THEORETICAL ANALYSIS OF ORIFICE COMPENSATED SYMMETRIC AND ASYMMETRIC HYDROSTATIC NON-RECESSEDJOURNAL BEARINGS UNDER COUPLE STRESS LUBRICANTS

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SUMMARY

In this research a hole-entry hydrostatic journal bearings with couple stress and Newtonian lubricants have been examined analytically. The Newton Rapshon Method and Finite Element Method have been applied on Reynolds equation for couple stress and for the Newtonian lubricants to achieve the film pressure. The results of disparate factors of couple stress lubricants and the external load have been modeled. The outcome of the achieved results showed that the static and dynamic actions of bearings enhanced under a couple stress lubricants assessed the bearings performance with Newtonian lubricant.

KEYWORDS

Journal bearings, Lubricants, Restrictors, Finite element method

1. INTRODUCTION

Non-Newtonian fluids have been using in many modern industrial applications. The couple stress lubricants theory discusses functioning of lubricants with long chain polymer molecules**.** The theory of couple stress for liquids was described through Stokes [1] and Ariman and Cakman [2] used the same for analyzing the flow between parallel plates. The investigation of a couple stress fluids in the bearings was analyzed in various authors references [3-17]. Das and Bhattacharjee [3] analyzed mixed effect of couple stress and MHD lubricants on porous bearing. The execution of the slider and parabolic shaped wide slider bearing under couple stress lubrication was presented by Ramanaiah and Sarkar [4], Lin and Yu [5]. They found that a couple stress parameters can intensify the behavior of bearings. Sulaiman et al. [6] used a couple stress lubricants for the development of slider bearings shape. The implementation of rolling contact bearings using couple stress effect of lubricants was analyzed by Sinha and Singh [7]. Later, Singh [8] evaluated the attributes of short bearings and reported a considerable impact on the functioning of the bearing with a couple stress lubricants. Lin [9] applied conjugate gradient method for solving the Reynolds equation for a couple stress lubricant to evaluate the conduct of finite journal bearings. Wang et al. [10] summarized results of thermal and cavitation on the lubricated bearing under couple stress lubricants. Ma et al. [11] examined bearing behavior with a couple stress lubricants under various active loads. Guha [12] found that the dynamic response coefficients of bearing are noticeable at increased values of the parameter of couple stress lubricant or eccentricity ratio. Liao et al. [13] found that the stiffness and damping coefficients of the bearing is higher when operating under couple stress lubricants. Later, Gupta and Sharma [14] presented that the impact of couple stresses on the lubricating film of a hydrostatic stepped thrust bearing. Lin [15] analyzed the dynamic attributes of a hydrostatic circular step thrust bearing using perturbation technique. Mokhiamar et al. [16] highlighted that the impact of elasticity on finite bearing reduces the load bearing capability because of the couple stress lubricant. Recently, Crosby and Chetti [17] evaluated results of the two-lobe bearing performing along a couple stress lubricants. The author concluded that coefficients of damping and the bearing stiffness improve with a couple stress lubricant related to the Newtonian lubricant.

The hydrostatic bearings are utilized in several engineering applications due to the high rotor dynamic coefficients and high fluid film thickness. The hole-entry hydrostatic journal bearings were researched by various authors [18-20]. The journal bearing with hole entry was investigated by Rowe, et al. [18]. He compared its accomplishments with other journal bearings with different values of power ratios. Afterwards, a selection procedure for designing hydrostatic bearings was displayed by Cheng and Rowe [19]. The investigation by Sharma et al. [20] analyzed impact of deformation coefficients on the hole-entry journal bearings.

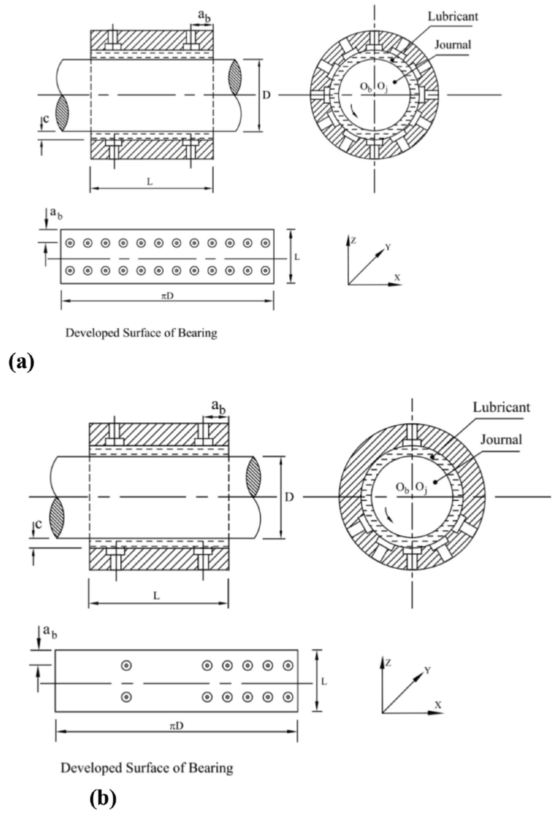

Figure 1. (a) Symmetric and (b) Asymmetric hole-entry journal bearings

The research study analyzes the influence of a couple stress lubricants on similar and dissimilar hole-entry hydrostatic bearing design shown in fig.1. The outcome of consequences evaluated the impact of a couple stress lubricants on the bearings, and it is found beneficial in designing of the bearing**.**

1.1 REYNOLDS EQUATION

Reynolds equation which accounts couple stress lubricant in hole-entry bearings is expressed as [8-10,12]

$$\frac{\partial}{\partial\alpha}\left(\frac{\bar{h}^3}{12}\bar{\Phi}\left(\bar{l},\bar{h}\right)\frac{\partial\bar{p}}{\partial\alpha}\right)+\frac{\partial}{\partial\beta}\left(\frac{\bar{h}^3}{12}\bar{\Phi}\left(\bar{l},\bar{h}\right)\frac{\partial\bar{p}}{\partial\beta}\right)=\frac{\Omega}{2}\frac{\partial\bar{h}}{\partial\alpha}+\frac{\partial\bar{h}}{\partial\bar{t}} \qquad (1)$$

where, $\bar{\Phi}\left(\bar{l},\bar{h}\right)=1-\frac{12}{\bar{l}^2\bar{h}^2}+\frac{24}{\bar{l}^3\bar{h}^3}tanh\left(\frac{\bar{h}\bar{l}}{2}\right)$

The couple stress lubricant's effects are indicated by couple stress parameter $\bar{l}$. If the value of parameter $\bar{l}$ decreases, the effect of couple stresses of the lubricant increases. The lubricant turns into Newtonian lubricant when parameter $\bar{l}$ reaches to infinity.

1.2 THICKNESS OF FLUID FILM

The thickness of film $\bar{h}$ with respect to journal centre coordinates X_J and Z_J can be given as [18,20]

$$\bar{h}=1-\bar{X}_J\cos\alpha-\bar{Z}_J\,sin\alpha \qquad (2)$$

1.3 RESTRICTOR FLOW EQUATION

The orifice flow devices in hole-entry bearing have been used and the flow of couple lubricant by this restrictor can be given as [18,20]

$$\bar{Q}_R=\bar{C}_{s2}\left(1-\bar{p}_c\right)^{1/2} \qquad (3)$$

where, $\bar{C}_{s2}=\left[\frac{1}{12}\left(\frac{3\pi a_o^2\mu_r\psi_d}{C^3}\right)\right]\left(\frac{2}{\rho\rho_s}\right)^{1/2}$

1.4 FINITE ELEMENT FORMULATION

The discretization of the field of lubricants flow issued by four noded isoparametric quadrilateral elements. Applying the Galerkin's procedure of FEM on transformed Reynolds equation (1), the resulting method equations in matrix form are given as [20]

$$\left[\bar{F}\right]^e\left\{\bar{p}\right\}^e=\left\{\bar{Q}\right\}^e+\Omega\left\{\bar{R}_H\right\}^e+\dot{\bar{X}}_j\left\{\bar{R}_{xj}\right\}^e+\dot{\bar{Z}}_j\left\{\bar{R}_{zj}\right\}^e \qquad (4)$$

1.5 BOUNDARY CONDITIONS

The conditions of boundary are utilized to resolve the equation (1) for the orifice compensated bearings and below are the conditions:

1. The exterior boundary pressure of bearing is comparable to the pressure of atmosphere.
2. Flow by an orificerestrictor is matching with the entering flow in the bearing at hole.

2. SOLUTION PROCEDURE

The similar and dissimilar hydrostatic bearings operating below the couple stress lubrication has been analyzed via iterative aspect scheme. A steady state case has been assumed in beginning for calculating the fluid film pressure by solving Eqn. (4) along with restrictor flow Eqn. (3) and given boundary conditions. In this paper, the Newton-Raphson method exhibits to understand the results of non-linear equations on the bearings, identified by an orifice-restrictor. The performance attributes specifications of bearings have been reproduced by using the relevant expressions used in Ref. [20] after convergence of solution.

3. RESULT AND DISCUSSION

A computer-based plan was established to inspect the execution of the bearing configurations. The outcomes of this study have been analyzed with the effects mentioned in Ref. [10] and it is found to be aligned. The bearing parameters of non-dimensional values are used to investigate the similar and dissimilar bearings which are mentioned in Table 1. The calculated outcome of the bearings behavior qualities which are affected by a couple stress lubricant are examined with the lubricated bearings and with Newtonian fluid in every figure. The differences between the parameters value of similar and dissimilar hydrostatic bearings working with Newtonian lubricants and a couple stress is shown in figure 2.

Table 1. Parameters used for symmetric and asymmetric hydrostatic journal bearings

Aspect ratio (λ)	1.0
Land width ratio $\left(\bar{a}_b\right)$	0.25
No. of holes for symmetric/asymmetric bearing For symmetric bearing For asymmetric bearing	 12 6
No. of rows in symmetric/asymmetric bearing	2
Concentric design pressure ratio $\left(\beta^*\right)$	0.5
Speed parameter (Ω)	0.0
Couple stress parameter $\left(\bar{l}\right)$	5,10,15
External load $\left(\bar{W}_o\right)$ For symmetric bearing For symmetric bearing	0.25-1.25 1.0-2.0

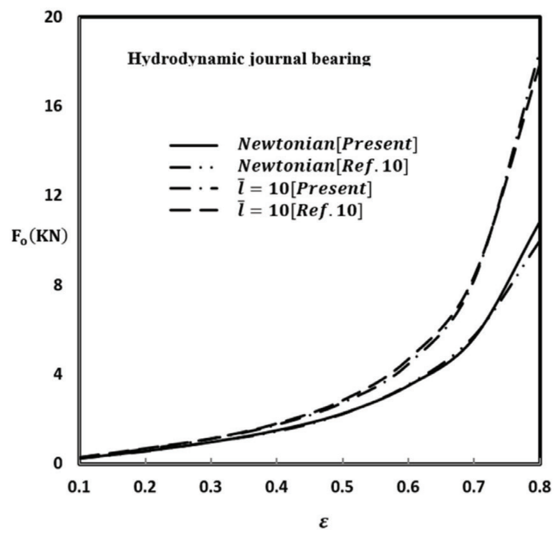

Figure 2. Variation of F_o with ε

Minimum Fluid Film Thickness $\left(\bar{h}_{min}\right)$

The variation of least film thickness $\left(\bar{h}_{min}\right)$ is appeared in the figs.3a and 3b. In the similar and dissimilar hydrostatic bearing configurations, the value of $\bar{h}_{min}$ rises with the constant load when both the configurations are lubricated with couple stress lubricants. The value of $\bar{h}_{min}$ is found higher at $\bar{W}_o = 1.0$ for symmetric configuration operating with couple stress factor at $\bar{l} = 5$ than the bearing including the Newtonian lubricant. As noticed from figures, the higher value of $\bar{h}_{min}$ is noticed for the bearing with a couple stress lubricant. Therefore, bearings operating through a couple stress lubricants can sustain more loads than bearing with Newtonian lubricant.

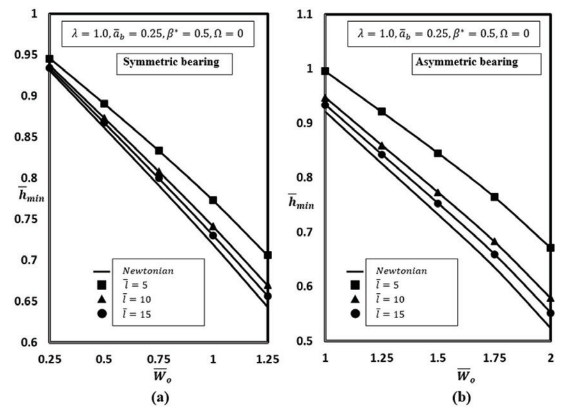

Figure 3. Variation of $\bar{h}_{min}$ with $\bar{W}_o$

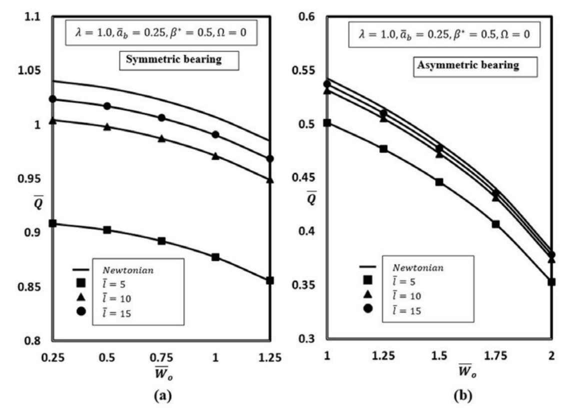

Figure 4. Variation of $\bar{Q}$ with $\bar{W}_o$

Bearing Lubricant Flow $\left(\bar{Q}\right)$

The impact on constraints of couple stress on the lubricant flow $\left(\bar{Q}\right)$ in the configurations of bearing is presented in figs.4a and 4b for both bearings. When symmetric and asymmetric configurations lubricated with the couple stress as well as Newtonian lubricants, the requirement of lubricant flow $\left(\bar{Q}\right)$ reduces for increase in the externally applied load. However, the flow $\bar{Q}$ in both the bearing configurations are observed lower for decreasing couple stress parameter $\bar{l}$ than bearings under Newtonian lubricant. After wards, it may be notable that minimization of flow of lubricant $\left(\bar{Q}\right)$ is more for stable value of $\bar{W}_o$ in case of symmetric bearing than asymmetric configuration performing with couple stress lubricant. The decline of $\left(\bar{Q}\right)$ is noticed 12.88% at $\bar{W}_o = 1.0$ for symmetric configuration operating at $\bar{l} = 5$ than bearing with Newtonian lubricant.

Fluid-Film Stiffness Coefficients $\left(\bar{S}_{11}, \bar{S}_{22}\right)$

It is seen in figs.5 and 6 that the impact of a couple stress lubricant on the film stiffness coefficients of bearings. An increased values of film stiffness coefficient $\left(\bar{S}_{11}\right)$ are noticed when both the bearings operate using couple stress lubricant for persistent for exterior load. It is noticed in Figure 5(b) that it consists of certain value of load for that the value of $\bar{S}_{11}$ increases and after that it decreases for Newtonian lubricated bearing and for couple stress lubricants as well. Though, the stiffness coefficient $\left(\bar{S}_{11}\right)$ is observed to be higher when the lubricated bearing with couple stress lubricant when applied external load constantly.

The selected value of externally applied load at $\bar{W}_o = 1.0$ and $\beta^* = 0.5$, an increase of 15.77% for symmetric and 23.44% for asymmetric bearings in the value of $\bar{S}_{11}$ is obtained when operates at $\bar{l} = 5$ than bearings with Newtonian lubricant. From Figs.6(a) and (b), value of $\bar{S}_{22}$ is more at decreased value of load at $\bar{W}_o = 0.25$ for symmetric bearing and $\bar{W}_o = 1.0$ for similar bearing working with couple stress lubricant. For constant load at

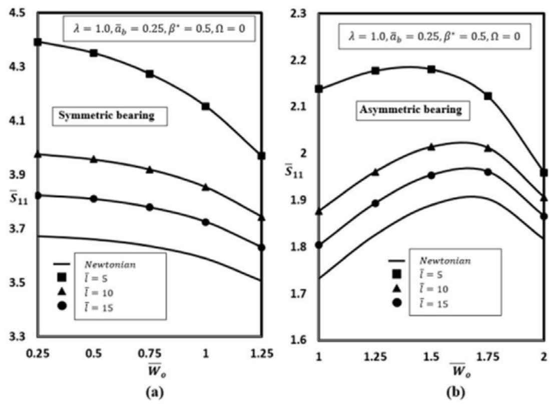

Figure 5. Variation of $\bar{S}_{11}$ with $\bar{W}_o$

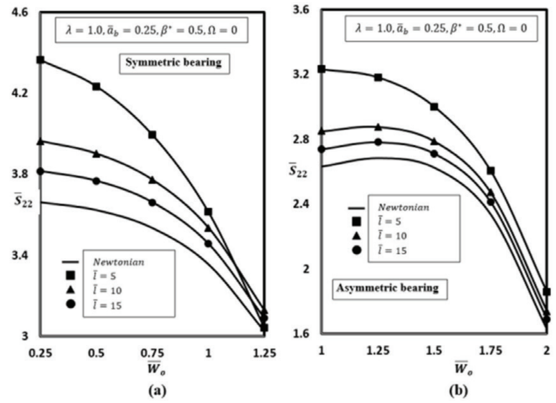

Figure 6. Variation of $\bar{S}_{22}$ with $\bar{W}_o$

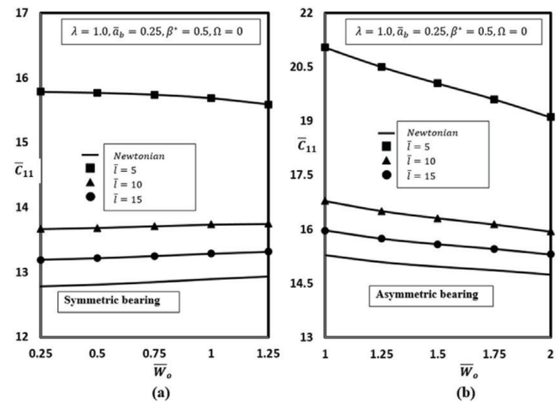

Figure 7. Variation of $\bar{C}_{11}$ with $\bar{W}_o$

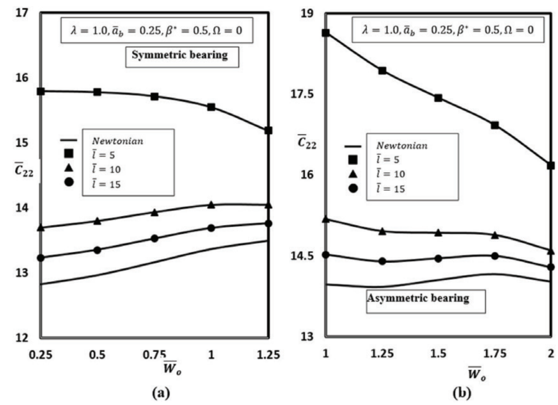

Figure 8. Variation of $\bar{C}_{22}$ with $\bar{W}_o$

$\overline{W}_o = 1.0$, an increase of 22.83% in stiffness coefficient $\overline{S}_{22}$ is found when asymmetric bearing operates at $\overline{l} = 5$ than bearing with Newtonian lubricant.

Fluid-Film Damping Coefficients $\left(\overline{C}_{11}, \overline{C}_{22}\right)$:

As noticed in Fig.7 and 8, the damping coefficients $\overline{C}_{11}$ and $\overline{C}_{22}$ improves with lesser value of couple stress consideration $\overline{l}$ at constant load for similar and dissimilar bearings. An increase in the value of c is 21.66% and 37.72% at $\overline{W}_o = 1.0$ for similar and dissimilar bearings respectively operating with couple stress lubricant at $\overline{l} = 5$ observed in bearing with Newtonian lubricant. The higher damping coefficients are beneficial for reducing the oscillation of bearing with couple stress lubricant. Further, Fig.8 shows the same tendency for damping coefficient $\overline{C}_{22}$ for both the bearings as in Fig.7. The damping coefficient $\overline{C}_{22}$ is 33.47% at $\overline{W}_o = 1.0$ for similar bearing correlated with couple stress parameter $\overline{l} = 5$ in connection to the lubricated bearing with Newtonian lubricant.

4. CONCLUSIONS

The conclusions came out from the study, are:

1. The minimal film thickness improves under couple stress lubricant for both the bearings than similar bearings with Newtonian lubricants. However, the value of $\overline{h}_{min}$ is more at constant load for similar bearing as compared to dissimilar bearing, which is performed with a couple stress lubricant.
2. For the similar working parameters, the similar bearing working through couple stress lubricant requires lesser amount flow of lubricant $\left(\overline{Q}\right)$ as examined with similar bearing which is determined under Newtonian lubricant.
3. Symmetric and asymmetric bearings accommodate higher values of fluid-film stiffness coefficients when performing under a couple stress lubricant as examined with similar bearings operating with Newtonian lubricant.
4. Dissimilar couple stress lubricated bearings provide more damping coefficients as compared with the alike bearing operating with Newtonian lubricant.

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