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Design and Analysis of Hydrodynamic Journal Bearing using Raimondi and Boyd Chart

[1]Arjun Panthi
Student of M. Tech in Mechanical Engineering Deptt.
VITS Indore, MP, Email ID:- panthiarjun1@gmail.com

[2]Prof. Jai Balwanshi
HOD and Asst. Prof. in Mechanical Engineering Deptt.
VIT Indore, MP, Email ID:- jai764u@yahoo.com

[3]Prof. Ajay Chandravanshi
Asst. Prof. in Mechanical Engineering Deptt.
Mahakal Institute of Technology Ujjain, Email ID:- chandravanshiajay87@yahoo.in

[4]Prof. Gourav Gupta
Asst. Prof. in Mechanical Engineering Deptt.
SGSITS, Indore

Abstract

The hydrodynamic bearing is generally used in many industrial applications because of their characteristic like high load carrying capacity and for optimum speed application with minimum power loss in friction, but the optimum modeling of hydrodynamic journal bearing for high load and maximum speed is little critical due to limitations incorporated with manual calculations but with the Finite Element Method (FEM) approach the modeling and simulation of hydrodynamic journal bearing is more suitable, accurate and less time consumable. This work deals with the modeling and simulation of journal bearing to determine the pressure profile and minimum oil film thickness using FEM approach. The pressure generated inside the fluid film is analyzed by solving the Reynolds's equation, with the help of Raimondi and Boyd. Charts the value of minimum film thickness, attitude angle, power loss, oil supply requirements, dynamic coefficients, eccentricity and ultimately the maximum pressure is calculated in this project.

Keywords*: - Hydrodynamic journal bearing, pressure profile, Raimondi and Boyd chart, Reynolds equation, FEM.*

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I. Introduction

Journal bearings are machine elements in which the applied force is entirely supported by an oil film pressure. As with motion, load is applied to a bearing in either of two directions, or in both directions simultaneously. Radial load act at right angle to a bearing axis of rotation. Axial load are applied parallel to, rather than at right angle to the bearing axis of rotation. In many situations bearing may support radial and axial loads simultaneous They are used in many different engineering applications, for example as supports of rotating shafts, component for compressor, pump, turbines, internal-combustion engine . They are considered superior to roll bearings because of their higher load-bearing capacity, higher operating angular speed, lower cost and easier manufacturing. Furthermore, a proper design can assure very large service lives.

In most basic form journal bearing consists of a rotatable shaft (Journal) contain within a close-fitting cylindrical sleeve (bearing). Generally, but not always, the bearing is fixed in a housing. The journal and bearing surface are separated by a film of lubricant that is applied to the clearance space between the surfaces. The redial clearance space is generally quite small (in order of 1/ 1000th of journal radius).

Now a days due advancement in technology, rotating machineries are running on higher load and higher speed, it is well known that Journal bearing is a critical power transmission component that carries the high support load in machine at higher speed. Fluid journal bearing is widely used for such an operation because of its long life, low cost, simple operation, low maintenance etc. Bearings are used to support lighter computer’s hard drives to Heavy Turbine load. Due to its significance in wide application; it is always an important topic for researchers for a research. In Machine design this is very critical element, therefore it is essential to know the operating conditions viz. temperature, pressure, RPM, clearance etc.

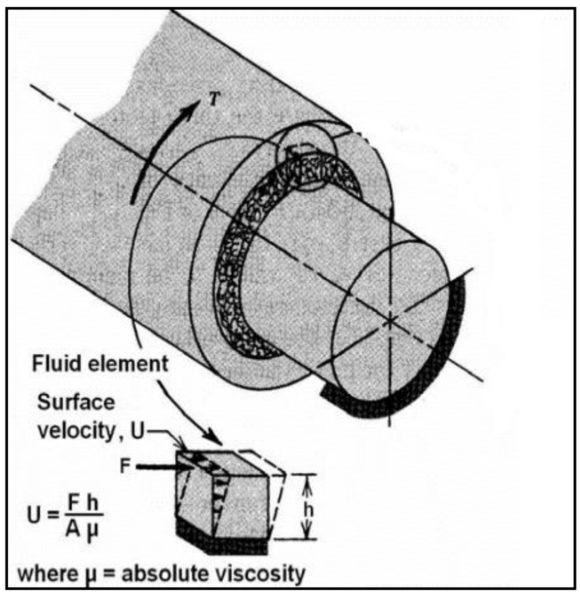

Figure 1. Journal Bearing schematic 3D diagram

Fluid film bearings describe the bearing type that is designed to operate under the principal of building up a hydrodynamic wedge between parts in relative sliding motion. In bearing lubrication, the rotating shaft inside the bearing is in the presence of oil, which generates a wedge between the two due to the dynamics of the fluid. The fluid generally adheres to each body and must shear in order to accommodate the relative motion. Using basic principles such as Newton's concentric cylinders, Figure 1-1, a fluid film thickness between the bearing surface and rotor provides lubrication, of which one can determine velocity and temperature profile. Many factors play a role in the dependent parameters of oil pressure and temperature in bearings, such as rotor weight, forces generated during operation, bearing geometry, fluid properties, rotational speed (RPM), and bearing type. All these elements must be considered when designing bearings for any application.

Journal bearing is one of the critical elements of machine; therefore, many studies of the operating conditions of hydrodynamic journal bearings have been made during the last decades. However, still attempts are being made to reach to closer to true operating conditions. Some of the researchers use the numerical techniques and matlab software and some do experimental analysis. There is a limited number of studies that carry out an in-depth examination of the true operating conditions of bearings, therefore experimentally, there is a need for experimental studies to verify the theoretical results.

They are considered superior to roll-bearings because of their higher load-bearing capacity, higher operating angular speed, lower cost and easier manufacturing. Furthermore, a proper design can assure very large service lives. The early studies on the fluid-dynamic behavior of journal bearings based on the numerical solution of Reynolds equation date back to the fifties, thanks to the work of Raimondi and Boyd (R&B) . They summarized results in useful dimensionless charts ready for design, which are nowadays accepted also in code standards. Raimondi and Boyd analysis is based on some simplifying assumptions, as the hypothesis of constant viscosity of oil film, independency of viscosity on pressure and finally the postulation of perfectly rigid components (shaft and bushing). Such assumptions, however, can be somewhat oversimplified, considering for example that deformation of journal bearing components under imposed oil film pressure is expected to produce a change in lubrication gap and thus a modification in the resultant pressure distribution. Moreover, also the assumption of constant viscosity and its independence from pressure should be critically reviewed, as it is experimentally known how viscosity depends, other than temperature, also on pressure, as summarized by many constitutive models . It would be then of interest to investigate in more detail the correlation existing between all the above-mentioned aspects and journal bearing performance and design.

The objectives of present work are as follows:

1) To study effect of various parameters like RPM, L/D ratio and Eccentricity ratio on the pressure distribution on bearing.
2) To study the cavitation effects on load carrying capacity of journal bearing.
3) To perform the thermo-hydrodynamic analysis on the journal bearing.

The main aim of the study is to decide the oil film pressure in hydrodynamic journal bearings carrying realistic loads. In addition, the relationships between the oil film pressure and other key operating limits of journal bearings like viscosity, speed, eccentricity has been studied. In addition to that study also includes the determination of the operating range, oil film temperature and oil film thickness.

The analysis has been carried out with the help of CFD Tool which is ANSYS-Fluent 14.0. The results obtained are validated with that obtained by using Raimondi and Boyd chart and available experimental results.

II. Problem Identification

Based on the literature review including several research paper and reference paper following problems are identified as below:

1. Design of journal bearing requires assumption of oil film temperature, which is a matter of guess work leading to lot of iterations, and sometimes not leading to satisfactory design.
2. Need is felt to find an alternative approach, using numerical methods, by which the necessity of this assumption may either be eliminated, or at least fast convergence to acceptable solution may be achieved.
3. Lubrication viscosity changes with rise in temperature, which lead to incorrect bearing simulation therefore proper algorithm need to be find out.

On changing the temperature, cavitation started, lead to reduce load carrying capacity.

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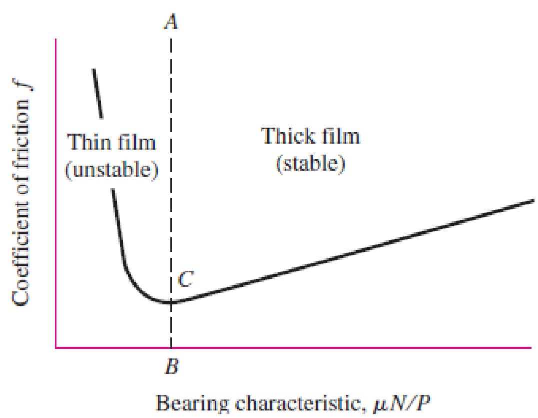
III. Theory of Hydrodynamic Journal Bearing

The lubrication is one of the most interesting researches in field of rotator body. Several theories were concluded by many researchers. They provide Fundamental principle behind the hydrodynamic lubrication theory and there mathematical representation.

Fundamental of stable lubrication was given by **S. A. McKee and T. R. McKee,** in paper "Journal Bearing Friction in the Region of Thin Film Lubrication,"



$$\frac{\mu N}{P} \geq 1.7(10^{-6})$$

Figure 1 Plane journal bearing model

Above figure indicate that if we are operating to the right of line B A and something happens say, an increase in lubricant temperature, this cause reduction in viscosity and hence a smaller value of μN/P which lead to reduction in friction but same time heat is generated in shearing the lubricant, and consequently the lubricant temperature drops. Thus the region to the right of line B A defines stable lubrication because variations are self-correcting. To the left of line B A, a decrease in viscosity would increase the friction. A temperature rise would ensue, and the viscosity would be reduced still more. The result would be compounded. Thus the region to the left of line B A represents unstable lubrication.

$$\sum F_x = p\,dy\,dz - \left(p + \frac{dp}{dx}dx\right) dy\,dz - \tau\,dx\,dz + \left(\tau + \frac{\partial \tau}{\partial y}dy\right) dx\,dz = 0$$

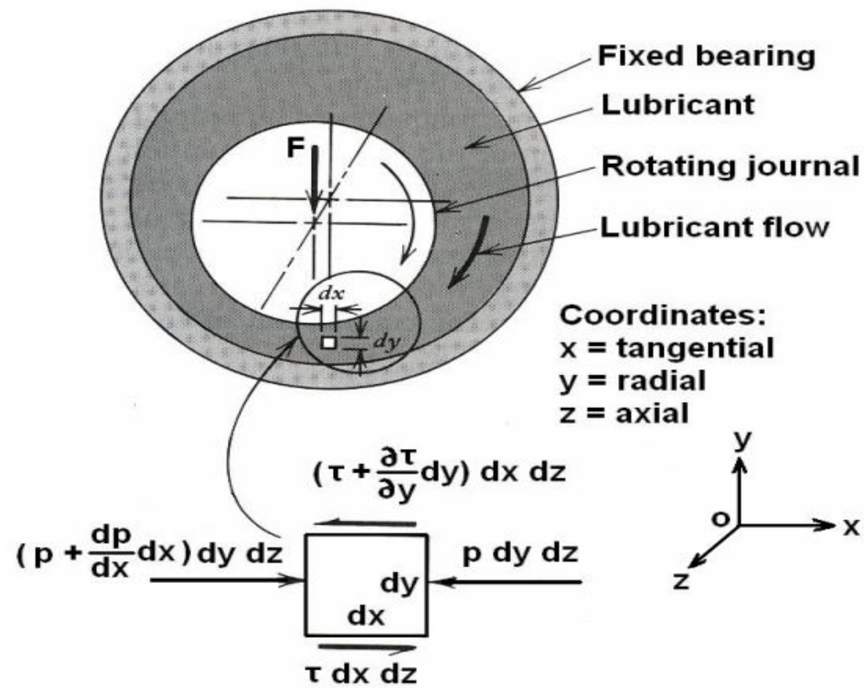


Figure 2 Pressure and viscous forces acting on an element of lubricant. Only X components are shown

The mathematical theory is best upon Reynolds's work in "Theory of art II "phil. Trans. Roy. Soc. London, 1886. Reynolds pictured the lubricant as adhering to both surfaces and being pulled by the moving surface into a narrowing, wedge-shaped space so as to create a fluid or film pressure of sufficient intensity to support the bearing load. One of the important simplifying assumptions resulted from Reynolds' realization that the fluid films were so thin in comparison with the bearing radius that the curvature could be neglected.

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IV. Terminology of journal bearing used in Raimondi and Boyd chart

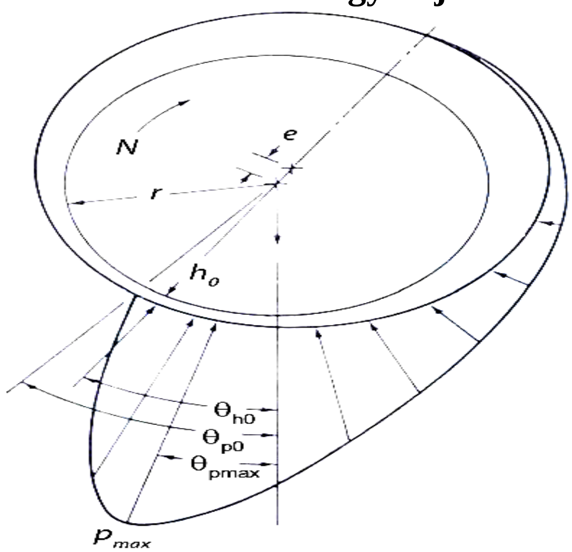

Figure 3 Terminology of journal bearing

- P_{max} is the peak pressure that occurs at angle θ_{pmax}
- pressure $p(\theta)$ over the attitude
- angle β
- Minimum hight of film h_o at angle θ_{ho}
- eccentricity e
- The viscosity μ
- The speed *N*
- The bearing dimensions *r, c, β, and l*

Maximum Oil-Film Pressure In Journal Bearing

Oil pressure is important parameter for designing the journal bearing so many research was performed to find out exact maximum pressure with location. Diyar I. Ahmed, S. Kasolang, (Ref-8) predict maximum pressure and location using Fuzzy logic (FL) and particle swam optimization (PSO) approaches model. Journal bearing parameters of rotational speed, bearing load and oil-feed ,pressure are considered as model independent variables. A number of experiments, based Box-Behnken experiment Design technique (BBD), were performed to observe the maximum oil-film pressure. The results revealed that both models are able to predict the maximum oil-film pressure.

V. Numerical Solutions for Journal Bearing

D. M. Nuruzzaman et al. perform the comparative study of pressure distribution and load capacity calculated both by analytic method and finite element method. Reynolds equation was used as a function and Galerkin weighted residual approach has been adopted. The effects of variations in operating variables such as eccentricity ratio and shaft speed on the load capacity of the bearing were calculated.

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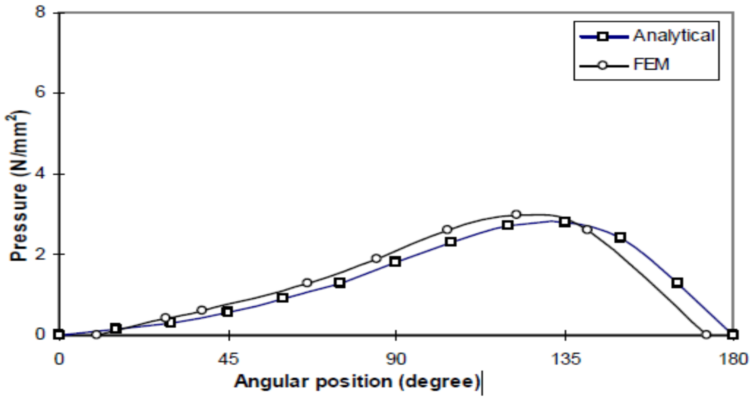

Figure 4 Comparison of variation of pressure with angular position

Where as **D. Benasciutti et al**. presents a numerical approach for the analysis of hydrodynamic radial journal bearings.The effect of shaft and housing elastic deformation on pressure distribution withinoil film is investigated. Aniterative algorithm that couples Reynolds equation with a plane finite elements structural model is solved.Temperature and pressure effects on viscosity are also included with the Vogel-Barus model. The deformedlubrication gap and the overall stress state were calculated. Numerical results arepresented with reference to atypical journal bearing configuration at two different inlet oil temperatures. Obtained results show the greatinfluence of elastic deformation of bearing components on oil pressure distribution, compared with results forideally rigid components obtained by Raimondi and Boyd solution.

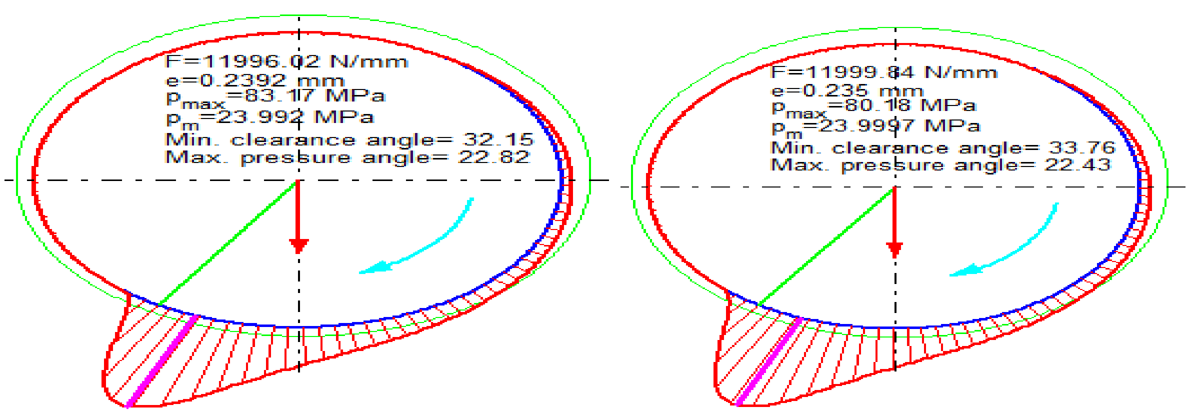

Figure 5 Effect of viscosity-to-pressure sensitivity on oil pressure distribution

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Hassan A. EL Gamal analyzed the steady state performance of wedge shaped hydrodynamic journal bearing. This work deals with the steady state performance of a hydrodynamic bearing having wedge shaped in axial direction and the results are compared with cylindrical bearing. It has been found that if the wedge angle is less than 30 degree, it is superior to a cylindrical bearing for smaller eccentricity ratios and for large eccentricity ratios the wedge angle should be very small. But this work has some limitations such as for short bearing the wedge shaped hydrodynamic journal bearing is not applicable. Also in this research very few performance parameters are taken into account. Also manufacturing tolerances in hydrodynamic journal bearing is not considered.

Mahesh Aheret. al. did a Comparative study and experimental analysis is carried out for getting the pressure distribution and load carrying capacity of plain and lobe bearing at different speed and load. The result obtained reveals the higher load carrying capacity of lobe bearing with good stability.

VI. Modelling & Simulation of Hydrodynamic Journal Bearing

TABLE 1 Input Parameter involve in modelling

Length of the bearing (L)	133mm
Radius of Shaft (Rs)	50 mm
Radial Clearance (C)	0.145mm
Eccentricity ratio(ε)	0.61
Angular Velocity (ω)	48.1 Rad/sec
Lubricant density (ρ)	840 Kg/m3
Viscosity of the lubricant (η)	0.0127Pas
Temperature	65^0 C
Load	2250N

By Above data we find other derived data (Raimondi and Boyd):

- Radius of Bearing (Rb) : (Rs + C) = 50.145mm
- Attitude angle (φ) :68.4^0. (Ref 6)
- Eccentricity (e) : (ε × C) = (0.61 × 0.0145) =0.008845mm.
- Max Pressure = 310kPa

VII. Conclusions

The present papers developed a numerical procedure for the analysis of hydrodynamic radial journal bearing. Influence of temperature and pressure on viscosity and thus on resultant pressure distribution were studied. A mechanical plane finite element model, coupled with solution of Reynolds equation, was also developed to study journal bearing structural behavior and its influence on pressure distribution. Finally, a perturbation approach was implemented to evaluate stiffness and damping coefficients.

The main findings of the work can be summarized as follows:

- Temperature increase was shown to give a decrease of attitude angle β and an increase in pressure peak.
- An increase of viscosity-to-pressure sensitivity (α value) gives a general increase of peak pressure for pressure peaks greater than about 90 to 100 MPa.
- Component deformation gives a more uniform pressure distribution, with a considerable reducing of the peak pressure compared to the case of ideally rigid components.
- Stiffness and damping coefficient were calculated and a high non-linear trend with journal bearing eccentricity *e* was observed.

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