Numerical Study Of Performance Of Porous Journal Bearing Operating With Micropolar Fluids

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Abstract- This paper numerically studies the effects of the micropolar fluid on characteristics of lubrication performance on finite porous journal bearing. The lubricant between the journal and bearing is taken to be the micropolar fluid which is very-viscous fluid. The modified Reynolds equation accounting micropolar fluid is derived and solved numerically using finite difference based multigrid technique. The multigrid method is found to be suitable and more accurate for the solution of the Reynolds equation which is elliptical in nature since the multigrid method is independent of grid-size used. According to the results obtained it is observed that the micropolar fluid has a significant effect in increasing the fluid film pressure as well as the load carrying capacity compared to the corresponding Newtonian case. It is further noticed that the load capacity is decreased for enhanced permeability of the porous medium. The physical dynamics behind these interesting results are demonstrated.

Keywords – Squeeze film; Journal bearing; Micropolar fluid; Porous; Multigrid.

I. INTRODUCTION

It is wide common experience that two surfaces can slide over one another provided a very thin fluid layer develops between them. As a result, a large number of positive pressure will be developed in this fluid layer. This high pressure between two surfaces can be used widely in many engineering applications as a means of replacing fluid-solid friction for all sorts of frictions in them. The fluid layer also offers a great resistance to the moving fluid thereby remaining as a lubricating film between the two surfaces. In some applications, the fluid layer develops by the motion of one surface normal to the other thereby supporting a heavy load. Some of the engineering applications where the fluid layer supporting load are machine tools, gears, bearings, hydraulic systems, automotive engines, rolling elements, etc (Archibald 1956; Cameron 1966; Hamrock 1994). Which means anti-friction is the first concern in these bearing applications.

In most of the above applications, usage of the porous journal bearing is quite common in which when the normal motion of the journal takes place, the fluid in the pores comes out of the porous material to lubricate the bearing surface, and goes back into pores when normal motion stops. Since the pores are irregularly arranged, sufficient fluid is available to lubricate the system thereby reducing friction of the bearing system. On the other hand, in various applications, self-lubricated porous bearings have been used which are made out of sintered powders like iron, bronze, steel etc. This process leads to have pores in the bearing that can absorb lubricating oil. Thus, the porous bearings are used in vehicles, machines, home appliances etc. (Cameron and Morgan 1972; Murti 1971; Naduvinanmani 2003; Kudenatti, Murali and Patil 2015).

Most of the studies on journal bearings have included Newtonian fluid as lubricant in the fluid layer. The theory of Newtonian fluids cannot accurately describe the coarse structure in the fluid, fibres such as colloidal fluids, any liquids containing external additives, etc. To this end, the non-Newtonian fluids have been widely used in industrial applications in the recent past. Also use of quality lubricant that sustains any small variation in temperature has been increased in industrial applications. Thus, the quality of lubricant can be increased by addition of certain chemical compounds. These naturally increase the viscosity of the lubricant and make systems to function efficiently. Viscosity improvers are usually isobutylene and acrylate polymers that can be added to lubricant. Once any additives are added to the lubricant, it starts acting as a non-Newtonian fluid. In particular, the theory of polar fluids has been studied in the recent past over classical Newtonian fluids. These fluids deform, shrink and expand and also they may rotate. To study their behavioral descriptions, one would require the theory that accounts the geometry, deformation and also intrinsic motion of individual particles (Łukaszewicz 1999).

Further, the suspended particles in the polar fluids produce a spin field and micro rotation takes place thereby forming micropolar fluids (Eringen 1966). Physically, the micropolar fluids take care of the intrinsic motions of micro fluidics as well as local effects that may arise from microstructures. Also, the micro rotation in micropolar fluids is mechanically significant and also balances with the natural vorticity of the fluid. Micropolar fluids
predominately alter the viscosity of the fluid clearly demarcating the flows from traditional Newtonian model (Lukasiewicz 1999). Thus, for a special kind on non-Newtonian (micropolar) fluids the constitutive equations which are a simple generalization of the classical Navier-Stokes equations contain a new vector field defining the angular velocity field of rotation of particles. Thus, in the framework of lubrication approximations, the equations of motion for micropolar fluids and of conservation of angular momentum along with continuity equation are derived. Indeed, the lubrication approximations give a good deal of simplification in the model of micropolar fluids leading to the modified Reynolds equation in unknown hydrodynamic pressure in the fluid layer. This modified Reynolds equation for micropolar fluids can be regarded as a natural generalization of the Newtonian fluids and can be treated numerically using multigrid method. This multigrid method is so chosen that we should capture even a small variation in the fluid layer. For this, it helps selecting a fine grid in the flow domain thereby giving the accurate solution (Kudenatti 2012).

Organization of the present paper proceeds as follows. In section 2, the equation for continuity, motion of fluids and angular momentum are given along with their solutions. From these velocity solutions, we obtain the modified Reynolds equation. In section 3, we give all details of the multigrid solution of the Reynolds equation. Section 4 devotes to discussing the various results obtained for all physical parameters. These results clearly distinguish various mechanisms of micropolar fluids and porous media from the Newtonian fluid and Non-porous region. Final section summarizes important findings of the present investigation.

II. MATHEMATICAL FORMULATION
The schematic diagram of a finite journal bearing is shown in figure 1. A journal of radius $R$ approaches the porous bearing with a constant velocity $\frac{\partial H}{\partial t}$ at any circumferential section $\theta$. The difference between the radius of the shaft and journal is given by the radial clearance $e$ and is small compared to the averaged radius $R$. The journal bearing is filled with the micropolar fluid as a lubricant that prevents metal to metal contact. Since the radial clearance $e$ is too small compared to the radius $R$, the gap height $H$ can be approximated by

$$H = e \left( 1 + \varepsilon \cos \left( \frac{x}{R} \right) \right)$$  \hspace{1cm} (1)

where $\varepsilon$ is the eccentricity. Further, we assume that viscosity $\mu$ and density $\rho$ of the lubricant are constants. Also, since the Reynolds number $\left( \text{Re} = \frac{UL}{\nu} \right)$ where $U$ is the characteristic velocity, $L$ is the length of the bearing and $\nu$ is the kinematic viscosity is too small for a slow viscous flow, both inertia forces and external forces are neglected in comparison with viscous forces. With usual hydrodynamic lubrication approximations, the constitutive equations for micropolar fluids (Eringen 1966) are given by

Continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$  \hspace{1cm} (2)

$$\left( \mu + \frac{\chi}{2} \right) \frac{\partial^2 u}{\partial x^2} + \chi \frac{\partial^2 u_m}{\partial x \partial z} = \frac{\partial p}{\partial x}$$ \hspace{1cm} (3)

$$\left( \mu + \frac{\chi}{2} \right) \frac{\partial^2 v}{\partial y^2} - \chi \frac{\partial^2 v_m}{\partial y \partial z} = \frac{\partial p}{\partial y}$$ \hspace{1cm} (4)

$$\gamma \frac{\partial^2 u_m}{\partial x^2} - 2\chi u_m + \chi \frac{\partial v}{\partial z} = 0$$ \hspace{1cm} (5)

$$\gamma \frac{\partial^2 v_m}{\partial x^2} - 2\chi v_m - \chi \frac{\partial u}{\partial z} = 0$$ \hspace{1cm} (6)

2.1 Conservation of angular momentum:

where $(u, v, w)$ are the velocity components in the $x, y$ and $z$ directions respectively, $u_m, v_m$ are the microrotational velocity components, $\chi$ is the spin viscosity set up by the suspended particles and $\gamma$ is the coefficient of viscosity of the micropolar fluid. Note that for $\chi = 0$ and $\gamma = 0$, the above system (3)-(4) reduces to the classical case of the Newtonian fluids (Szeri 2005). In the aforementioned equations, the velocity components vary only slowly along streamlines, the nonlinear acceleration terms, although not zero identically, are appreciably small, and hence as an approximation these can be neglected. This is further justifiable by the fact that the thickness of the fluid layer between two surfaces is too small compared to their lengths, the rate of strain and stress due to viscosity is quite large. The pertinent boundary conditions for the above system are:

on the bearing surface $z = 0$:  

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where $w^*$ on the bearing surface can be obtained from the porous region and (8) gives the interface boundary condition. The bearing surface has a porous matrix of thickness $\delta$ in which the micropolar fluid easily percolates into the porous region and vice versa. Constitutive equations for micropolar fluid in the porous region are governed by the Darcy's law

\[ \vec{q} = -\frac{k}{\mu + \chi} \nabla p^* \]  
\[ \nabla q^* = 0 \]

Where $\vec{q}(= u^*, v^*, w^*)$ is the velocity vector, $\chi$ is the spin viscosity, $k$ is the permeability of porous matrix and $p^*$ is the Darcy pressure. From equations (10) and (11), we get

\[ \nabla^2 p^* = 0 \]  

(12) is the Laplace equation that governs the hydrostatic pressure in the porous region. Integrating the Laplace equation (12) with respect to $z$ using solid backing boundary condition

\[ \frac{\partial p^*}{\partial z} |_{z=-\delta} = 0 \]

we get

\[ \frac{\partial p^*}{\partial z} |_{z=0} = -\int_{-\delta}^{0} \left( \frac{\partial^2 p^*}{\partial x^2} + \frac{\partial^2 p^*}{\partial y^2} \right) \, dz \]  

(13)

which is valid if the thickness $\delta$ of the porous region is too small in comparison with the fluid layer. Using the interface boundary condition $p = p^*$ in (13) we get

\[ \frac{\partial p^*}{\partial z} |_{z=0} = \delta \left( \frac{\partial^2 p^*}{\partial x^2} + \frac{\partial^2 p^*}{\partial y^2} \right) \]  

(14)

Further to obtain the Reynolds equation for the unknown pressure, the solutions of (3)-(6) subject to the boundary conditions (7)-(9) are given by

\[ u = \frac{1}{2} \left( \frac{z^2}{\mu} \frac{\partial p}{\partial x} + A_{11} z \right) - 2NM \left( A_{21} \sinh \left( \frac{Nz}{M} \right) + A_{31} \cosh \left( \frac{Nz}{M} \right) \right) + A_{41} \]  

(15)

\[ w = 2NM \left( A_{22} \sinh \left( \frac{Nz}{M} \right) + A_{32} \cosh \left( \frac{Nz}{M} \right) \right) + \frac{z^2}{\mu} \frac{\partial p}{\partial y} + A_{12} \frac{z}{\mu} + A_{42} \]  

(16)

\[ u_m = A_{22} \cosh \left( \frac{Nz}{M} \right) + A_{32} \sinh \left( \frac{Nz}{M} \right) + \frac{1}{2\mu} \left( \frac{\partial p}{\partial y} + A_{12} \right) \]  

(17)

\[ v_m = A_{21} \cosh \left( \frac{Nz}{M} \right) + A_{31} \sinh \left( \frac{Nz}{M} \right) - \frac{1}{2\mu} \left( \frac{\partial p}{\partial x} + A_{11} \right) \]  

(18)

Where

\[ A_{11} = 2\mu A_{21}, \quad A_{21} = \frac{A_{31} \sinh \left( \frac{NH}{M} \right) - \frac{H}{2\mu} \left( \frac{\partial p}{\partial x} \right)}{1 - \cosh \left( \frac{NH}{M} \right)}, \quad A_{41} = 2NM(A_{31}) \]

\[ A_{31} = \frac{H \frac{\partial p}{\partial x} \left( \frac{H}{2} \left( \cosh \left( \frac{NH}{M} \right) - 1 \right) + H - N \sinh \left( \frac{NH}{M} \right) \right)}{2\mu} \]

\[ A_5 = H \left( \sinh \left( \frac{NH}{M} \right) - 2NM \left( \cosh \left( \frac{NH}{M} \right) - 1 \right) \right), \quad A_{12} = (-2\mu)A_{22} \]

\[ A_{22} = -\frac{A_{32} \sinh \left( \frac{NH}{M} \right) - \frac{H}{2\mu} \left( \frac{\partial p}{\partial y} \right)}{1 - \cosh \left( \frac{NH}{M} \right)}, \quad A_{42} = -2NM(A_{32}) \]

\[ A_{32} = \frac{\frac{\partial p}{\partial y} \left( -N \sinh \left( \frac{NH}{M} \right) - H \left( 1 - \cosh \left( \frac{NH}{M} \right) \right) + \frac{H}{2} \right)}{\mu A_{52}} \]

\[ A_{52} = -\left( \sinh \left( \frac{NH}{M} \right) - 4NM \left( \cosh \left( \frac{NH}{M} \right) - 1 \right) \right) \]

Plugging the above solutions (15) and (16) in the continuity equation (2) and integrating it over the fluid layer, we get
\[
\frac{\partial}{\partial x} \left( F(N, M, H) \frac{\partial \theta}{\partial x} \right) + \frac{\partial}{\partial y} \left( F(N, M, H) \frac{\partial \theta}{\partial y} \right) = - \left( \frac{\partial H}{\partial t} + w \right)_{z=0}
\]  

(19)

where \( F(N, M, H) = H^3 + 12M^2H - 6NMH^2\coth \left( \frac{NH}{2M} \right) \)

From the third component of (10) and from (14), the Reynolds equation (19) is rewritten as

\[
\frac{\partial}{\partial x} \left( \left( F(N, M, H) + \frac{\delta y}{\mu + x^2} \right) \frac{\partial \theta}{\partial x} \right) + \frac{\partial}{\partial y} \left( \left( F(N, M, H) + \frac{\delta y}{\mu + x^2} \right) \frac{\partial \theta}{\partial y} \right) = 12\frac{\partial H}{\partial t}
\]  

(20)

which is in dimensional form. Introducing the non-dimensional variable and parameters

\[
\theta = \frac{x}{R}, \quad y = \frac{y}{L}, \quad \bar{M} = \frac{M}{e}, \quad \bar{H} = \frac{H}{e}, \quad \bar{k} = \frac{k}{e^2}, \quad \bar{\delta} = \frac{\delta}{e}, \quad \bar{p} = \frac{p e^2}{\mu R^2 \frac{\partial e}{\partial t}}, \quad \psi = \frac{\delta X}{e^3}
\]

\[
N = \left( \frac{X}{2\mu + \chi} \right)^{1/2}, \quad \lambda = \frac{L}{2R}
\]

where \( \bar{M} \) is some characteristic length of polar suspension, \( N \) is a non-dimensional coupling number, \( \psi \) is the permeability parameter and \( \lambda \) is the aspect ratio, in equation (20) we get the non-dimensional Reynolds equation (overbars are dropped for convenience)

\[
\frac{\partial}{\partial \psi} \left( \left( F(N, M, H) + 12\psi \left( 1 - \frac{N^2}{1 + N^2} \right) \frac{\partial p}{\partial \psi} \right) + \frac{1}{4\lambda^2} \frac{\partial}{\partial y} \left( \left( F(N, M, H) + 12\psi \left( 1 - \frac{N^2}{1 + N^2} \right) \right) \frac{\partial p}{\partial y} \right) = 12\cos \theta
\]  

(21)

where \( F(N, M, H) = H^3 + 12M^2H - 6NMH^2\coth \left( \frac{NH}{2M} \right) \)

(22)

The first two terms on the left side of (21) indicate that flow is due to the pressure gradient and the Poiseuille flow. This Poiseuille flow is generally influenced by the presence of micropolar fluid and porous matrix. The term on the right side of (21) expresses the contribution due to the squeezing effects. When \( N = 1, M = 0 \) and \( \psi = 0 \), the present model reduces to the classical Reynolds equation given by (Szeri 2005). Some of the results are compared with those obtained by Szeri (2005). The boundary conditions imposed on the pressure in the fluid layer are

\[
p = 0 \quad \text{at} \quad \theta = \frac{\pi}{2} \quad \text{and} \quad \frac{3\pi}{2}
\]

\[
p = 0 \quad \text{at} \quad y = -\frac{1}{2} \quad \text{and} \quad \frac{1}{2}
\]

Equation (21) is a two-dimensional second-order partial differential equation, and it can be used to study the micropolar fluid and permeability effect of the bearing system. Once the pressure distribution is obtained, we determine the load carrying capacity of the journal bearing. This load carrying capacity can be obtained by integrating the pressure distribution across the fluid layer

\[
W(t) = \int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} \frac{1}{2} \int_{\frac{1}{2}}^{\frac{3\pi}{2}} p(\theta, y) \cos \theta d\theta dy
\]

(25)

which in non-dimensional form becomes (see non-dimensional forms)

\[
W(t) = \frac{W(\psi)e^2}{\mu e^2} = \int_{\frac{1}{2}}^{\frac{3\pi}{2}} \int_{\frac{1}{2}}^{\frac{3\pi}{2}} p(\theta, y) \cos \theta d\theta dy
\]

(26)

The Reynolds equation (21) is not amenable to solve analytically in a closed form solution (because of 22). Thus, the solution for the pressure profile in a journal bearing is obtained numerically using the multigrid method. In the following section all the essential steps of multigrid algorithm for the modified Reynolds equation are described. We follow the steps similar to that of Kudenatti (2012).

### III. NUMERICAL SOLUTION

In the previous section we have obtained the modified Reynolds equation which is essentially partial differential equation and is not solvable as a whole. However, using short or long bearing approximations, one can reduce two-dimensional equation to a one-dimensional equation, and hence obtain analytical expressions for pressure and the load carrying capacity. In the process, the full Reynolds equation loses the coupling in the \( y \) – direction or \( \theta \) – direction due to the approximation, it will become weak, and hence special attention needs to be paid for the problem. As a result one-dimensional models wouldn't capture any significant flow variations. Nevertheless, advances in numerical methods have made it possible to solve the full-Reynolds equation, and these simulations would compare many of experimentally observed dynamic phenomena. On the other hand, multigrid methods have been proved to be far better than the traditional methods (Venner and Lubrecht 2000) for various forms of the full-Reynolds equations. These methods effectively suppress all sorts of errors at various stages and eventually give the most accurate solution, and provide simple way to compute the pressure distribution in the fluid layer. We use a
standard second-order finite difference operators to discretize the system of equations (21)-(24). The discretized Reynolds equation (21) can be written (after much simplification) as

\[ A_1 p_{i+1,j} + A_2 p_{i-1,j} + A_3 p_{i,j+1} + A_4 p_{i,j-1} - A_5 p_{i,j} = R_i \]  

where

\[
\begin{align*}
A_1 &= 4\lambda^2 \left( \frac{\Delta z}{\Delta y} \right)^2 \left( F_{i+1/2,j} - 12\psi \left( \frac{1-N^2}{1+N^2} \right) \right), \\
A_2 &= 4\lambda^2 \left( \frac{\Delta z}{\Delta y} \right)^2 \left( F_{i-1/2,j} - 12\psi \left( \frac{1-N^2}{1+N^2} \right) \right), \\
A_3 &= \left( F_{i,j+1/2} + 12\psi \left( \frac{1-N^2}{1+N^2} \right) \right), \\
A_4 &= \left( F_{i,j-1/2} + 12\psi \left( \frac{1-N^2}{1+N^2} \right) \right), \\
A_5 &= (A_1 + A_2 + A_3 + A_4) \\
\end{align*}
\]

and the boundary conditions become \( p_{i,j} = 0 \) on the cavitation boundaries.

To capture any flow variations, we essentially take a very small grid size in the simulation. A few Gauss-Seidel iterations are applied on the discretized Reynolds equation (27) which smoothen the error components with wavelengths which are comparable to mesh size. While those with wavelengths which are greater than the grid size converge slowly. At this stage a smooth error can be accurately represented on a coarser grid by using the half-weighting restriction operator and again use some Gauss-Seidel iterations. This procedure is continued till we get a single grid in the coarsest level, and is solved there. Now the bilinear interpolation is applied to determine the value of fine grid from the coarsest level. At this stage we again apply a few Gauss-Seidel iterations that smoothen the error introduced by the interpolation. Repeating this technique till we get the original fine grid. Convergence of the solution is set to \( 10^{-6} \) for all pressure distribution simulations. The number of grid points in both directions is taken to be \( 65 \times 65 \), but also checked for \( 129 \times 129 \) grid points, and found that the pressure distributions between the two are graphically indistinguishable. We, therefore, presented all pressure distribution and load capacity using former grid-size. Validations for the full-Reynolds equation solver (multigrid method) have been performed extensively on the Newtonian fluid which serve as a benchmark for further investigation. We extensively use multigrid method to study the effects of micropolar fluid and permeability on the finite journal bearing.

After obtaining the required pressure distribution from (27), we determine the corresponding load capacity of the journal bearing using the numerical integration of (26) as

\[ W = \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} p_{i,j} \cos(\theta_i) \Delta \theta \Delta y \]  

where \( N_1 \) and \( M_1 \) are total number of grid points and \( \Delta \theta \) and \( \Delta y \) are step lengths. These results shall be discussed in the next section.

IV. RESULTS AND DISCUSSION

We study the dependence of the micropolar fluid and permeability on the performance of the journal bearing model by taking the parameters \( N \) measuring the coupling number which couples the Newtonian and micropolar viscosities, \( M \) measuring the chain length of microstructure suspensions, \( \psi \) measuring the permeability and \( \varepsilon \) measuring the eccentricity of the bearing model. To understand these effects on the system, We proceed to analyze the corresponding Newtonian and non-Newtonian(micropolar fluid), porous and non-porous solution using the full-numerical solver (multigrid method). All the results presented in this paper are obtained using the length to diameter ratio = 0.45. We first study the pressure distribution in the fluid layer by varying both \( N \) and \( M \).

Before studying any effects of micropolar fluid, the Newtonian fluid effect on the journal bearing is studied. This is done by solving (25) with \( M = 0 = N \), and the corresponding pressure distribution is shown in figure 2. Now, in order to study the effects of micropolar fluid on the journal bearing, in figures 3 and 4, we plot the variation of the pressure distribution \( P(\theta,y) \) with coordinates \( \theta \) and \( y \) for different values of \( M \) and \( N \) respectively keeping other parameters \( \psi = 0.0001 \) (permeability) and \( \varepsilon = 0.5 \) (eccentric constant). The pressure distribution in the fluid layer is obtained for \( M = 0.1, 0.3 \) and \( 0.5 \) in figure 3 and for \( N = 0.1, 0.3 \) and \( 0.5 \) in figure 4. Compared to the Newtonian fluid, the pressure distribution is rather more. Addition of micropolar suspension to the Newtonian fluid can alter the flow properties significantly. A well-known effect is essentially increase in the viscosity of the lubricant. As a result pressure distribution also increases in the fluid layer. Moreover, the micropolar fluid present in the lubricant drastically reduce the temperature effects on viscosity. These results of micropolar fluid of lubricant are more pronounced than the Newtonian fluid, and the similar results are reported in Khatak and Garg (2017) in which their analysis also carries the thermal effects on the performance of journal bearing. We now move onto discuss the effects of the micropolar fluids and the permeability in terms of the load carrying capacity of the journal bearing. These results are obtained from (27) in which the pressure distribution is obtained by solving the Reynolds equation using the multigrid method for selected values of \( M \) and \( N \). For their various values of \( M \) and \( N \), there is a
developed hydrodynamic interaction between the micropolar fluid and the porous bearing. Figure 5 shows the load carrying capacity of the bearing system as a function of eccentricity $\varepsilon$ for various $M$ and $N$ including the case of the Newtonian fluid. A very thick (the below one) line is for the Newtonian fluid. One can easily see that the multigrid method starts to predict the enhancement in the load carrying capacity for $M$ and $N$, compared to the Newtonian case. For larger values of eccentricity higher the load carrying capacity. These results are qualitatively agreeing with those of Wang and Zhu (2006) and the experimental work of Xu(1994). The rise in pressure distribution with micropolar lubricant can be attributed to increased viscosity due to lubricant additives. We know that bearing flow is rather highest for the Newtonian fluid whereas this bearing flow reduces for increasing micropolar fluid due to increased viscosity. Therefore, the fluid layer arrests maximum lubricant which results into rise in pressure distribution and hence the load carrying capacity.

Figures 6 and 7 show the variation of the load carrying capacity of the bearing system with the permeability $\psi$ respectively for various $M$ (characteristic length of the micropolar lubricant) and for various coupling parameter $N$. In these figures we have intentionally not shown the results for the Newtonian fluid because results are obvious. It is immediately clear from these figures that for increasing $\psi$ ($>1$) the load carrying capacity decreases. For smaller values of $\psi$ (between 0.0001 and 0.01), load carrying capacity decreases very little otherwise there is a sharp decrease in the load carrying capacity. As discussed in the previous paragraph, due to presence of micropolar lubricant, there is a enormous amount of fluid available in the fluid layer. For increasing $\psi$ means that there are more voids available on the porous facing which allow the lubricant to percolate into porous region. It results into decrease the pressure distribution and hence the load carrying capacity. This trend is preserved for all values of $M$ and $N$.

Fig1: Schematic diagram of the porous journal bearing

Fig 2: Pressure distribution $P$ for Newtonian fluid at $N = 0$ and $M = 0$ with $\psi = 0.0001$, $\lambda = 0.45$ and $\varepsilon = 0.4$. 
Fig 3: Pressure distribution $P$ for different values of $M$ with $N = 0.2$, $\psi = 0.0001$, $\lambda = 0.45$ and $\epsilon = 0.4$
Fig 4: Pressure distribution $P$ for different values of $N$ with $M = 0.2$, $\psi = 0.0001$, $\lambda = 0.45$ and $\varepsilon = 0.4$.
Fig 5: Variation of the Load capacity $W$ with Eccentricity $\varepsilon$ for different values of $M$ and $N$ with $\psi = 0.01$, $\lambda = 0.45$

Fig 6a: Variation of the Load capacity $W$ with Permeability $\psi$ for different values of $M$ with $N = 0.3$, $\lambda = 0.45$ and $\varepsilon = 0.6$

Fig 6b: Variation of the Load capacity $W$ with Permeability $\psi$ for different values of $N$ with $M = 0.6$, $\lambda = 0.5$ and $\varepsilon = 0.6$

Fig 7: Variation of $\frac{d\varepsilon}{dt}$ with squeezing time $\tau$ for different values of $\lambda = 0.5$ and $\varepsilon = 0.6$
V. REFERENCES


