Dynamic Analysis of Non-Circular Journal Bearings operating with Nano Fluids

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Abstract
The purpose of this article is to provide design guidelines for Non-Circular Journal Bearings that use nano lubricants (Non-Newtonian Fluids). The effects of eccentricity ratio on pressure distribution in non-Newtonian fluids are examined. Next, rotational speeds with different angular Coordinates are used to conduct a numerical analysis of journal bearings. A finite difference technique iterative approach that fulfils the necessary design parameters is employed to solve the Reynolds equation numerically. Different aspect ratios (L/D) and eccentricity ratios have been investigated. Increasing (L/D) led to a rise in maximal pressure, as per the results.

Keywords: Non-Newtonian Fluids, eccentricity ratio, Non-Circular Journal Bearings etc.

1.Introduction

Tribology is the study and science of interacting surfaces in relative motion and associated disciplines and activities This topic deals with the technology of lubrication, friction management and wear prevention of the surface undergoing relative motion under load. To have a complete grasp of the topic and its applications to machine elements, it is required to comprehend various disciplines . It is the goal of all researchers to develop new lubrication technologies, develop new lubricants, and discover new materials that can withstand repeated use in order to reduce machine wear and friction. When friction and wear are regulated and decreased, the service life of the machine parts will rise and it saves money.

Lubrication is the Science of lowering frictional resistance by use of some form of material injected between the two surfaces undergoing relative motion. Such a material which has some level of viscosity is known as lubricant. A bearing is a set of machine parts whose role is to sustain an imposed load by decreasing friction between the relatively moving surfaces. It is used to prevent friction, which causes wear and tear of moving equipment. A radial, axial, or a mix of the two types of load may be applied. To describe a bearing that can handle radial loads, we use the terms radial or journal bearing, while a bearing that can support thrust or axial loads is referred to as a thrust bearing. Some bearings can withstand both radial and axial load and they are known as conical bearings. The purpose of the lubrication is to decrease friction, wear and heating of machine components which are in a relative motion. In fluid film lubrication a very thin layer of fluid entirely separates two solid surfaces which are in relative motion with in the fluid film. This motion creates a shearing action that takes a relatively modest effort in the direction of motion. The surfaces are generally part of the bearing which locates and maintains fluid film dependent on the kind of lubrication.

Hydraulic bearings are required as the need for turbo-machinery performance enhancement rises in order to function at higher speeds and with lower friction while still preserving power. Different bearing designs are now being designed and manufactured for high precision and high speed in response to new technologies. When it comes to making bearings, there are a variety of materials to choose from that may be utilised in a wide range of designs and combinations. Analysis of non-circular journal bearings in a variety of situations has shown remarkable results. Following design, fabrication, and installation, bearing lubrication plays a critical role in bearing performance. Different characteristics of lubrication mechanisms are examined under various operating situations, such as lubricant selection, thermal properties, and flow rates. If the fluid is Newtonian, shear stress and strain are linearly related. If the fluid is not Newtonian, the connection is not linear. Traditionally, bearing design has relied on the Reynolds equation and assumed a Newtonian lubricant, but experimental results in fluid film lubrication have shown unusually unexpected viscosity values that can't be explained by conventional wisdom[1]. The evolution of current industrial materials necessitates the employment of diverse additives to increase the performance of lubricating fluids [2,3].Deploying new lubricant compositions that can achieve energy efficiency in various locations and when used under harsher circumstances is a serious scientific task, despite the fact that the bulk of current lubricants have exceeded their performance constraints. Lubricant behavior becomes non-Newtonian when additives are intentionally added to base oils or contaminants are accidentally introduced to lubricants during use. Lubricants may be enhanced with anti-wear, low-friction, high-pressure, and heat-dissipating additives. When it comes to non-Newtonian lubricants, researchers have used a variety of words to describe them. Non-Newtonian lubricants include Bingham fluids, Ferro fluids, coupled stress fluids, & micro polar fluids. Many rotating machinery components contain essential components that are hydrodynamic, hydrostatic, or hybrid, and all three types of bearings have been widely employed. Hybrid journal bearings, which combine the advantages of hydrostatic and hydrodynamic bearings, are now being used in a wide range of industrial and space applications. Non-circular bearing types and geometries have been compared against regular circular/ cylindrical bearings and various oils [4,5] on several occasions. There is a schematic diagram for both circular and elliptical bearings shown in Figure 1.

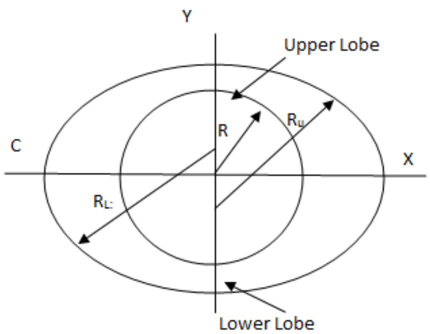

Figure 1 . Schematic diagram of Elliptical bearing.

Literature Review

Eringen[6] presented the first application of micro polar fluid theory to lubrication. The steady motion of micro polar fluids in a circular channel was demonstrated. On the fluid surface adjacent to the wall are graphs showing the profiles of the fluid's flow velocity, shear stress difference, micro rotational velocity, and couple stress. This reduction in shear occurred even though shear stress remained constant and the effect of distributed couples arose in a thin layer adjacent to the fluid's surface. A boundary layer phenomenon that could not be explained by Navier-Stokes theory appeared to be developing.

Poiseuille and Couette flow problems for one-dimensional fully developed and steady flow of incompressible fluid between two parallel plates were first solved by Ariman and Cakmak[7] . There were developed in this study equations for the distribution of velocity and flux of mass. Comparative graphs depicting the velocities for both types of flow and mass flux for couple stress and micro polar fluids were created and compared. Studies on Poiseuille flow and Couette flow in micro polar fluid flow between two concentric cylinders were later carried out by Ariman and colleagues [8]. We talked about velocity, shear stress difference and micro rotational velocity.

Misaligned hydrodynamic journal bearings were the subject of a steady state analysis by Das et al. [9] that took axial and twisting displacements into account while applying the micro polar lubrication theory. In order to obtain a steady state film pressure profile, the modified Reynolds equation based on micro polar fluid theory is solved using the FDM technique. Compared to Newtonian flow, journal bearings under misalignment showed better load-carrying capacity with micro polar lubricant regime. Friction was found to have positive effects as well.

An investigation into the effect of micro polar fluids on dynamically loaded journal bearings was presented by Wang and Zhu [10]. For dynamic loads, they developed a generalized modified Reynolds equation in place of the traditional Reynolds equation. For the same dynamic stresses, micro polar fluids have higher oil film pressure and thickness than Newtonian fluids, and side leakage flow has been reduced.

In terms of hydrodynamic journal bearing stability characteristics under micro polar lubrication, Das et al. [11] compared linear dynamic analysis with non-linear dynamic analysis. At increasing eccentricity ratios, non-linear analysis demonstrates greater stability. For short and finite bearing configurations, linear analysis offers conservative findings, as can be shown from the results. Qualitative agreement may be found between nonlinear analysis and perturbation method.

For hydrodynamic journal bearings under micro polar lubrication, das et al. used linear dynamic analysis to derive theoretical stability parameters. The results of this study show that the stability threshold is higher when the journal bearing is operating in a micro polar fluid regime than in a Newtonian fluid regime. As the magnitude of the micro polar effect grows, so does the threshold of stability, and when the non-dimensional characteristic length reaches a value of roughly 10.0, the effect is at its greatest magnitude[12].

For a finite grooved hydrodynamic journal bearing under micro polar lubrication, Wang and Zhu conducted a theoretical analysis of steady-state performance characteristics[13]. Micro polar fluids have a larger non-dimensional density, yet frictional film content values for Newtonian and micro polar fluids are the same in the cavitated area.

A study by Nair et al. [14] examined the steady-state and linear dynamic properties of elliptical micro polar elasto hydrodynamic journal bearings. Increased volume concentration of additives raises threshold speed, according to the results of a research. When the deformation coefficient is held constant, the damping frequency of a whirl drops.

In their study of a four-pocket hydrostatic journal bearing system using micro polar fluids as lubricant, Verma et al. [15] conducted research. Static and dynamic properties are calculated using FEM. Increases in micro polar effect lead to higher pocket pressure and a thinner layer, according to the data. Stiffness and damping coefficients were found to be higher when the micro polar effect was amplified.

For the capillary compensated four-pocket hydrostatic journal bearing, Nicodemus and Sharma [16] conducted a research to assess the combined influence of wear, bearing arrangement, and micro polar lubricant behavior on bearing performance. Compared to Newtonian fluids, micro polar fluids have higher performance characteristics, however this advantage is lost when the impact of wear is taken into account.

Rahamtabadi et al.[17] reported on the steady-state performance characteristics of non-circular two, three, and four lobed bearings lubricated by micro polar oil. Micro polar fluids provide better performance properties.

Analytical study of the static and dynamic performance features of squeeze film lubrication for finite porous journal bearings was provided by Naduvinamani and Santosh [18]. Under cyclic loading, the velocity of the journal centre decreases due to the impact of micro polar fluids. Under the influence of a porous matrix, the steady state load bearing capacity and maximum fluid pressure drop, while the journal centre velocity rises.

For a multi-recess hybrid journal bearing with micro polar lubrication, Nicodemus and Sharma [19] investigated the effect of wear analytically by calculating fluid film pressure using a modified Reynolds equation and the Newton-Raphson method in conjunction with Dufrane's abrasive wear model developed by Dufrane. Wear and the micro polar effect have a considerable impact on bearing performance, hence these two elements must be taken into account while developing bearings.

For parabolic-film slider bearings lubricated with micro polar oil, Lin et al. [20] found linear dynamic performance characteristics. It was found that bearings with greater fluid-gap interaction and coupling numbers adopting bearings of lesser height improved performance.

Sharma and Rajput[21] published an analytical investigation on the effects of different journal geometric abnormalities, such as bellmounth form, barrel shape, and circumferential undulation, when lubricated with micro polar oil in a 4-pocket hybrid journal bearing. If the correct lubricant and compensating device are used, these geometric defects may be reduced in the journal bearings.

Under micro polar lubrication, Dhawan and Verma[22] predicted the dynamic and steady state properties of noncircular hybrid journal bearings. Bearing flow and film thickness will be reduced if the design parameter for the restrictor is increased. According to the study, noncircular bearings will perform better when working with micro polar fluids.

Under micro polar lubrication, Mehrzadi and colleagues [23] calculated the stability of circular and non-circular journal bearings. Using a modified Reynolds equation, a FEM was used to calculate dynamic properties. Stability is improved by employing noncircular bearings, according to the results of a research. Micro polar lubrication produced better results in terms of performance. At larger coupling values, the effect of micro polar fluids is more pronounced.

Noncircular hybrid Journal bearings were studied by Kumar and Verma [24]. The Modified Reynolds equation was solved using FEM to provide a dynamic solution. Graphs show how micro polar fluids affect bearings in circular and noncircular configurations. Specifications of the micro polar fluid have an impact on the bearing's overall performance.

Thermo hydrostatic study of hybrid journal bearings was theoretically estimated most recently by Khatak and Garg[25]. Three-dimensional energy and conduction equations are used to calculate the performance characteristics of modified Reynolds equations. The research concludes that journal bearing analysis cannot ignore thermal impacts.

3.Methdology

The use of a single element at a time technique to simulate journal bearings was a major worry for many researchers. Journal bearings were incorrectly simulated using the aforementioned technique. Finite element methods may overcome the aforementioned approach's drawbacks [26, 27]. It was possible to arrive at a numerical solution for a hydrodynamic journal bearing using finite element modeling (FEA). It was necessary to refine the model for use with nano-based lubricants in order to make it more accurate. Therefore, FEA's assistance in figuring out how a system's hydrodynamic journal bearing works could be useful. The outer bearing encircles the inner journal of a bearing. An oil-filled gap between the bearing and journal was created by the journal being out of alignment with its bearing axis. A groove provides lubrication for the journal bearing system. The eccentricity of the journal is determined by the pressure of an oil film that forms in the bearing. At normal operating conditions, the lubricating oils gases dissolved in cavitations caused the bearing to fail. Because an oil layer in the lubricating oil has lost pressure below saturation, this occurs. Cavitation was not included in the model's calculations, hence it predicted pressures below ambient. The bearing generated sub-ambient pressure, which led to the Somerfield boundary condition. Reynolds' equation determined the pressure of an oil film that formed in a journal bearing lubricated using nano lubricants. Hydrodynamic lubrication may be represented numerically using the Reynolds formula. Hydrodynamic bearing analysis begins with determining the fluid film pressure for a certain bearing geometry. Resolving this case's Reynolds equation will provide a solution to this issue. The pressure distribution of the journal bearing is discussed in the next paragraphs. It is assumed that the oil film ends at a point where both the pressure and the pressure gradient are zero at the same time under the Reynolds' boundary condition. When it comes to boundary conditions, the Reynolds boundary condition is the most accurate.

Using the FEM, the Reynolds equation describes how lubricant pressure is distributed. Reynolds equation governs the pressure distribution in hydrodynamic journal bearings. The pressure distribution inside the oil film that forms in the space between the bearing and the journal is calculated numerically using Reynolds equation. Reynolds equation:

$$\frac{\partial}{\partial x}\left[h^3\frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial z}\left[h^3\frac{\partial p}{\partial z}\right]=6\mu U\frac{dh}{dx}$$

The non dimensional form of the Reynolds equation is expressed as:

$$\frac{\partial}{\partial\theta}\left[h^{-3}\frac{\partial\bar{p}}{\partial\theta}\right]+\left(\frac{R^2}{L^2}\right)\frac{\partial}{\partial\bar{z}}\left[h^{-3}\frac{\partial\bar{p}}{\partial\bar{z}}\right]=6\bar{\mu}\frac{\partial\bar{h}}{\partial\theta}$$

Where

$$\mathrm{h} = \text{ Fluid film thickness (m)}$$

$$p \;\; = \; Lubricant\ fluid\ film\ pressure\ (\frac{N}{m2})$$

$$U = \; Surface\ Velocity\ of\ Journal\ (m/s)$$

$$\bar{\mu} = \frac{\mu_{nl}}{\mu_{bl}}$$

Where

μ_{bl} *is Viscosity of plain engine oil in* $(Pa - s)$,

μ_{nl} *is Viscosity of the nanolubricant in* $(Pa - s)$

And $\bar{\mu}$ *is relative viscosity.*

$$R \; = \; Journal\ Radius\ (m),$$

$$L \; = \; Bearing\ length\ (m),$$

$\bar{p}$
$= \; Fluid\ film\ Pressure\ in\ Non\ Dimensional\ form$

$\bar{h}$
$= \; Fluid\ film\ thickness\ in\ Non\ Dimensional\ form$

Pressure distribution

The pressure around the Journal in Bearing considering long bearing approximation is expressed as :

$$p = \frac{6\mu_{bl} R^2 \omega \bar{p}}{C^2}$$

Where C= Radial clearance (m)

Load Carrying capacity

The following formula determines the load carrying capability of a journal bearing:

$$W = \frac{12\mu_{bl} R^3 \omega L \bar{W}}{C^2}$$

Friction Force

The friction force is calculated by integrating the shear stress throughout the bearing area of the bearing. It is possible to represent the friction force in non-dimensional form as follows:

$$\bar{F} = \frac{FC}{\mu_{bl} URL} = \int_0^1 \int_0^0 \left[\frac{\bar{\mu}}{\bar{h}} + \frac{\bar{h}}{2} \frac{\partial \bar{p}}{\partial \theta} \right] d\theta d\bar{z}$$

$$Where\ F = Friction\ force\ (N),$$

$$\bar{F} = Non-dimensional\ friction\ force.$$

$The\ friction\ parameter\ is\ then\ obtained\ as$:'

$$f\left(\frac{R}{C}\right) = \frac{\bar{F}}{\bar{W}}$$

The eccentricity ratio of 0.7 was studied by the authors. The clearance ratio is 0.0001 in this case. The bearing's angular velocity is 1200/600. Bearing length (m) is set as 100nm. D (Fractal index) is also thought to be 100nm.

Table 1: Details of Experiments

Nano particle used	TIO_2
Eccentricity ratio	0.7
Clearance-0.1e-3	1.00E-04
Rps	1200/600
L	100nm
D	100nm

4. Result and Discussion

In this research, author has chosen eccentricity ratio 0.7 with concentration rising with 0.2 percent nano-lubricants. And concentration of nano particles is raised and pressure is noticed to be enhanced with regard to it.

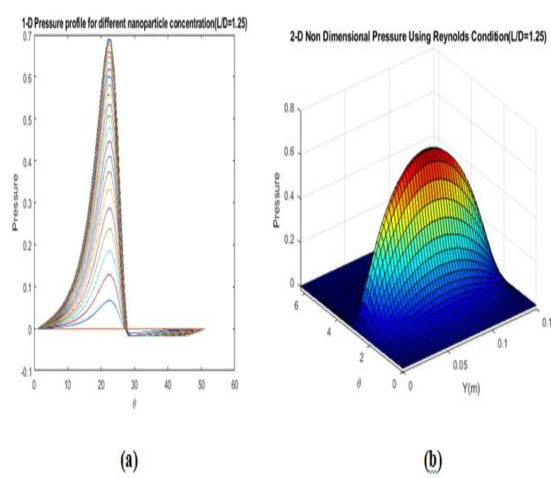

Figure 2: Pressure distribution profile with respect to $\boldsymbol{\theta}$ for L/D=1.25 (Fig.2(a) 1-D Plot and Fig.2(b) 2-D plot)

Fig. 2 to figure 5 represent the relation between hydrodynamic pressure and angular position for oil and water lubricated bearings for different L/D ratio. As the lubricant viscosity increase, the hydrodynamic pressure increase and load carrying capacity increase as shown in Fig 2-figure 5 . In this study, researcher has consider L/D ratio of .25,0.5 1 and 1.5.

From figure 2 to 5 ,there is indication from graphs that as eccentricity increases pressure concentration increases with respect to angle $\boldsymbol{\theta}$.

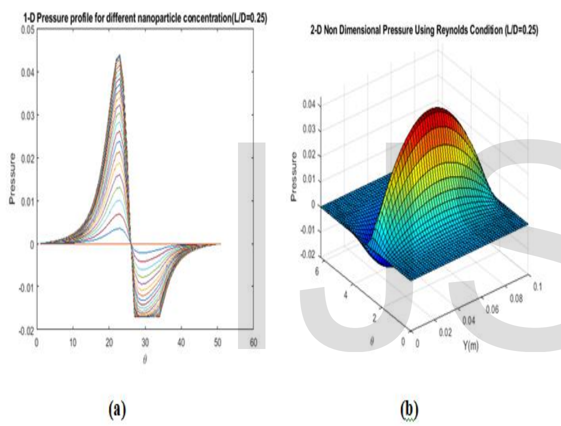

Figure 3: - Pressure distribution profile with respect to $\boldsymbol{\theta}$ for L/D=0.25 (Fig.3(a) 1-D Plot and Fig.3(b) 2-D plot)

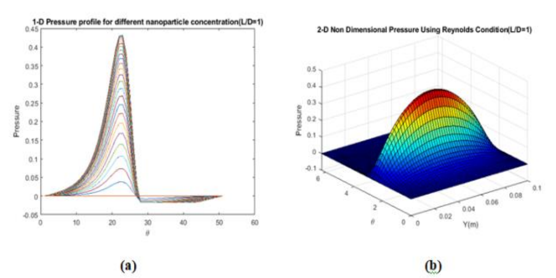

Figure 4: Pressure distribution profile with respect to $\boldsymbol{\theta}$ for L/D=1 ((Fig.4(a) 1-D Plot and Fig.4(b) 2-D plot)

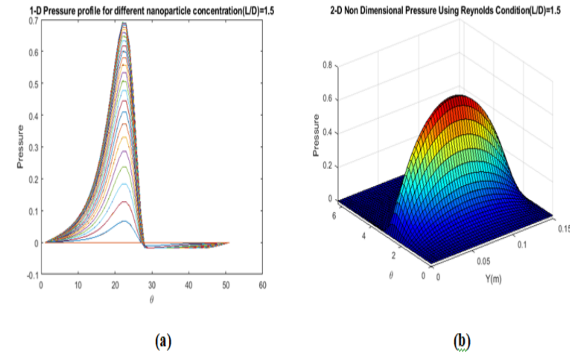

Figure 5: Pressure distribution profile with respect to θ for L/D=1.5 ((Fig.5(a) 1-D Plot and Fig.4(b) 2-D plot)

The authors discovered the bearing's friction force and load carrying capability as a result of their investigation. When comparing TiO2 nano particle additions to plain engine oil and TiO2 nano particle additives shows a 0.77 percent increase in friction force. This improvement in load bearing capacity is consistent with the results of [28]Nair et al., who have published their findings. According to the findings, the improvement in load bearing capacity is more significant at greater volume fractions. When compared to normal engine oil, the results of the investigation indicate a 21.5 percent improvement in load bearing capability.

5.Conclusion

Using lubricants with nano particle additives, a new method for assessing the load carrying capacity of journal bearings is presented. In comparison to plain engine oil without nano particle additives, the presence of TiO_2 nano particles boosts journal bearing load carrying capacity by 21.4%. The main size of TiO_2 nano particles is revealed by the DLS particle size study. The bearing's performance is influenced by the ratio of the bearing's length to its diameter. The pressure in the picture increases as the ratio rises. Compared to a short bearing, a long bearing has a greater bearing capacity.

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