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FERROFLUID BASED SQUEEZE FILM PERFORMANCE IN ANNULAR DISKS WITH NON NEWTONIAN COUPLE STRESSES

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Abstract: The squeeze film behavior in annular disks with a non Newtonian Ferro fluid in the presence of transverse magnetic fields is presented. By the application of Shliomis Ferro hydrodynamic model the modified Reynolds equation has been obtained. The graphical representations of the result suggests that the non Newtonian Ferro fluid lubricated squeeze film registers higher load carrying capacity in comparison with Newtonian non Ferro fluid cases.
Keywords: Annular disks, Squeeze film, ferrofluid, couple stress effect, load carrying capacity

1. INTRODUCTION

In the field of Technology and engineering, annular bearings are often designed to bear the transverse loads. The study of performance characteristics of annular bearings with different shapes and different lubricants has been conducted from time to time by many investigators. Ramanaiah (1979) discussed the squeeze film behavior between finite plates of various shapes lubricated by fluids with couple stress and found that squeeze time increased using couple stress as the lubricant. Bhat and Deheri (1991) analyzed the performance as of the squeeze film between two annular disks with the upper disk having a porous facing approaching the parallel lower disk. It was noticed that the performance of the bearing with the magnetic fluid lubricant was better than that with the conventional lubricant. Shah et al. (2002) theoretically analyzed the performance of the curved upper plate with a uniform porous facing approaching the impermeable and flat lower plate, considering a magnetic fluid lubricant in the presence of an external magnetic field oblique to the plate. It was seen that the increase in pressure and load capacity depended only on the magnetization. However, the increase in response time depended on magnetization, fluid inertia and speed of rotation of the plates.

Chiang et al. (2004) investigated the performance characteristics of finite journal-bearing systems including the combined effects of couple stress due to a Newtonian lubricant blended with additives and the presence of roughness. It was noticed that the couple stress effect could raise the film pressure of the lubricant fluid, improve the load-carrying capacity and reduce the friction parameter, especially, at high eccentricity ratio. Naduvinamani et al. (2005) observed the effect of surface roughness on the hydrodynamic lubrication of couple-stress squeeze film between a sphere and a flat plate on the basis of Christensen's stochastic theory for hydrodynamic lubrication of rough surfaces. The load carrying capacity and squeeze film time were found to increase for an azimuthal roughness pattern as compared to the corresponding smooth case, whereas the reverse trend was observed for a radial roughness pattern.

Deheri et al. (2006) dealt with the performance of a magnetic fluid based circular step bearing. It was observed that the radii ratio had a strong effect on the performance of the bearing system and got enhanced considerably owing to the presence of the magnetic fluid. Nada and Osman (2007) investigated the couple stresses due to the microstructure additives and the magnetic effect due to the magnetization of the magnetic fluid. The modified Reynolds equation was obtained. It was concluded that fluids with couple stresses were better than Newtonian fluids so far as the performance characteristics were concerned. The improvement of the bearing characteristics was enhanced if the magnetic effects were in force. Elsharkawy and Fadhalah (2008) analyzed the separation flow of a fully flooded sphere from a flat under the condition of constant load. Assuming the lubricant between the sphere and the flat to contain additives, the couple stress effect, presented by the characteristic length of the additives, was considered to account for the non-Newtonian behaviour. The results of the numerical solution indicated that the separation time increased with increasing characteristic length of the additives. It was also found that the additive characteristic length had negligible effect on the thickness of the lubricant film at the separation point.

Deheri et al. (2011) analyzed the performance of magnetic fluid based squeeze film between transversely rough curved annular plates by embarking on a comparative study of the geometrical structure of the curved annular plates. It was manifest that magnetic fluid lubrication of squeeze film enhanced the performance of the bearing system; as compared to that of conventional lubricant based squeeze film. Shimpi and Deheri (2012) investigated the behavior of a magnetic fluid based squeeze film between rotating transversely rough porous annular plates incorporating elastic deformation effect. It was revealed that the negative effect of porosity, deformation and standard deviation could be minimized up to certain extent by the positive effect of the magnetic fluid lubricant in the case of negatively skewed roughness. Basti (2013) studied the combined effects of couple stresses and surface roughness patterns on the squeeze film characteristics of curved annular plates.

Lin et al. (2013) observed the behaviour of a squeeze film in parallel circular disks with a non Newtonian ferrofluid in the presence of a transverse magnetic field. It was found that the non Newtonian ferrofluid lubricated squeeze films provided a higher load capacity and lengthened the approaching time. Patel and Deheri (2013) analyzed the performance of a ferrofluid based squeeze film in rotating rough curved circular plates resorting to Shliomis model. It was seen that Shliomis model based ferrofluid lubrication was relatively better as compared to the Neuringer – Rosensweig model for magnetic fluid lubrication of rough curved circular plates. Furthermore, the adverse effect of roughness could be reduced considerably at least in the case of negatively skewed roughness with a suitable choice of curvature parameters. Patel and Deheri (2014) discussed the effect of Shliomis model based ferrofluid lubrication on the squeeze film between curved rough annular plates with comparison between two different porous structures. It was found that the adverse effect of transverse roughness could be minimized by the positive effect of magnetization in the case of negatively skewed roughness. Patel et al. [2014] analyzed the effect of transverse surface roughness on the performance of a squeeze film in parallel circular disks with non-Newtonian ferrofluid under the presence of a transverse magnetic field. The results established that the transverse surface roughness significantly influenced the squeeze film performance. It was established that the adverse effect of surface roughness under suitable conditions got reduced due to the positive effect of non-Newtonian ferrofluid lubrication.

Here, it has been thought proper to study the non-Newtonian couple stress effect on an annular squeeze film under the presence of a magnetic fluid lubricant.

2. ANALYSIS

The configuration of the bearing system is shown below.

It consists of two parallel annular disks each of inner radius r_i and outer radius r_o.

The upper disk approaches the lower one with a squeezing velocity $-dh/dt$.

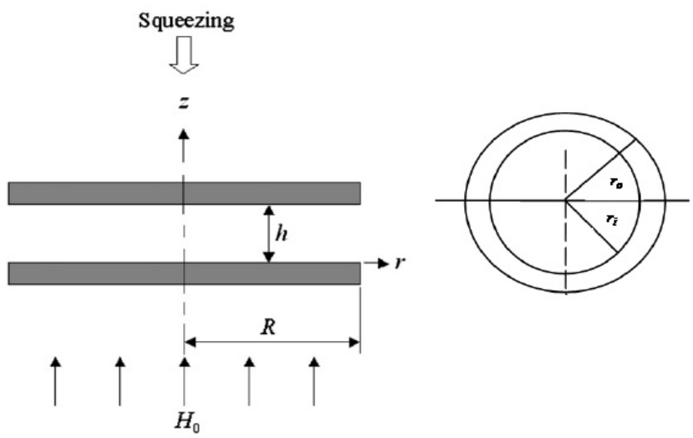

Figure1.Geometry of cross section of annular bearing

The ferro-hydrodynamic model of Shliomis (1972, 1974) is taken in to consideration.

Following the analysis of Lin et al. (2013) the modified Reynolds equation governing the pressure distribution for the performance of a ferrofluid lubricated squeeze film in annular disks with non-Newtonian couple stress effect is obtained as

$$f(h, l_c, \emptyset, \tau)\frac{1}{r}\frac{d}{dr}\left\{r\frac{dp}{dr}\right\} = 12\eta_0(1+\tau)(1+2.5\emptyset)\frac{dh}{dt} \tag{1}$$

where,

$$f(h, lc, \emptyset, \tau) = h^3 - 12\frac{l_c^2}{(1+\tau)(1+2.5\emptyset)}h + 24\frac{l_c^3}{(1+\tau)^{3/2}(1+2.5\emptyset)^{3/2}}\tanh\left(\frac{\sqrt{(1+\tau)(1+2.5\emptyset)}}{2l_c}h\right)$$

Introducing the dimension less quantities and solving the equation (1) with the boundary conditions,

$$r^* = \frac{r}{r_0}, P^* = \frac{ph_0^3}{\eta_0 r_0^2\left(\frac{dh}{dt}\right)}, h^* = \frac{h}{h_0}, f^* = \frac{f}{h_0^3} \tag{2}$$

$p = 0$ at $r = r_i$, $r = r_0$

the expression for non-dimensional pressure distribution is obtained as

$$P^{*}=\frac{3(1+\tau)(1+2.5\phi)}{f^{*}}\left\{r^{*2}+\frac{1}{\log K}\left[\left(1-K^{2}\right)\log r^{*}\right]-1\right\} \qquad (3)$$

where, aspect ratio is, $K=\frac{r_i}{r_0}$.

Integration of the film pressure over the film region yields the load carrying capacity in non-dimensional form as

$$W^{*}=\frac{3}{2}(1+\tau)(1+2.5\phi)\left(K^{2}-1\right)\left[1-\frac{1}{\log K}\left(K^{2}-1\right)\right]. \qquad (4)$$

In the limiting case $r_i \rightarrow 0$ the results of Lin et al. (2013) can be had from the present analysis.

3. RESULT & DISCUSSION

It is clearly seen that the equation (3) determines the pressure distribution while the load carrying capacity is obtained from equation (4).

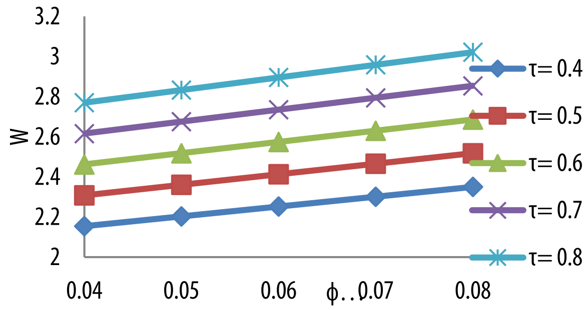

Figure 2. Variations of load carrying capacity w.r.to ϕ &**τ** .

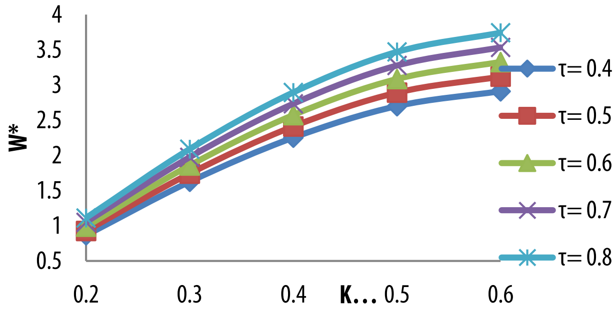

Figure 3. Variations of load carrying capacity w.r.to K &**τ** .

Figure 2 expresses the combined effect of volume concentration parameter and rotational viscosity parameter. It is found that the load carrying capacity rises sharply with increase in both the parameters, therefore the non Newtonian Ferro fluid lubricated squeeze film provides higher load carrying capacity in comparison with Newtonian non ferro fluid cases.

Figure 3 underlines that the aspectratio also plays a good role in improving the performance of the bearing system by increasing the load carrying capacity.

However figure 4 makes it clear that the effect of volume concentration parameter on the distribution of load carrying capacity with respect to aspect ratioremains marginal.

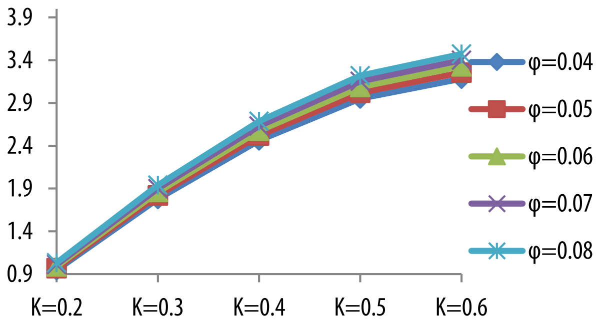

Figure 4. Variations of load carrying capacity w.r.to K &ϕ.

4. CONCLUSION

The non-Newtonian ferrofluid lubricated squeeze film provides higher load carrying capacity in comparison with Newtonian non ferrofluid cases. It is needless to say that the aspect ratio may play crucial role in providing a better performance especially when the couple stress effect is at low level.

Nomenclature:

C :	*couple stress parameter,* $C=l_c/h_0$	v_s :	*squeezing velocity,* $v_s=-dh/dt$
h :	*film thickness*	u, w :	*velocity components in the r – and z – directions*
h_0 :	*initialfilm thickness*	$\vec{V}$:	*fluid velocity vector*
H_0 :	*transverse magnetic field*	W :	*load capacity*
$\vec{H}$:	*applied magnetic field vector*	W^* :	*non-dimensional load capacity*
k_B :	*Boltzmann constant*	η :	*viscosity of the suspension*
m :	*magnetic moment of a particle*	η_0 :	*viscosity of the main fluid*
M_E :	*equilibrium magnetization,*	η_c :	*new material constant responsible for couple stress fluid property*
$M_E=nm(\coth\xi-1/\xi)$		μ_0 :	*permeability of free space*
$\vec{M}$:	*magnetization vector*	ϕ :	*volume concentration of particles*

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n : *number of particles per unit volume*
P : *film pressure*
P^* : *dimension less film pressure*
r, z : *radial and vertical coordinates*
ξ : *Langevin parameter,* $\xi = \mu_0 m H_0 / k_B T$
τ : *rotational viscosity parameter,*
$\tau = \dfrac{(3\phi/2)(\xi - \tanh \xi)}{(\xi + \tanh \xi)}$

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