INFLUENCE OF GEOMETRICAL PARAMETERS ON THE PERFORMANCE OF ASYMMETRIC HOLE ENTRY HYBRID JOURNAL BEARING WITH MICROPOLAR LUBRICANT

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ABSTRACT
The performance characteristics of a asymmetric constant flow valve compensated hole entry hybrid journal bearings operating with micropolar lubricant have been studied theoretically by varying the land width ratio. The modified Reynolds' equation, energy equation and conduction equation are solved simultaneously to obtain static performance for the hybrid journal bearing. The performance characteristics of the bearing have been presented and compared with Newtonian lubricant, for various values of land-width ratio and the micropolar parameters.
Keywords: constant flow valve restrictor, micropolar lubricant, asymmetric configuration, hybrid journal bearing, land-width ratio,

1. INTRODUCTION

Modern lubricants in journal bearings use polymeric additives to enhance their performance. The flow of polymer added lubricants is no longer governed by Newtonian hypothesis. The inadequacies of classical Newtonian theory can be overcome by the lubrication theory for micropolar fluids. Micropolar fluids represent fluids consisting of rigid, randomly oriented particles suspended in a viscous medium, where the deformation of particles is ignored. The theory of micropolar fluids has been widely used to study the fluid solutions with microstructures. Eringen [1] explained the behavior of micro particles in fluid flow in his micropoplar fluid theory. This theory has been used in various configurations of bearings in lubrication analysis. Khatak and Garg [2] studied the applications of Eringen micropolar theory to different configurations of bearing. They showed significant performance variation in bearings with micropolar lubrication. Many researchers have studied the hybrid bearings with micropolar lubrication under different test conditions. Recently Mehrjardi et al. [3] studied journal bearing of different geometrical configurations with micropolar lubrication. They showed that performance characteristics of circular and non circular journal bearings enhance due to increase in micropoplar effects of the lubricant. Bansal et al. [4] concluded that stability of flexible liner hydrodynamic journal bearing improves with increase in micropolar characteristics of lubricant while stability decreases with increase in deformation factor of the journal bearing. From above it could be noted that micropolar effects has been accepted in the lubrication analysis of the bearing

The areas of high load, high speed, and high accuracy often require the use of hybrid journal bearing. The working of these classes of bearing at high speed often results in high rise of temperatures. The increases temperature results in decrease in viscosity of lubricant. Thermohydrostatic analysis of hybrid bearing compensated with constant valve [5] and capillary restrictor [6] was performed with non-Newtonian lubricant. A comparison in the analysis of slot and hole entry hybrid bearings is performed by Garg et al. [7] by considering thermal effects and non-Newtonian lubricant. These available studies indicate that performance characteristics of hybrid journal bearing are significantly affected by the temperature increase of lubricant.

The performance analysis of hybrid bearing lubricated with micropolar lubricant has been limited to isothermal conditions and simple configurations. To the best of authors knowledge no investigation is yet available in literature that consider the influence of land-width ratio on the thermal performance of constant flow valve compensated hole entry hybrid journal bearing operating with micropolar lubricant.

An attempt has been made to seek more realistic performance characteristics for asymmetric configuration of micropolar fluid lubricated hybrid journal bearings for given range of micropolar lubricant parameters and land width ratios. The presented results in this article are expected to be useful in bearing design.

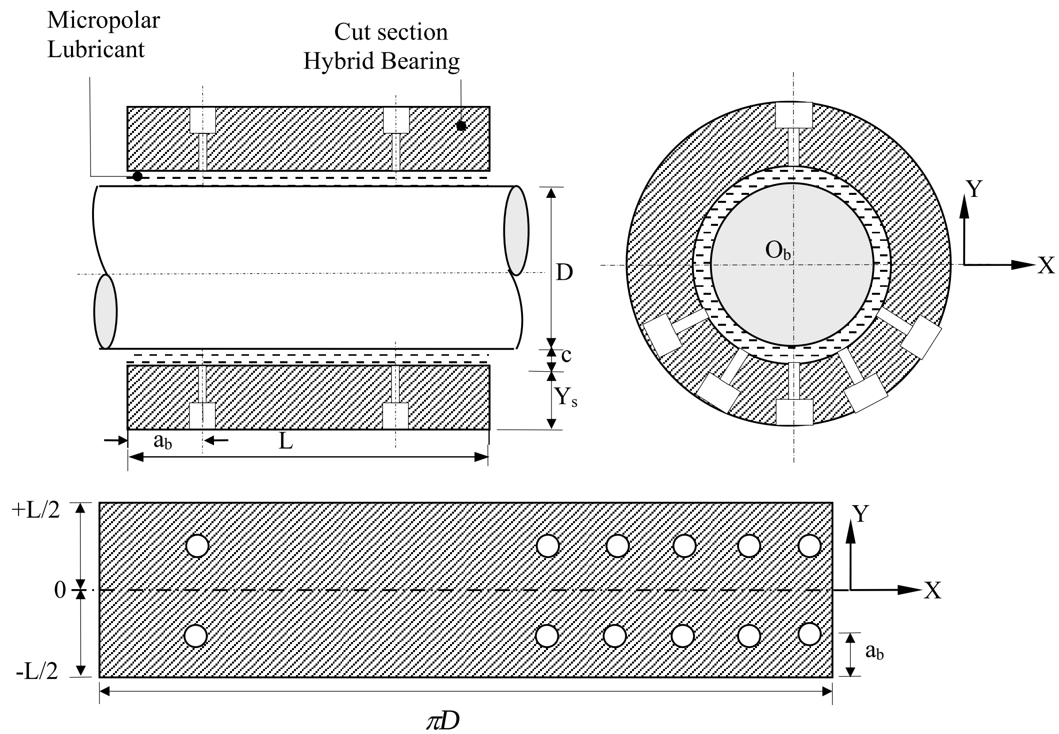

Fig. 1: *Asymmetric Configuration of hole entry hybrid journal bearing*

2. ANALYSIS

The asymmetric configuration of hybrid journal bearing (Fig. 1) is considered in this paper. The hole distribution along circumferential direction is shown in Fig. 1. Thermohydrostatic (THS) analysis of bearing lubricated with micropolar fluid involves the concurrent solution of modified Reynolds, three dimensional energy and three dimensional heat conduction equations. The explanation to the equations is given in the following sections.

2.1 MODIFIED REYNOLDS EQUATION

The non-dimensional modified form of Reynolds equation as in [8] for hybrid bearing lubricated with micropolar fluid and usual assumptions is:

$$\frac{\partial}{\partial\alpha}\left(\frac{\bar{h}^3}{\bar{\mu}}\bar{f}\left(l_m,N,\bar{h}\right)\frac{\partial\bar{p}}{\partial\alpha}\right)+\frac{\partial}{\partial\beta}\left(\frac{\bar{h}^3}{\bar{\mu}}\bar{f}\left(l_m,N,\bar{h}\right)\frac{\partial\bar{p}}{\partial\beta}\right)=6\Omega\frac{\partial\bar{h}}{\partial\alpha}+12\frac{\partial\bar{h}}{\partial\bar{t}} \quad (1)$$

Where $\bar{f}=\frac{f}{c^3\bar{h}^3}=1+\frac{12}{\bar{h}^2 l_m^2}-\frac{6N}{\bar{h}l_m}\coth\left(\frac{N\bar{h}l_m}{2}\right)$

$$N=\left(\frac{\kappa}{2\mu+\kappa}\right)^{\frac{1}{2}};\ l_m=\left(\frac{\gamma}{4\mu}\right)^{\frac{1}{2}};$$

Here μ is the classical viscosity coefficient of the lubricant, κ is the spin viscosity, γ is the material coefficient, N and l_m are two parameters to define a micropolar lubricant. N is called the coupling number which couples the linear and angular momentum equations due to the micro-rotational effects of the suspended particles in the lubricant. l_m represents the interaction between the length of lubricant particle and the clearance space of a journal bearing and is termed as the characteristic length of the micropolar lubricant.

2.2 RESTRICTOR EQUATION

Lubricant flow in bearing compensated with constant flow restrictor is:

$$\overline{Q}_R = \overline{Q}_C \tag{3}$$

$\overline{Q}_C$ is flow rate specified in restrictor.

2.3 VISCOSITY-TEMPERATURE EXPRESSION

Viscosity $\overline{\mu}$ of lubricant is supposed to be temperature dependent and is expressed as [8] :

$$\overline{\mu} = K_0 - K_1\overline{T}_f + K_2\overline{T}_f^2 \tag{4}$$

Where K_0, K_1 and K_2 are nondimensional constants having values 3.287, 3.064 and 0.777 respectively.

2.4 HEAT TRANSFER EQUATIONS

The heat transfer interaction between lubricant and the bearing can be expressed by three dimensional energy equation for the lubricant flow and three dimensional conduction equation for the bearing shell. The modified non-dimensional form of the micropolar energy equation [8] for the present application is :

$$\overline{h}^2\left(\overline{u}\frac{\partial\overline{T}}{\partial\alpha} + \overline{v}\frac{\partial\overline{T}}{\partial\beta} + \frac{\overline{w}}{\overline{h}}\frac{\partial\overline{T}}{\partial\overline{z}}\right) = P_e^*\frac{\partial^2\overline{T}}{\partial\overline{z}^2} + D_e\overline{\phi} \tag{5}$$

Temperature in bearing shell is computed by using the non-dimensional conduction equation in the cylindrical form [8]:

$$\frac{1}{\overline{r}}\frac{\partial}{\partial\overline{r}}\left(\overline{k}_b\overline{r}\frac{\partial\overline{T}_b}{\partial\overline{r}}\right) + \frac{1}{\overline{r}^2}\frac{\partial}{\partial\alpha}\left(\overline{k}_b\frac{\partial\overline{T}_b}{\partial\alpha}\right) + \overline{r}\frac{\partial}{\partial\beta}\left(\overline{k}_b\frac{\partial\overline{T}_b}{\partial\beta}\right) = 0 \tag{1}$$

2.5 BOUNDARY CONDITIONS

Boundary conditions used in the present study are [9]:

1. External boundary nodes in bearing have zero gage pressure.
2. Internal nodes have zero flow except external boundary and hole nodes.
3. It is assumed as per Swift-Stieber condition of cavitation that in the positive region of trailing edge of bearingTemperatures along the interface surfaces of lubricant-fluid and fluid-bush are same i.e. $\overline{T}_f = \overline{T}_J$ (at $\overline{z} = 1.0$) and ($\overline{T}_f = \overline{T}_b$) (at $\overline{z} = 0.0$) respectively.
4. At lubricant-bush surface interface
$$\frac{k_f}{\overline{h}\overline{c}}\left(\frac{\partial\overline{T}_f}{\partial\overline{z}}\right)\bigg|_{\overline{z}=0} = -k_b\left(\frac{\partial\overline{T}_b}{\partial\overline{r}}\right)\bigg|_{\overline{r}=\overline{R}_1}$$
5. At lateral surface of bearing
$$\frac{k_b}{R_j}\frac{\partial\overline{T}_b}{\partial\beta}\bigg|_{\beta=\pm\lambda} = -h_b\left(\overline{T}_b\big|_{\beta=\pm\lambda} - \overline{T}_a\right)$$
6. At hole inlet edge
$$\overline{T}_s = \overline{T}_b$$

3. SOLUTION PROCEDURE

A concurrent solution of micropolar Reynolds, energy and conduction equations along with given boundary conditions is performed. The performance of hybrid journal bearing of asymmetric configuration in terms of static performance characteristics is computed from the solution of governing equations.

4. RESULT AND DISCUSSION

A program code based on the technical analysis of the hybrid journal bearing has been developed. The performance characteristics of constant flow valve compensated hybrid journal bearing are computed by considering the thermal effects and micropolar parameters of lubricant. The results published by Khonsari and Brewe (10) for micropolar lubricated journal bearing are used to compare the numerical results obtained from the present study. It can be observed from Fig. 2 that present results of maximum pressure compares well with previous results and indicates correct use of methodology. A maximum deviation of about 3-4% is noted at higher end values of N^2 and lower end values of l_m. The viscous thermal effects are computed by combining typical bearing and lubricant characteristics in terms of Peclet inverse number ($\overline{P}_e^*$) and dissipation number ($\overline{D}_e$) [9].

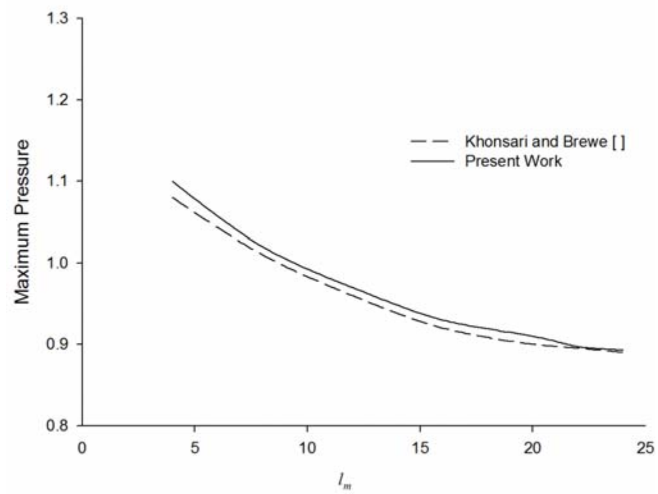

***Fig.2:** Maximum pressure variation with l_m.*

4.1 MINIMUM FLUID FILM THICKNESS ($\overline{h}_{min}$)

The variation of minimum fluid film thickness ($\overline{h}_{min}$) against land width ratio (a_b) is shown in Fig. 4. It can be observed that for a particular value of a_b, $\overline{h}_{min}$ increases with increase of coupling number (N^2). A maximum increase of 24.2% is observed for a_b value of 0.1 for micropolar lubricant ($N^2 = 0.8, l_m = 10$) in comparison to Newtonian lubricant.

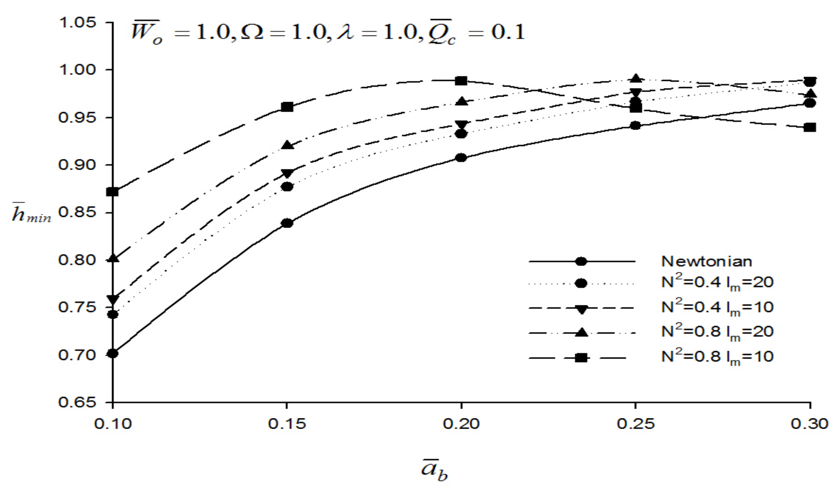

***Fig.4:** Minimum fluid film thickness variation with characteristic length.*

4.2 MAXIMUM PRESSURE ($\overline{p}_{max}$)

The variation of maximum pressure ($\overline{p}_{max}$) against land width ratio (a_b) is represented in Fig. 5. It can be observed that values of $\overline{p}_{max}$ are significantly increased for land width ratio (a_b) more than 0.15. The values of $\overline{p}_{max}$ are lowest for Newtonian lubricant and increases with increase in micropolar effects in the lubricant. The maximum pressure is increased by 27.3% for micropolar lubricant ($N^2 = 0.8, l_m = 10$) in comparison to Newtonian lubricant.

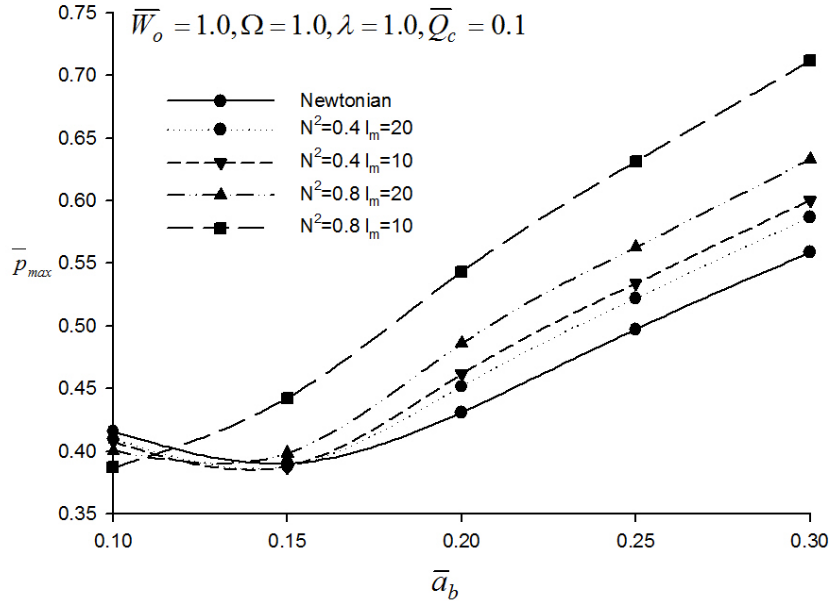

Fig. 5: *Variation of maximum pressure with characteristic length*

4.3 ATTITUDE ANGLE (ϕ)

Figure 6 shows that attitude angle **(ϕ)** remains constant till the land width ratios (a_b) 0.15. The values of ϕ show cyclic variation with further increase in a_b.

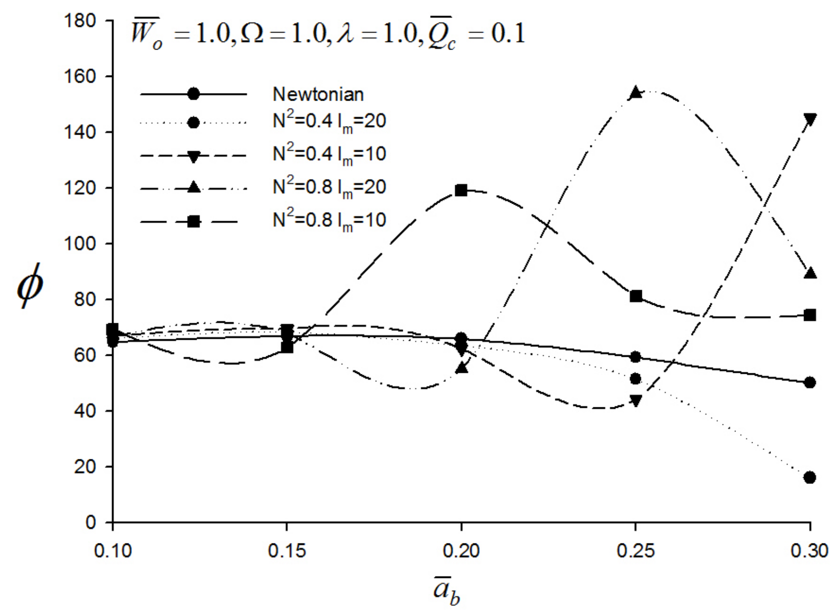

Fig. 6: *Variation of attitude angle with characteristic length .*

CONCLUSION

The effects of land-width ratio ($\overline{a}_b$) on the performance characteristics of a asymmetric constant flow valve compensated non recessed hole entry hybrid journal bearing operating with micropolar lubricant have been presented. The following conclusions can be drawn from the results presented in this study:

(1) The performance of asymmetric hole entry hybrid journal bearing in terms of $\overline{p}_{\max}$ rises with increase in micropolar effect and land width ratios ($\overline{a}_b$).

(2) For the constant land width ratio ($\overline{a}_b$), the $\overline{h}_{\min}$ increases with increase in micropolar effect of the lubricant.

(3) No definite pattern in the variation of attitude angles is observed with the increase in land width ratios and micropolar lubricants for asymmetric

configuration of hole entry hybrid journal bearing.

NOMENCLATURE

a_b	=	Land width (axial) [mm]	μ	=	Viscosity of lubricant [Pa s]
c	=	Clearance (radial) [mm]	μ_r	=	Reference viscosity of lubricant [Pa s]
D	=	Journal mean diameter [mm]	ρ_f	=	Lubricant density [kg / m^3]
h	=	Lubricant -film thickness [mm]	ϕ	=	Journal attitude angle [deg]
$h_{\min}$	=	Minimum lubricant -film thickness [mm]	x_j, z_j	=	Steady state coordinates of journal center
k_b	=	Thermal conductivity of bush $[W/m/K]$	y	=	Coordinate in axial direction
k_l	=	Lubricant Thermal conductivity $[W/m/K]$	z	=	Coordinate along lubricant film thickness
k_r	=	Reference thermal conductivity $[W/m/K]$	$\bar{a}_b$	=	a_b/L
l	=	Micropolar characteristic length [mm]	$\bar{c}$	=	c/R_J
L	=	Length of bearing [mm]	$\bar{h}, \bar{h}_{\min}$	=	$(h, h_{\min})/c$
O	=	Geometric center	$\bar{\mu}$	=	μ/μ_r
p	=	Pressure [Pa]	l_m	=	Characteristic length number , c/l
p_s	=	Supply pressure [Pa]	N	=	Coupling number
Q	=	Flow of lubricant [m^3 / s]	$\bar{p}$	=	p/p_s
r	=	Coordinate (radial)	$\bar{u}, \bar{v}$	=	$(u,v)(\mu_r R_J/c^2 p_s)$
R_J	=	Journal radius [mm]	$\bar{w}$	=	$w(\mu_r R_J/c^2 p_s)(R_J/c)$
t	=	Time [s]	$\bar{W}_o$	=	$W_o/p_s R_J^2$
T	=	Temperature [^{o}C]	α	=	Circumferential cylindrical coordinate
T_a	=	Temperature of air [^{o}C]	$\bar{z}$	=	z/h
T_f	=	Temperature of lubricant film[^{o}C]	α, β	=	$(x,y)/R_J$
T_r	=	Reference temperature [^{o}C]	λ	=	L/D , aspect ratio
u, v, w	=	Lubricant velocity components (X, Y, Z directions) [m / s]	Ω	=	Speed parameter $\omega_J(\mu_r R_J^2/c^2 p_s)$
W_o	=	External load [N]	$\bar{T}$	=	T/T_r
x	=	circumferential direction	γ, χ	=	micropolar viscosity coefficients

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