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Influence of Surface Texture on the Performance of Hydrodynamic Porous Journal Bearing

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Abstract: ***In the Present study we reveal the effects of surface texture (spherical dimple) on the performance of porous journal bearing by incorporation these dimples in particular location. The numerical work has been performed with the help of computational technique and it has been concluded that the influence of spherical type of texture (spherical dimple) on the bearing performance is very appreciating. The location of dimples in the particular location has been suggested with reference to the work of previous researchers. The modified governing equation (Reynolds equation) is solved computationally through finite difference method and Simpson's 1/3rd rule and over relaxation method are used in calculating the various bearing parameters such as load carry capacity eccentricity ratio fluid film pressure etc.***

Keywords: porous journal bearing; surface texture; finite difference approach; spherical dimples

1. Introduction

As we well aware that porous journal bearing is a self lubricating type of journal bearing. Porous journal bearing infused with oils are used in many industrial and daily life applications. This is best where we are not able to do lubrication on regular basis, with the development of modern machines; the use of various fluids as lubricants under various circumstances has been given much importance. Most bearings are normally used to support rotating shafts in machines. Appropriate bearing design can minimize friction and wear as well as early failure of machinery. The objectives of bearing design are to extend bearing life in machines, reduce friction energy losses and wear, and minimize maintenance expenses and downtime of machinery due to frequent bearing failure. In manufacturing plants, unexpected bearing failure often causes expensive loss of production. The classification of bearing includes the rolling element bearing, hydrostatic, hydrodynamic and magnetic bearing.

Hydrodynamic bearings are used in various machines ranging from small engines to large turbines or in turbo machinery and these are operated at very high loads and speeds. At these operating conditions, friction losses are more, it means lubricant and bearing temperature becomes too high which becomes a serious problem. Normally, a hydrodynamic bearing refers to a sleeve bearing or an inclined thrust-slider where the sliding plane floats on a thin film of lubrication. The fluid film is maintained at a high pressure that supports the bearing load and completely separates the sliding surfaces. The lubricant can be fed into the bearing at atmospheric or higher pressure. The pressure wave in the lubrication film is generated by hydrodynamic action due to the rapid rotation of the journal. The fluid film acts like a viscous wedge and generates high pressure and load-carrying capacity. The sliding surface floats on the fluid film, and wear is prevented [1-4].

The theoretical study for porous journal bearings was further extended by the works of Rouleau and Steiner, Shir and Joseph and Murti [5-12]. All these studies were based on the Darcy model (DM), in which Darcy's equation was used to guide the oil motion through the porous medium, and the no-slip condition was assumed at the porous bearing/clear oil interface.

A critical review on various types and aspects of porous metal bearings was made by Kumar. Many researchers have worked in the field of plain journal and porous journal bearings. They have found the bearing performance parameters with both theoretical and experimental investigation by using some principles of lubrication and appropriate boundary conditions. In addition to this, authors have also found the effects of surface roughness on the performance of bearing parameters. In recent, there is also some work performed on the thermal investigations on the hydrodynamic lubrication of porous journal bearing [13]. A number of authors work on the texturing aspects of bearings [14-21].A comparative study has been reported by Kango and Sharma between three different roughnesses models using transverse and longitudinal both type of roughness with power law model for non-Newtonian lubricant. They used sinusoidal wave equation for bearing surface while considering different configurations with different asperity amplitude and wavelength at various eccentricity ratios. They found that the load carrying capacity and friction force increases with increasing the flow behavior index whereas, friction coefficient decreases with increasing the flow behavior index. They concluded that the longitudinal sinusoidal roughness is best suited for decreasing the friction force. Kango et al. numerically investigated the micro cavities on journal bearing and found that the effects of texture are noticeable if the dimple depth is greater than minimum film thickness of the lubricant. Kango et al. also investigated the microtextured journal bearing including non-Newtonian fluid effects and JFO (Jakobsson, Floberg and Olsson) boundary conditions. They also performed the thermal analysis in their study i.e. viscous heat dissipation to find the performance parameters. The authors found that the average temperature of the lubricant gets reduced in case of texturing surface in comparison to smooth surface/ without texturing. Kango et al. again investigated on different type of textures, i.e. dimpled surface and grooved surface and gave a brief comparative study on the effect of these types of textured journal bearings. The numerical results for these types of textures suggest that the micro-grooving type of texture reduces the average temperature and friction coefficient in comparison with spherical texture. Sharma et al. presented the influence of sinusoidal wave textures on three different locations of the surface of bearing and obtain the best configuration among all. They also gave a comparison for the performance of a textured porous bearing for different configurations with the combined effects of two different non-Newtonian fluid models. Sharma et al. also considered the combined influence of surface texturing with couple stress fluids for a finite journal bearing with JFO boundary conditions and reported that load carrying capacity gets increased with couple stresses for smooth journal bearings at different eccentricity ratios. However the increase in load carrying capacity with texture marks only at low eccentricity ratios. Moreover, at low eccentricity ratio and for low values of dimple depth, the combined effects of texturing with couple stress fluids improve the load capacity of journal bearing while it decreased the load capacity by about 20% in case of high values of dimple depth and couple stress parameter. Tala-Ighil et al. studied the effect of surface texture for hydrodynamic journal bearings. In case of investigations on journal bearing, the shaft has been assumed smooth and rigid as first case. However, in the second case, bearing surface has been textured with spherical dimples. The authors have reported that the film thickness, pressure distribution, side leakage, and frictional torque are significantly affected due to presence of surface texture. It has also been reported that the attributes of dimples (size, depth, density, and orientation) affect the bearing characteristics significantly. The type of geometry of texture (spherical dimples) has been taken from the author's work. In the present investigation, spherical types of dimples are incorporated on the bearing surface on a particular location and performance is investigated.

2. Numerical Analysis

The Reynolds equation for an incompressible, Iso-viscous fluid rheology of the bearing system for a combination of flow in the bearing clearance and that within the porous wall is given by (Cameron, 1983) Figure 1 shows the schematic diagram for a porous journal bearing.

The circumferential length in the x-direction is rθ, the porous bearing length in the axial direction is L and nominal film thickness in the radial direction is h. The origin is taken on the oil sinter interface. The sinter is of thickness H, extending down to y = -H, and has a permeability ∅. The journal moves at a surface velocity U and the oil film thickness can be given as:

$$h = C_r(1 + e\cos\theta)$$

The flow through the sinter was governed by Darcy's law which can be given mathematically as

$$w = -\frac{\partial p}{\partial y}\frac{\phi}{\eta}$$

There is a negative sign as the flow is in decreasing pressure. The equation of continuity of flow is given as.

$$\frac{\partial}{\partial x}\left(h^3\frac{\partial p}{\partial x}\right)+\frac{\partial}{\partial z}\left(h^3\frac{\partial p}{\partial z}\right)=6\eta\left[U\frac{dh}{dx}-2\left(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial z^2}\right)\frac{\phi H}{\eta}\right] \quad (1)$$

Equation (1) is the generalized Reynolds equation for porous journal bearing.

Figure 2 depicts the geometry for spherical dimple supposed on the bearing surface in the present work. The mathematical model for ellipsoidal texture is also adopted from the work of previous authors. The work of spherical texture incorporated on the bearing surface is adopted from Kango et al. [17].

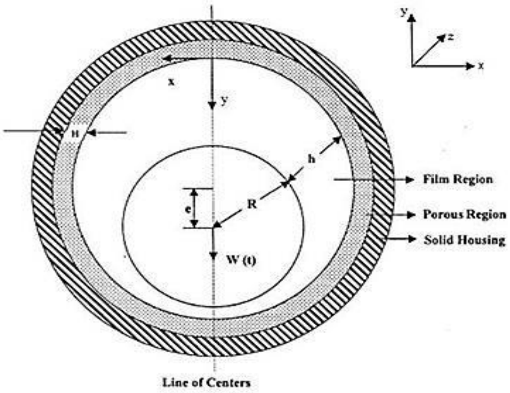


Figure 1: Schematic diagram of a porous journal bearing

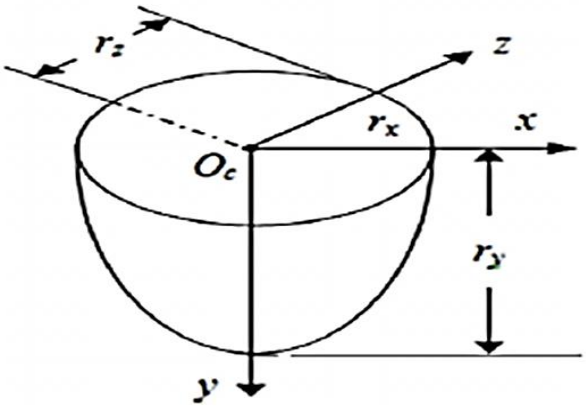


Figure 2: Geometry of spherical dimple

The three dimensional geometry of anspherical dimple is taken from [17] and as follows:

$$\left(\frac{(x-x_c)^2}{r_x^2}+\frac{(y-y_c)}{r_y^2}+\frac{(z-z_c)^2}{r_z^2}\right)=1$$

r_x, r_y and r_z are the radii of the ellipsoidal dimples in the x, y and z directions respectively. The expressions for x, x_c and z_c are also adopted from [17]

$$x = R\theta,\ x_c = n_1 a + \frac{(2n_1 - 1)L_x}{2},$$

$$z_c = n_1 b + \frac{(2n_1 - 1)L_z}{2} \quad (2)$$

Where n_1 is the number of dimples and a and b are the distances.

From above equations,

$$\Delta h = r_y \times \sqrt{(1.0 - r_y)} \quad (3)$$

Where

$$r_y = \left(\frac{(R\theta - x_c)^2}{r_x{}^2} + \frac{(z - z_c)^2}{r_z{}^2} \right)$$

If $r_x = r_z = r_{sph,}$ the film thickness expression will take the form of spherical dimple can be written as

$$\Delta h_{Sph} = \frac{r_y}{r_{Sph}} \sqrt{(r_{Sph})^2 - (R\theta - x_c)^2 - (z - z_c)^2} \quad (4)$$

The film thickness equation for textured (spherical dimple) journal bearing is presented in equations as given below:

$$H_{texture} = C_r\,(1 + \varepsilon \cos\theta) + \Delta h \quad (5)$$

H_T is the film thickness for dimpled bearing, εdenotes the eccentricity ratio, Δh_{Sph} represnts the dimensionless film thickness component which is the measure of spherical texture on the bearing surface.

3. Boundary Conditions

The boundary conditions for the Reynolds equation for the smooth and rough bearings are:

$$p = 0 \text{ At } \theta = 0^0, 360^0$$

$$p = 0 \text{ And } \frac{\partial p}{\partial \theta} = 0 \text{ at } \theta = \theta_c$$

Where θc corresponds to initiation of cavitation. In this boundary condition, some positive pressure is considered in the divergent zone.

Bearing performance characteristics

Various Bearing Performance Characteristics for finite porous journal bearing are calculated which include the fluid film pressure (p), load carrying capacity (W). The total load supported by the bearing is calculated by integrating the pressure. Load is calculated from two components (W_1 and W_2) which act along the line of centers and perpendicular to the line of centers respectively. Simpson's 1/3rd rule is used for calculating the Load carrying capacity, friction force and other parameters.

$$W_1 = \int_0^l \int_0^{2\pi} pr \cos\theta d\theta dz$$

$$W_2 = \int_0^l \int_0^{2\pi} pr \sin\theta d\theta dz$$

$$W = \sqrt{W_1{}^2 + W_2{}^2}$$

The expressions used in calculating percentage change in load capacity can be given in the following equation as:

$$\%W = \frac{W_{textured} - W_{smooth}}{W_{smooth}} \text{ x } 100$$

The convergence criteria for the derived equations can be taken as given below:

$$\Sigma\Sigma \left| \frac{\left(P_{I,J} - P(I,J)_{K-1} \right)}{P(I,J)_K} \right| < 0.0001$$

Where I, J denotes the number of nodes and k denotes the number of iterations respectively. For this work, we used 150 nodes in x- direction and 48 nodes in z-direction. The pressure is computed iteratively through Gauss- Seidel method and over relaxation factor is used for finding solutions. In this program, the over relaxation factor is taken as 1.4-1.5. We also represent the algorithm and the flow chart for these numerical computations.

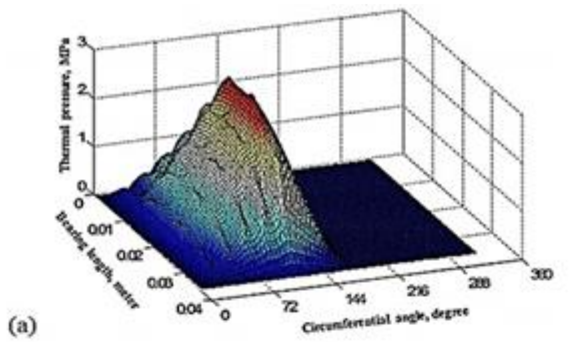
4. Results and Discussion

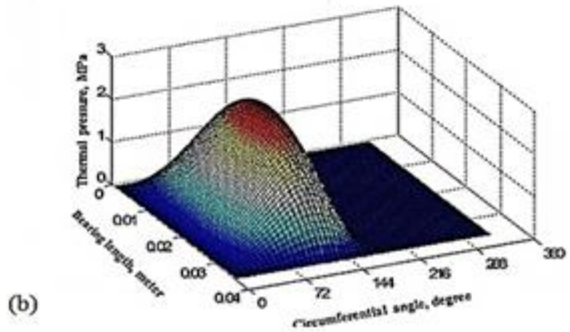
Table 1: Input Data

Input	Numerical Value
Eccentricity ratio (ε)	0.1-0.5
Shaft speed (N), rpm	2000, 4000
Radial Clearance (C_r), m	50×10^{-6}
Shaft Radius (R), m	0.02
Bearing length (L), m	0.04
Consistency parameter at inlet temperature (m_0), Pa-s	0.08
Nodes in circumferential direction (N_θ)	150
Permeability parameter (ψ)	0, 0.01, 0.1
Nodes in axial direction (N_z)	48
$d\theta$, m	0.000566
dz, m	0.000566
Dimple radius (r_s), m	0.003
Spherical radius (r_x and r_z), m	0.003 and 0.003
Dimple depth (r_y), µm	0,10, 20,30,40
L_x,m L_z, m	0.0076 0.0076
a	0.001132
b	0.001689
Number of dimples in circumferential direction (N_{tx})	5
Number of dimples in axial direction	4 (N_{tz})

The results are calculated by varying different parameters such as eccentricity ratio, permeability parameters, shaft speed etc. to find the performance of the textured porous bearings. The performance of textured porous bearing is compared with smooth porous bearing and is shown graphically. The location of dimples and numbers and dimensions of the texture (ellipsoidal dimples) has been taken with reference to the work of Kango et al. (2014). They have found that the optimized angular location for texture (ellipsoidal dimple) was from 0º to 128.5º. They have clearly found that partial texturing is fruitful as compared to full texturing and smooth surface i.e., without textures. The improvement in bearing performance reveals in Figure 3 which shows a three dimensional representation of comparison between smooth and textured (spherical dimples) bearing for variation of fluid film pressures. The fluid film pressures are significantly higher in textured case while compared with smooth case. The texturing enhances the bearing performance as clearly shown by results.

Figure 4 and figure 5 shows the effects of dimple depth on the load carrying capacity for the considered textures. The dimple depth is varied from 10 to 40 microns and load carrying capacity is calculated. It has been obtained that the load carrying capacity gets increased with increase in dimple depth. The results shown here are for low and high shaft speed (2000 rpm and 4000 rpm). An increase of approximately 200 N in load carrying capacity is observed when the dimple depth is increased from 10 to 40 microns. The results are also calculated for high shaft speed (4000 rpm) in which same trends is obtained; the larger the depth of dimple, the load carrying capacity is higher. At high shaft speed, an increase of approximately 400 N in load carrying capacity is observed when the dimple depth is increased from 10 to 40 microns.





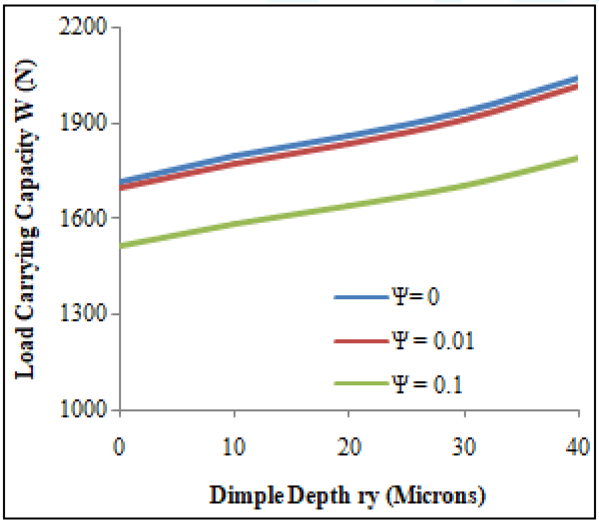


Figure 3: Three dimensional representations for variation of fluid film pressure in case of (a) spherical dimple (textured surface) and (b) smooth surface

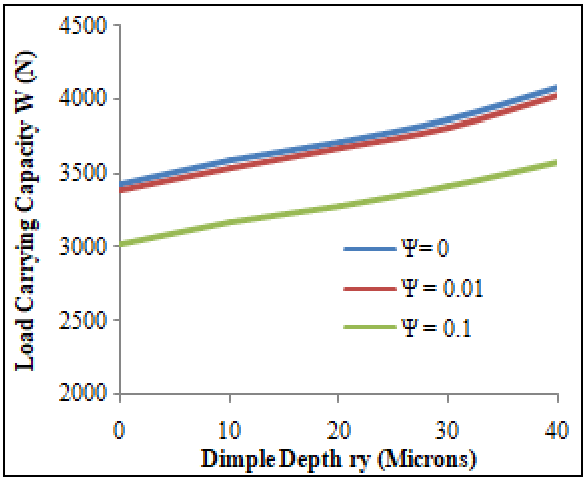


Figure 4: Effect of dimple depth on the load carrying capacity of a spherical textured porous journal bearing at shaft speed (N= 2000 rpm, ε=0.3, Ψ= 0, 0.01, and 0.1)

Figure 5: Effect of dimple depth on the load carrying capacity of a spherical textured porous journal bearing at shaft speed (N= 4000 rpm, ε=0.3, Ψ= 0, 0.01, and 0.1)

From previous results it has been revealed that large value of dimple depth and an intermediate eccentricity ratio with optimized shaft speed is advantageous for the better performance of porous journal bearing. Thus, the upcoming results are precisely taken on the basis of previously obtained results (N= 2000 rpm, ε = 0.3, cr=0.00005 m). The study on the effect of permeability parameter is also an important aspect of porous bearing to be obtained. In the present work, the permeability parameter is varied from 0 to 0.1 and results are calculated. The results have been calculated at high speed due to application of porous bearings i.e., low load and high speed applications. It has been observed that at high speed and at high value of dimple depth, the permeability parameter influences load carrying capacity as inclusion of texture enhances significantly. Moreover, the permeability parameter reduces the load carrying capacity in both cases. High value of permeability parameter reduces the load capacity at higher rate. So, an intermediate value of permeability parameter is taken (ψ=0.01) and load carrying capacity is calculated with variation of eccentricity ratio. As the applications of porous bearings are for low load and high speed equipments. Figure 6 shoes the result Eccentricity ratio ε also improves the load carrying capacity with texture conditions.

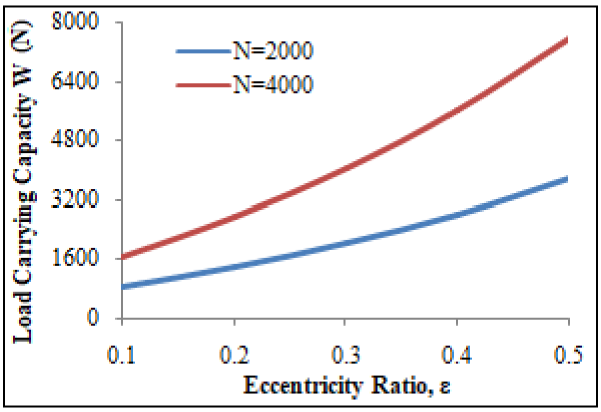


Figure 6: Load carrying capacity is calculated with variation of eccentricity ratio

5. Conclusions

The results calculated in the previous section gives the following conclusions for various bearing performance characteristics such as fluid film pressures, load carrying capacity, percentage change in load carrying capacity for the effects of spherical type of textures incorporated on the bearing surface to investigate the performance of a finite porous journal bearing:

1) The load carrying capacity in cases of textured case gets improved with increase in dimple depth and decreased with increase in permeability parameter.
2) Eccentricity ratio ε also improves the load carrying capacity with texture conditions.
3) The effect of permeability parameter is to decrease the load carrying capacity and the decrement is enlarged at high values of permeability parameters.
4) The location of texture is also an important parameter in improving the bearing performance as texture with fully pattern (0º to 360º) and in case of divergent zone does not give fruitful results. So the best location observed for incorporating texture is in convergent zone (0º to 128.5º).

References

[1] Hori Y (2006).Hydrodynamic Lubrication, *Springer*.
[2] Hamrock BJ, Schmid SR and Jacobson BO (2004). Fundamentals of fluid film lubrication, *Marcel Dekker, 2nd Edition*.
[3] Stachowiak GW and Batchelor A W (2005). Engineering Tribology, *Elsevier*, *3rd Edition*.
[4] Morgan VT and Cameron A (1957). Mechanism of lubrication in porous metal bearings, *Proc. Conf. on Lubrication and Wear, Inst. Mech. Eng., London*, 151 - 157.
[5] Rouleau WT and Steiner LS (1974). Hydrodynamic Porous Journal Bearings. Part 1-Finite Full Bearings, *Journal of lubrication technology, Transactions of ASME*, 346-353.
[6] Shir CC and Joseph DD (1966).Lubrication of a porous bearing – Reynolds solution, *Journal of applied mechanics*, paper no. 66-APM-IJ.
[7] Murti PRK (1971).Hydrodynamic lubrication of long porous bearings, *Wear* 18 449-460.
[8] Murti PRK (1972).Hydrodynamic lubrication of short porous bearings, *Wear* 19 17-25.
[9] Murti PRK (1973).Lubrication of finite porous journal bearings, *Wear* 26 95-104.
[10] Jang JY and Chang CC (1988). Adiabatic analysis of finite width journal bearings with non-Newtonian lubricants, *Wear* 122 63-70.
[11] Prakash J and Tiwari K (1982). Lubrication of a Porous Bearing with Surface Corrugations, *Journal of Lubrication Technology- ASME* 104 127-134.
[12] Prakash J and Tiwari K (1983).Roughness effects in porous circular squeeze-plates with arbitrary wall thickness,*Journal of Lubrication Technology- ASME* 105 90-95.
[13] Kumar V (1980).Porous metal bearings - a critical review, *Wear* 63 271-287.
[14] Chiang HL, Hsu CH and Lin JR (2004). Lubrication performance of finite journal bearings considering effects of couple stresses and surface roughness, *Tribology International* 37 297-307.
[15] Kango S and Sharma RK (2010).Studies on the influence of surface texture on the performance of hydrodynamic journal bearing using power law model, Int. J. Surface Science and Engineering, 4, 505-524.
[16] Kango S, Singh D and Sharma RK (2012).Numerical investigation on the influence of surface texture on the performance of hydrodynamic journal bearing,*Meccanica* 47 469-482.
[17] Kango S, Sharma RK and Pandey RK (2014).Thermal analyses of micro-textured journal bearings using non-Newtonian rheology of lubricant and JFO boundary conditions, *Tribology International* 6919-29.
[18] Sharma N, Kango S, Sharma RK and Sunil (2014). Investigations on the effects of surface texture on the performance of a porous journal bearing operating with couple stress fluids, *International journal of surface science and engineering* 8 (4) 392-407.
[19] Sharma N, Kango S, Tayal A, Sharma RK and Sunil (2014). Investigation on the influence of surface texturing on a couple stress fluid based journal bearing by using JFO boundary conditions," Tribology Transactions, vol. 59, pp. 579-584, 2016.
[20] Tala-Ighil N, Maspeyrot P, Fillon M and Bounif A (2007).Effects of surface texture on journal bearing characteristics under steady state operating conditions, *Proceedings of Institutions of Mechanical Engineers, Part J, Journal of Engineering Tribology*, 221 623-633.

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