that, the variation of viscosity due to temperature rise of the lubricant fluid-film have a quite appreciable influence on the static and dynamic performance of a hole-entry hybrid journal bearing system. Nassab et al. [22] solved numerically the set of continuity and momentum equations for compressible two-dimensional lubricant flow in journal bearings by CFD method. The compressibility effect causes an increase in the generated hydrodynamic pressure, such that this effect is enhanced under the condition of high shaft rotational speed, small clearance and high eccentricity ratio. Mishra et al. [23] presented that, with increasing non-circularity the pressure gets reduced and duplicated after the non-circularity of 0.3 and the temperature rise is less in the case of a journal bearing with higher non-circularity value. Kuznetsov et al. [24] showed that, increased load carrying capacity, significantly reduced peak pressures and thicker oil film in the loaded zone compared to a white metal bearing. Load carrying capacity is more sensitive to thermal expansion while pressure and oil film thickness profiles are more sensitive to elastic deformation. Brito et al. [25] analyzed the main factors which can affect the lubricant feeding – feeding pressure and temperature, groove length ratio, groove width ratio and number of grooves (single/twin) for a broad range of specific loads, extended well beyond the range of practical applications. Ostayen et al. [26] presented a finite element analysis which has been used to calculate the pressure and temperature distribution in the lubricating film of a lemon- bore journal bearing. The model has been used to study the influence of different design parameters on the maximum temperature and other operating conditions. Wang et al. [27] proved that, lubricants with couple stresses, compared with Newtonian lubricants, not only yield an obvious increase in load capacity and decrease in friction coefficient, but also produce a lower bearing temperature field. The lubricant with couple stress does improve the performance of journal bearings.

## III. CONCLUSION

A thermo hydrodynamic (THD) model for bearing analysis can be developed which treats the viscosity as a function of both the temperature and pressure. Moreover, it also considers the variation of temperature across the film thickness and through the bounding solids (housing and Journal). The thermo hydrodynamic model can present coupled solutions of governing equations by incorporating appropriate boundary conditions and considering the heat conduction across the bearing surfaces. An attempt would be made to compare the performance of two bearing configurations of same geometrical size by using common commercial grade oils under similar operating conditions. Three dimensional studies can to be carried out to predict pressure distribution & temperature profile along journal using different boundary conditions.

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