Performance of textured 3-lobe slot-entry hybrid journal bearing system operating with electro-rheological (ER) lubricant

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Abstract

For a new generation of fluid film journal bearings, the surface texturing approach and smart fluids like ER/MR fluids have been introduced by the bearing designers and lubricant engineers. Thus, the present theoretical investigation related to the combined influence of electro-rheological (ER) fluid lubrication and surface texturing approach on the performance of textured 3-lobe slot-entry hybrid journal bearing has been performed. In this work, Continuous Bingham fluid model has been used to obtaining the apparent viscosity of ER lubricant, consequently derive the modified Reynolds equation. Further, the FEM numerical approach has been used to solving the modified Reynolds equation. The current computed results indicated that the ER fluid lubrication in 3-lobe textured journal bearing improved the values of fluid film stiffness and threshold speed significantly by order of 45.34 % and 23.23% respectively, in respect to Newtonian fluid lubrication in non-textured circular journal bearing.

1. Introduction:

Nowadays, many tribologists and lubricant engineers around the world are focussing their research efforts towards the development of smart technology for the tribo-components using smart fluids like electro-rheological (ER) fluids to fulfil the desired operations in high speed and heavy loaded applications. Generally, these types of lubricants requires the imposition of an external electric field between the tribo-contacts which cause an alteration in the dynamic behaviour and makes possible to control the tribo-components (fluid film bearings) performance at a faster rate. The first theory of ER fluid was introduced by Winslow [1] in terms of his patent in 1947. Nikolakopoulos and Papadopoulos [2, 3] reported the experiment investigation concerning the effect of ER lubricant on the performance a of high speed journal bearing. From their experimental investigation, it has been noticed that the dynamic yield stress, relative viscosity and wall shear stress enhances with increasing the values of external applied electric field, which causes the improvement in the rotor dynamic coefficients of journal bearing. Jang and Tichy [4] used the Continuous Bingham Model to describes the flow behaviour of ER lubricant in journal bearing and simulated the rotor dynamic coefficients. They found that the external applied electric voltage in fluid domain gives enhanced values of rotor dynamic coefficients of journal bearing. Further, the roughness profile of bearing surfaces plays an important role on the lubrication of journal bearing. Thus, the surface modification is becoming an important activity over the last few years. Hence, many bearing designers have applied textured surfaces on bearing surfaces for modifying the bearing surface with great accuracy. Firstly, Hamilton et al. [5] reported the idea of surface texturing by producing large number of micro-surfaces on the bearing surface. It was noticed that these micro-surfaces act as micro-bearings and enhancing bearing performance. Lu and Khonsari [6] carried out the experimental study concerning the influence of different dimple-shapes, -sizes and -orientation on the performance of journal bearing. In their study, it has been found that the optimum dimple shapes, dimension and orientations gives improved value of load carrying capacity. Recently, Khatri and Sharma [7] investigated the combined influence of textured surfaces and couple stress lubricant-lubrication on the performance of two-lobe slot-entry hybrid journal bearing. In their study they indicated that the couple stress lubricant-lubricated textured two-lobe slot-entry hybrid journal bearing gives significant improvement in the stability parameters of journal bearing in comparison to Newtonian lubricant-lubricated smooth journal bearing.

The review of literature indicates that the ER fluid lubrication in journal bearing gives significant improvement in bearing performance and also reveals that the textured surface enhances the journal bearing performance. Thus, to investigation the influence of textured surface and ER fluid lubrication on journal bearing, the slot-entry three-lobe journal bearing configuration has been taken in the present study. In this bearing, the slotted shims are provided circumferentially on the bearing surface in symmetrically manner. The slot-entry hybrid journal bearing configurations gives some salient advantages as compared to recessed/pocket hybrid journal bearings in respect of high external load support at zero and high speed, zero starting wear, high overload capacity at full speed, ease of manufacture. Firstly, Shires and Dee [8] reported the concept of slot-entry journal bearing configuration in 1971. They found that the use of slot-entry restrictor encountered the problem of gas dispersion due to orifice restrictor. Later on, Rowe et al. [9] carried out the comparative studies between recessed and slot-entry circular journal bearings. It was observed that the circular slot-entry journal bearing gives enhanced performance in comparison circular recessed journal bearing. However, Circular fluid film journal bearings usually experience large scale self-excited vibrations due to fluid induced instability at high speed. In recent time, non-circular journal bearings are used to tackle this problem and also give research attention in these bearings because of their excellent bearing performance in respect to circular journal bearings. The three-lobe profile non-circular journal bearing is a one of most used non-circular journal bearing. In 1956, firstly Pinkus and Mass [10] reported the theoretical idea of elliptical and three-lobe bearings. They provide data for power loss and stability parameters over a range of ellipticity and aspect ratio. Recently, Kushare and Sharma [11] carried out the influence of various roughened patterns bearing on the performance of 3-lobe hole-entry hybrid journal bearing. It was found that the longitudinally roughened 3-lobe bearing gives enhancement in the values of fluid film stiffness and stability speed than that of other roughened bearing configurations.

2. Analysis:

The schematic diagram of three-lobe textured hybrid journal bearing is illustrated in Figure 1. The modified Reynold's equation to describing the lubricant flow of ER lubricant in the clearance gap of a journal and three-lobe textured bearing is written as [2, 7]

$$\frac{\partial}{\partial \alpha}\left(\bar{h}^3 \bar{F}_2 \frac{\partial \bar{p}}{\partial \alpha}\right)+\frac{\partial}{\partial \beta}\left(\bar{h}^3 \bar{F}_2 \frac{\partial \bar{p}}{\partial \beta}\right)=\Omega\left[\frac{\partial}{\partial \alpha}\left\{\left(1-\frac{\bar{F}_1}{\bar{F}_0}\right)\bar{h}\right\}\right]+\frac{\partial \bar{h}}{\partial \bar{t}} \quad (1)$$

Where, $\bar{F}_0$, $\bar{F}_1$ and $\bar{F}_2$ are the apparent viscosity functions; $\bar{F}_0=\int_0^1 \frac{1}{\bar{\mu}} d\bar{z}$; $\bar{F}_1=\int_0^1 \frac{\bar{z}}{\bar{\mu}} d\bar{z}$; $\bar{F}_2=\int_0^1 \frac{\bar{z}}{\bar{\mu}}\left(\bar{z}-\frac{\bar{F}_1}{\bar{F}_0}\right) d\bar{z}$ (2)

The expression of non-dimensional fluid-film thickness for textured journal bearing is defined by [7]

$\bar{h}=\bar{h}_L+\bar{h}_{ts}$ Where, $\bar{h}_L=\frac{1}{\delta}-\left(\bar{X}_J-\bar{X}_L^i\right)\cos\alpha-\left(\bar{Z}_J-\bar{Z}_L^i\right)\sin\alpha$ and

$$\bar{h}_{ts}=\begin{cases}\left[\left(\bar{h}_p/2+\bar{\delta}^2/2\bar{h}_p\right)^2-\bar{\delta}^2\left(\bar{x}_l^2+\bar{z}_l^2\right)\right]^{1/2}-\left[\left(\bar{\delta}^2/2\bar{h}_p-\bar{h}_p/2\right)\right] & at\ r'<r_p \\ 0 & at\ r'>r_p\end{cases} \quad (3)$$

The flow of the ER lubricant for slot-entry restrictor is defined by following relation [7, 9];

$\bar{Q}_R=\bar{C}_{SR}\left(1-\bar{p}_c\right)$; Where, $\bar{C}_{SR}$ is the design parameter for slot-entry restrictor $\bar{C}_{SR}=\frac{\pi}{36}\frac{SWR}{\lambda}\frac{N_r}{\bar{a}_b}\frac{a_b}{Y_s}\left[\frac{Z_s}{c}\right]^3$ (4)

Further, the behaviour of ER fluid is described with the help of Continuous Bingham fluid model and is expressed by [12]

$$\bar{\mu}\left(\bar{\dot{\gamma}}\right)=\bar{\mu}_0+\frac{2\bar{\tau}_0}{\pi\bar{\dot{\gamma}}}\tan^{-1}\left(\frac{\bar{\dot{\gamma}}}{\bar{\dot{\gamma}}_0}\right) \quad (5)$$

By using Galerkin's orthogonality technique and FEM solution procedure, the modified Reynolds's equation (Eqn. (1)) in below form [7]: $\left[\bar{F}^e\right]_{n\times n}\left\{\bar{p}^e\right\}_{n\times 1}=\left\{\bar{Q}^e\right\}_{n\times 1}+\Omega\left\{\bar{R}_H^e\right\}_{n\times 1}+\dot{\bar{X}}_J\left\{\bar{R}_{X_J}^e\right\}_{n\times 1}+\dot{\bar{Z}}_J\left\{\bar{R}_{Z_J}^e\right\}_{n\times 1}$ (6)

The above equation (Eqn. 6) has been solved iteratively to obtain nodal fluid film pressure and further simulate the fluid film stiffness coefficients by $\bar{S}_{ij}=-\frac{\partial \bar{F}_i}{\partial \bar{q}_j}\left(i=x,y\ or\ 1,2\right)$ and the threshold speed by $\bar{\omega}_{th}=\sqrt{\left(\bar{M}_c/\bar{F}_o\right)}$.

3. Results and Discussion:

To simulate the performance characteristics of textured three-lobe slot-entry hybrid journal bearing, a computer programming code has been written in MATLAB by using appropriate analysis and solution scheme. In the present work, the performance parameters of three-lobe slot-entry journal bearing are computed against load carrying capacity as shown in Figures 2-4. The variation in fluid film thickness $(\bar{h}_{\min})$ against external load $\left(\bar{W}_o\right)$ for three-lobe/circular textured/smooth slot-entry hybrid journal bearings lubricating with ER/Newtonian lubricant is computed in Figure 2. Based on simulated results, it can say that the presence of textured surface in slot-entry journal bearing reduces the value of $\bar{h}_{\min}$ over smooth journal bearing. While, the use of ER lubrication and three-lobe profile in slot-entry journal bearing provides improvement in the value of $\bar{h}_{\min}$ by order of 7.21 % as compared to Newtonian fluid lubricated smooth circular slot-entry journal bearing. Figure 3 presents the combined influence of ER lubricant behaviour, three-lobe profile bearing and textured surface on the value of fluid film stiffness coefficient $(\bar{S}_{22})$ of slot-entry hybrid journal bearing. In Figure 3, it can clear seen that the surface texturing technique gives significantly improvement in the value of $\bar{S}_{22}$. The presence of ER fluid lubrication and three-lobe configuration in textured slot-entry journal bearing gives further improvement in the value of $\bar{S}_{22}$ by amount of 44.81-51.15 % with respect to Newtonian fluid-lubricated circular smooth slot-entry journal bearing. Further, the variation in stability threshold speed $\left(\bar{\omega}_{th}\right)$ with respect to external load $\left(\bar{W}_o\right)$ for three-lobe/circular textured/non-textured slot-entry journal bearing lubricating with ER/Newtonian lubricant is illustrated in Figure 4. On the basis of simulated results, it has been revealed that the presence of micro-dimples in slot-entry journal bearing significantly enhances the value of $\bar{\omega}_{th}$ over smooth journal bearing. In Figure 4, it can also be seen that the value of $\bar{\omega}_{th}$ is further enhances by use of ER lubrication and three-lobe configuration in slot-entry journal bearing. For a certain value of external load $\left(\bar{W}_o\right)=1.3$, the presence of ER lubricant-lubrication in three-lobe textured slot-entry bearing enhances the value of $\bar{\omega}_{th}$ by amount of 23.33% as compared to Newtonian lubricant-lubrication in smooth circular slot-entry journal bearing.

4. Conclusion:

From the theoretically simulated results in this study, following useful conclusions may be observed;

(1) The textured slot-entry hybrid journal bearing gives reduction in the values of minimum fluid-film thickness $\left(\bar{h}_{\min}\right)$. Whereas, the use of ER lubricant and 3-lobe $\left(\delta=1.1\right)$ profile bearing provides improvement in the values of minimum fluid film thickness $\left(\bar{h}_{\min}\right)$.

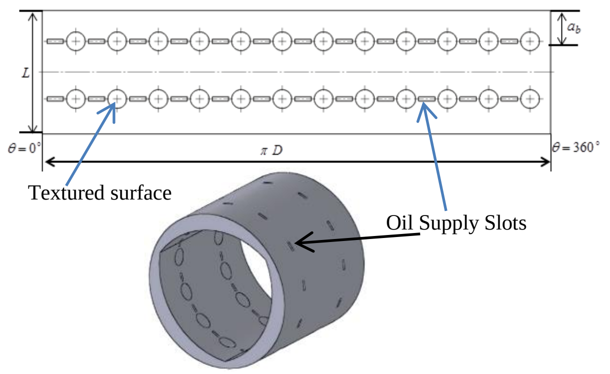

Figure 1: Three-lobe slot-entry journal bearing

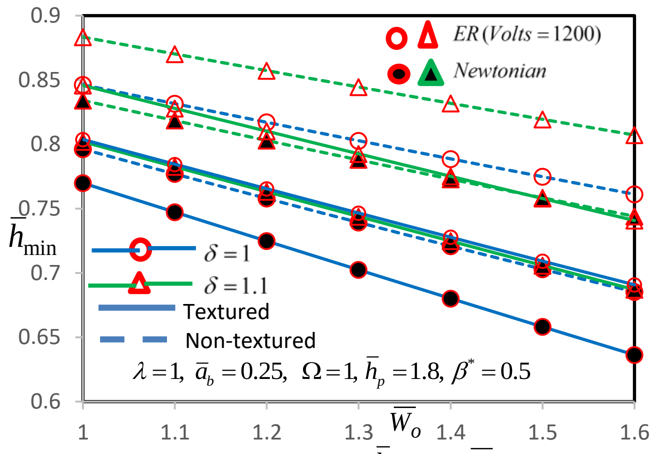

Figure 2: $\bar{h}_{min}$ vs $\overline{W}_o$

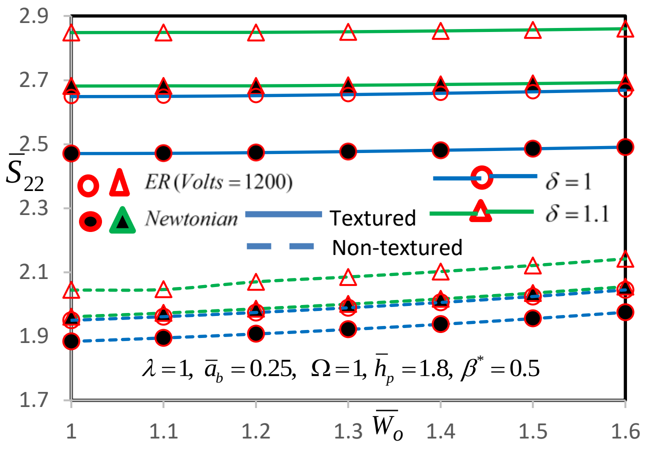

Figure 3: $\bar{S}_{22}$ vs $\overline{W}_o$

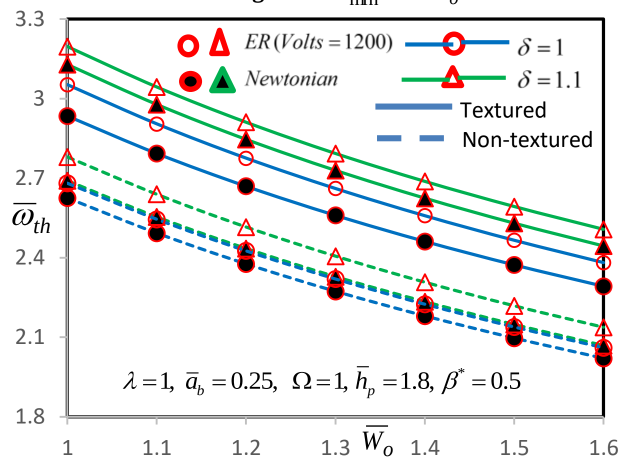

Figure 4: $\bar{\omega}_{th}$ vs $\overline{W}_o$

(2) The use of micro-surfaces on the surface of slot-entry hybrid journal bearing provides significant improvement in the values of fluid film stiffness coefficient $\left(\bar{S}_{22}\right)$ and threshold speed margin $\left(\bar{\omega}_{th}\right)$. The simulated results clearly indicate that the influence of ER lubrication and non-circular profile of bearing gives further enhancement in the textured slot-entry hybrid journal bearing than that of non-textured journal bearing lubricating with Newtonian lubricant.

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