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**Research Papers**

# A REVIEW ON NON-CIRCULAR HYDRODYNAMIC JOURNAL BEARING

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## Abstract

*This paper presents the review of important papers on non-circular hydrodynamic journal bearing pertaining to the stability, performance, load carrying capacity, power loss, stiffness, damping etc., of non-circular hydrodynamic journal bearing. These parameters are the very important aspects in the design of non-circular hydrodynamic journal bearings. The Reynolds, Energy and Viscosity equations were solved numerically under the assumptions of incompressible lubricant, the laminar and adiabatic flow of oil in the bearing gap. Reynolds Equation is solved by Finite Element Method using Galerkin's approach. Load Carrying capacity can be evaluated by the fluid reaction components.*

**KEY WORDS:**

Load carrying capacity, Stiffness, Damping, Reynolds Equation, Galerkin's approach, Finite Element Method, Power loss.

## INTRODUCTION

The bearing is a machine element that constraints the relative motion between two or more parts to desired type of motion and typically allows and controls rotation around any fixed axis. There are many types of bearings with varying shape, material and lubrication. A bearing is system of machine element whose function is to support an applied load by reducing friction between the relatively moving surfaces. The load may be radial, axial or combination of these. The word Tribology is relatively new. It has been derived from a Greek word Tribos which means rubbing process. Tribology is defined as the science and technology of interacting surface in relative motion and related subjects and particles. However the subject Tribology generally deals with the technology of lubrication, friction control and wear prevention of surfaces having relative motion under the load .To have a thorough understanding of the subject and its application to machine element it becomes necessary to know many areas, such as chemistry of lubricants, physical of fluid flow, surface topography, contact mechanics, material science, mathematics and mechanical engineering.

**Types of Journal Bearings:**

1.Plain Cylindrical Journal Bearing
2.Two-Lobe Journal Bearing
3.Three-Lobe Journal Bearing

**1.Plain Cylindrical Journal Bearing**

The plain Journal Bearing is simplest form of journal bearing shown in fig 1 in which a shaft or journal rotates in the bearing with a layer of lubricant (oil) separating the two parts through fluid dynamic effects. This bearing has a plain cylindrical bore. Since the bearing surface and journal are moving with relative speed, lubricant will be drawn into gap between them and forced to squirt out the sides of the bearing while the is converging. This can be observed in figure 1 which shows the oil film thickness as a function of angular position around the bearing starting with the maximum gap at 0° through the minimum gap at 180° back to the maximum gap. As the oil is drawn into the converging wedge by the relative motion, the pressure increases and the oil is forced out the sides of the bearing since the oil is relatively incompressible. The oil film pressure is shown in figure 1 that is generated around the bearing. This self generated pressure is what supports the load imposed by shaft. While the oil film is converging (getting thinner) the pressure will be positive which will support the load of the shaft. If the oil film diverging (getting thicker) the pressure will attempt to decrease the pressure.

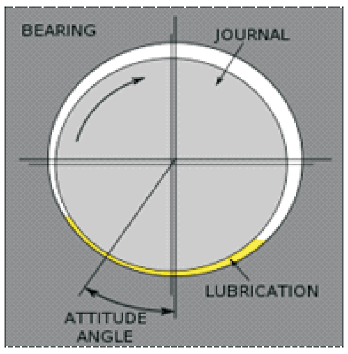


**Fig 1 Plain Cylindrical Journal Bearing**

In this Plain Journal Bearing one Converging and one Diverging film will create at the starting position.

**Advantages of Plain Cylindrical Journal Bearing:**

Infinite life.
Least expensive.
Design is compact and light weight.
Low transmitted vibrations.
Low noise compared to anti-friction.
Have high load carrying capacity.

**Disadvantages of Plain Cylindrical Journal Bearing:**

High power loss due to friction.
Requires lubrication oil supply.
Cannot operate without oil for any length of time.

**2.Two-Lobe Journal Bearing (Elliptical/lemon bore)**

The Two-Lobe Journal Bearing shown in fig 2 is a two-pad-fixed geometry bearing which is preloaded in the vertical direction. The bearing can be manufactured by inserting a shim in the split line before boring. When the shim is removed, the vertical clearance will be less than the horizontal clearance. The centers of the curvature of the top and bottom halves are not coincident with the true bearing center.

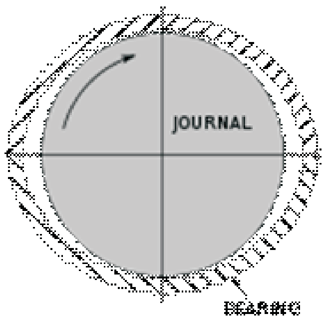


**Fig 2 Two-Lobe Journal Bearing**

Two-Lobe Journal Bearing offers improved resistance to oil whirl at a reasonable cost. The circulation of oil is higher in comparison to a full circular bearing with equivalent minimum clearance because two Converging and two Diverging fluid films will create at both sides as shown in the above fig.

The disadvantage of this design is its lower load carrying capacity, as compared to typical journal bearings. It is also still susceptible to oil whirl at high speeds, however its cost is relatively low. They are widely used in high-speed turbines and generators and other applications where the external force is in vertical direction.

### 3.Three-Lobe Journal Bearings

Three-Lobe Journal Bearing is also called as Multi-Lobe Journal Bearing shown in fig 3. This bearing is the similar in concept to the Lemon bore Journal Bearing. It has three curved segments that are referred to as lobes. During Operation the geometry of the three lobes introduces preload inside the bearing. This design improves the stability because it increases the bearing stiffness and reduces the magnitude of cross-stiffness components.

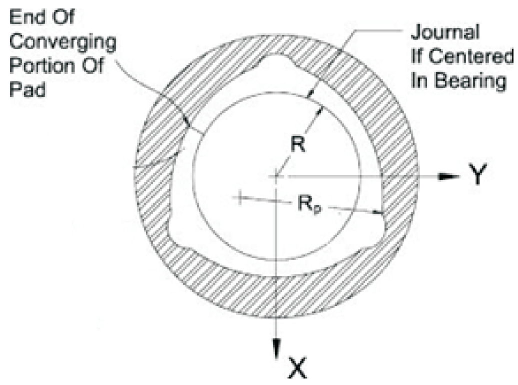


**Fig 3 Three-Lobe Journal Bearings**

The advantage of the Three-Lobe Journal Bearing is that it has oil grooves between the lobes. The oil circulation is obviously better than above Journal Bearings because it will create three converging and three diverging fluid film inside the bearing. This Bearing can carry higher loads compared to above journal bearings.

## LITERATURE REVIEW

The journal bearing will normally not fail gently, they either work or don't. The most common failure mode will be loss of lubricant. Since the shaft rides on a thin film of oil that could be thin as 0.0005 at the minimum film thickness, the loss of lubricant will result in the shaft and bearing contacting. The tremendous amount of heat is generated due to the siding friction between the shaft and liner which results in a major failure in a very short time. The journal bearing operates at higher DN (Diameter, Speed RPM) numbers will result in premature failure of anti friction bearings and likely excessive heat generation. The impact of heat generation and load in addition to speed and physical size can be evaluated using common engineering principles for predicted bearing life. The different bearing profiles are used in the industries. The Journal Bearing has predictable stiffness and damping characteristics that depend heavily on the bearing geometry and loading. The stiffness of a journal bearing is determined by the compressibility of the oil film. In mathematically terms, the stiffness (K)=(ΔForce/ΔDisplacement). The damping is the property of the bearing that controls the amplitude at resonance since damping(C)=(ΔForce/ΔVelocity). The journal bearing are made up of a number of different hydrodynamic bearing types including plain sleeve, fixed lobe and tilting pad. Vibration on journal bearings is most commonly measured and analyzed using proximity probes and shaft centerline and orbit plots. The primary failure mode of journal bearings will either be loss of lubricant or excessive loading [1]. The generalized Reynolds equation has been derived for carrying out the stability analysis of a two lobe hydrodynamic bearing operating with couple stress fluids that has been solved using the finite element method. A non-dimensional parameter, 'l' has been used to indicate the length of the long chain polymer added to the bulk Newtonian fluid. It has been observed that the dynamic characteristics, i.e. the stiffness and the damping coefficients, are greatly influenced with the variation of the couple stress parameter 'l'. The effect of couple stress parameter on dynamic performance of 2-Lobe bearing is analyzed. The results obtained for the 2-Lobe bearings with eccentricities 0.05 to 0.35 at an ellipticity ratio of 0.3 are plotted for the couple stress factor ranging from 0 (Newtonian fluid) to 0.4 in steps of 0.1. The bearing load increases with the increasing values of couple stress parameter, the stiffness and the damping coefficients also show a similar trend producing a larger restoring force when journal is displaced from equilibrium position. To show the influence of couple stress fluid on the stability of journal bearing system, analysis were carried out over a wider range of eccentricity ratio and couple stress parameter. From this it is clearly shows that the stability of the 2-Lobe journal bearing increases as the couple stress parameter or the eccentricity ratio increases. The use of couple stress fluid increases the load carrying capacity. The use of couple stress fluid increases the stability of the 2-Lobe journal bearing [2]. The theoretical investigations of power loss of the Multi-Lobe journal bearing were carried out for the one value of the clearance ratio, different lobe clearance ratios and relative length of the bearing. The Reynolds, Energy and Viscosity equations were solved numerically under the assumptions of incompressible lubricant, the laminar and adiabatic flow of oil in the bearing gap. The finite length of the bearing and pressurized oil supply has been assumed. The results of calculation can be used in the design process of multi-lobe bearing. The journal bearing performances can be determined by the numerical solution of the oil film geometry, Reynolds, Energy and Viscosity equations. The 2, 3, 4-Lobe journal bearings with lubricating grooves located between single segments of bearing were chosen for numerical calculation. The numerical calculations have been carried out for the bearing aspect ratios L/D=0.5 which representing the short bearing and L/D=1 representing the long one. The applied value of clearance ratio was $\psi$=1.2 at the segment clearance ratio $\psi$s=1.5, 2.0 and 3.0. The power loss was calculated under the assumption of the static equilibrium position of journal. The increase of lobe clearance ratio for the determined bearing shape decreases the power loss. The increase of relative eccentricity causes the increase of the power loss of the bearing [3]. The journal bearings can be designed with the same or different profile of upper and bottom lobe, e.g. the upper lobe has cylindrical and bottom one the offset profile. Shaping the bearing profile this way allows the variation of static and dynamic characteristics of bearing. The static characteristics consist among others the load capacity of bearing which is very important parameter. The results of calculations of load capacity of 2-lobe journal bearing characterized by different profiles of upper and bottom lobe. The laminar, adiabatic oil flow in the bearing lubricating gap, parallel orientation of journal and bearing axis as well as the static equilibrium position of journal have been assumed. As compare to the bearing with the cylindrical bush they have better stability in the range of higher rotational velocities and loads simultaneously assuring very good cooling conditions for the oil film. The range of peripheral velocities for these bearing is from 20 to 70 m/sec and the range of applied journal diameters from 40 up to 500 mm. The oil film pressure, temperature and viscosity distributions as well as the bearing load capacity have been received by iterative solution of the Reynolds energy and viscosity equations. The load capacity has been computed for operation of bearing with parallel axis of journal and bush and different sets of bearing parameters as aspect and lobe clearance ratios. The calculation of bearing load capacity have been carried out for the bearing aspect ratios L/D=0.5 and L/D=0.8. Two values of lobe relative clearance: $\psi s = 2$ and $\psi s = 3$ were used. For comparison purposes the 2-lobe journal bearings including the 2-lobe (2-L), Offset-Halves (2-LOF), combined bearing consisting the cylindrical and offset lobe (2-LCOF) as well as another type of combined one with the offset and cylindrical lobe (2-LOFC) have been considered. Load capacity of combined 2-lobe journal bearing type 2-LCOF is smaller than the load capacity of 2-lobe and Offset-Halves one. At assumed bearing type and bearing aspect ratio an increase in lobe relative clearance causes the decrease in load capacity. Except of 2-lobe bearing with offset upper half and cylindrical bottom one, the largest load capacity shows the 2-lobe journal bearing, particularly in the range of larger relative eccentricities [4]. The effect of the static characteristic of the bearing has been carried out for 2-Lobe elliptical and offset profile. The steady state form of Reynolds equation in two dimensions is solved numerically using finite difference methods. The eccentricity ratio decreases while attitude angle increases with an increase in L/D ratio. The minimum oil film thickness increases with an increase in L/d ratio. The maximum film thickness increases with increases in offset factor (eh). The load capacity of the elliptical bearing is better as compared with 2 lobe offset bearing with increase in eccentricity ratio and L/D ratio [5]. The journal rotates with an angular velocity $\omega$ which lead to attitude angle $\psi$. The journal remains in equilibrium position under the action of external load W which lead to eccentricity and developed hydrodynamic pressure. The journal centre O is eccentric to the bearing centre O'. The film thickness $h(\theta)$ varies from its maximum value hmax at bearing angle $\theta = 0$ to its minimum value, hmin at $\theta = \pi$. Some of the assumptions are made that the flow is laminar and isothermal and constant vertical load W is applied on journal. Using geometric dimension the model is created in CATIA V5 R20. The step file of geometry is use for meshing. The meshing is done in Hypermesh 10.0. After meshing the model is imported in to Ansys. The static pressure distribution is having maximum value in 3 lobe bearing than simple bearing. As the static pressure increases it increase force at the centre of bearing. The pressure distribution increases in 3lobe bearing with increasing eccentricity and with increasing angular velocity. The load carrying capacity of lobe bearing is more than the plain bearing [6]. The ordinary circular bearings, which are the most common type of the bearings, are found to be unstable at high speeds. The factors affecting the bearing stability are load, L/D ratio, viscosity of the fluid, clearance between the journal and the bearing, type of fluid (Compressible or incompressible), rotor unbalance, flow regime (laminar or turbulent), ellipticity ratio, load orientation, friction, shaft and liner flexibility, groove angle etc. Load orientation is one of the parameters that affect the stability of a bearing. The Reynolds equation is analyzed for a pressure profile using the Finite Element Method. The stability of a three-lobe bearing is affected by the load orientation. The negative values of the load orientation adversely affect the stability while there is improvement in the stability for the positive values of load orientation. The increase in flexibility of the rotor decreases the stability of three-lobe bearing for a particular value of load orientation. Multilobe bearings are found to be more stable than circular bearings [7]. The stability of journal bearing is dependent on bearing dynamic characteristics, which are function of bearing geometry, shaft speed, load and lubricant properties. Under the high loads, or high sommerfeld number, the shaft operated close to the bearing center. As the load increased, the sommerfeld number decreased. As the load increased, the shaft would move progressively further from the bearing center position [8]. The performance of automotive engines and turbo machinery require the crankshaft and connecting rod bearing to operate under more severe condition like higher speeds, higher loads and higher temperature. To meet these requirements plain bearing with symmetrical lobe has been developed. Various tests has been conducted to improve performance of plain bearing under these condition in both materials and design and possibility has been formed in modifying the geometry of bearing. Theoretical analysis has been revealed a multilobe bearing has found to be more stable than circular bearings. A three lobe bearing possesses good stability characteristics as turbo machinery works on higher speed and load, hence would act has better replacement for plain journal bearing. The performance of ordinary circular bearings is not very satisfactory. By use of lobe can improve properties including increase in maximum load capacity, stiffness and damping and decrease in power losses. Also it gives provision of good stability at higher speed application. The pressure distribution obtained from the experimental work of three lobe bearing has the maximum pressure value over the plain hydrodynamic journal bearing [9]. Finite element method has been used to solve the generalized Reynolds equation for each lobe to obtain the respective pressure distributions. Stable equilibrium conditions in terms of eccentricity ratios and the attitude angles have been obtained for the vertical load condition. The use of couple stress fluid increases the load carrying capacity. The use of couple stress fluid increases the stability of the 3-Lobe journal bearing. For any given load the bearing system will be operating at a lower eccentricity ratio. This can be concluded from an increased bearing load capacity with increase in couple stress parameter for any eccentricity. The use of couple stress fluid increases the "safe operating zone" signifying that the journal will finally return to the static operating state when perturbed from the equilibrium condition [10]. Hydrodynamic journal bearing stability tests were conducted with three-lobe bearings with and without axial grooves. A total of 39 stability tests were performed on two types of centrally lobed three-lobe bearings. One type had an axial groove separating each lobe arc and the other type had no grooves. Bearings of each type, having a variety of lobe heights, were run at a number of different radial clearances. The clearances varied from 0.009 to 0.052 milli-meter (350 to 2050 µin.), and the lobe heights from 0 to 0.102 millimeter (0 to4000µin.). The bearings were run hydrodynamically in water at an average temperature of 300 K (80' F) at speeds to 7000 rpm. The test bearings had a diameter of 3.8 centimeters (1.5 in.) and a length-diameter ratio of 1. The lobes on the test bearings were generated by means of shims inserted at three equidistant lines between the bearing back and housing rather than by conventional machining techniques. Maximum stability of a three-lobe centrally lobed bearing with axial grooves occurred at a lobe height of 0.025 millimeter (1000 µin.) over a clearance range of 0.015 to 0.052 millimeter (600 to 2050 µin.). Stable operation of a three-lobe bearing without axial grooves was impossible to attain at clearances above 0.018 millimeter (700 µin.) over a range of lobe heights from 0.025 to 0.102 millimeter (1000 to 4000 µin.) [11]. Stiffness and damping coefficients are required for stability calculations of rotor-bearing systems. The Reynolds equation governing the pressure field within a bearing is obtained by simplifying the Navier-Stokes equations in Cartesian coordinates. It is then solved analytically using the short bearing approximation to obtain pressures in the fluid film. Integration of the pressure obtained by the solution of the Reynolds equation defines the bearing forces and the corresponding dynamic stiffness and damping coefficients of short circular bearings [12].

## CONCLUSION

The primary failure mode of journal bearings will either be loss of lubricant or excessive loading. When either of these occurs, failure will be sudden and can be catastrophic. The use of couple stress fluid increases the load carrying capacity and the stability of the 2 and 3 Lobe journal bearing. The increase of lobe clearance ratio for the determined bearing shape decreases the power loss. The performance of ordinary circular bearings is not very satisfactory. By use of lobe can improve properties including increase in maximum load capacity, stiffness and damping and decrease in power losses. Also it gives provision of good stability at higher speed application. This paper finally concluded that the performance of non-circular hydrodynamic journal bearings is better than circular bearings.

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