HYDROMAGNETIC SHORT BEARINGS

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ABSTRACT

This article deals with the performance of a hydromagnetic short porous bearing. An electrically conducting lubricant in the presence of a transverse magnetic field has been taken into consideration while the plates are electrically conducting. The related Reynolds' equation governing the fluid film pressure is solved under suitable boundary conditions to get the pressure distribution leading to the computation of load carrying capacity. The results presented in graphical form establish that the bearing system registers an improved performance due to hydromagnetization. Besides, the load carrying capacity increases considerably with respect to the conductivity. It is revealed that the negative effect of porosity and the ratio of breadth to height can be neutralized up to a considerable extent by the positive effect of hydromagnetization suitably choosing the plate conductivity and the aspect ratio. It is found that the hydromagnetization presents the friction at both the plates to be equal.

***KEYWORDS**: Hydromagnetic lubrication,short bearing, Reynolds' equation, load carrying capacity, friction*

1.0 INTRODUCTION

(Pinkus and Sternlicht, 1961) laid down the classical analysis of the hydrodynamic lubrication of slider bearings. Subsequently, in this direction significant amount of works were done by several investigators (Lord Rayleigh, 1918), (Archibald, 1950), (Charnes and Saibel, 1952), (Cameron, 1966), (Gross et al., 1980), (Hamrock, 1994), (Basu et al., 2005), (Majmudar, 2008). Equally important are the contributions of (Bagci and Singh, 1983), (Osterle et al., 1958), (Patel and Gupta, 1983) and (Abramovitz, 1955) concerning the performance of hydrodynamic slider bearing. (Mc. Allister et al. 1980) discussed the design of optimum

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one dimensional slider bearing in terms of the load carrying capacity. An approximate analytic solution for performance characteristics of a porous metal bearing was proposed for the first time by (Morgan and Cameron, 1957). The exact solution of this problem was obtained by (Rouleau, 1963). (Prakash and Vij, 1973) investigated the hydrodynamic lubrication of a plane slider bearing resorting to several geometries.

It is a well known fact that if the liquid metals such as mercury and sodium are pumped or held between moving surfaces of a bearing, larger loads can be supported by employing a strong magnetic field. The application of a large magnetic field results in electromagnetic pressurization as the liquid metals are large electrical conductors. This aspect of study was explored by (Elco and Huges, 1962), (Kuzma, 1964) and (Kuzma et al. 1964). From these investigations, it becomes clear that it is possible to increase the load carrying capacity by the utilization of electromagnetic force, thereby overcoming the defects associated with the lubricant at higher temperature and hence alleviating the drawback of low viscosity. The load carrying capacity can be made to register high increase by taking recourse to super conducting magnets while little amount of power is required to provide the magnetic field. A good deal of research has been done regarding the theoretical and experimental studies on the hydromagnetic lubrication of porous as well as plane metal bearings (Snyder, 1962), (Shukla, 1963), (Patel and Hingu, 1978). (Shukla and Prasad, 1965) analyzed the performance of hydromagnetic squeeze films between two conducting non-porous surfaces and discussed the effect of conductivities on the behavior of squeeze film. (Sinha and Gupta, 1974) investigated the hydromagnetic effect on the behavior of squeeze film between porous annular plates. (Patel and Gupta, 1979) deployed Morgan – Cameron approximations simplifying the analysis for hydromagnetic squeeze films between parallel plates for a number of geometrical shapes. (Prajapati, 1995) also studied the behavior of magnetic fluid based porous squeeze film between plates of various geometries. For a short bearing (Patel et al. 2010) observed that the magnetic fluid resulted in a marginally improved performance. Here it has been sought to analyze the performance of a hydromagnetic short bearing.

2.0 ANALYSIS

The geometrical configuration of the bearing which is infinite in Z-direction is presented in Figure 1.

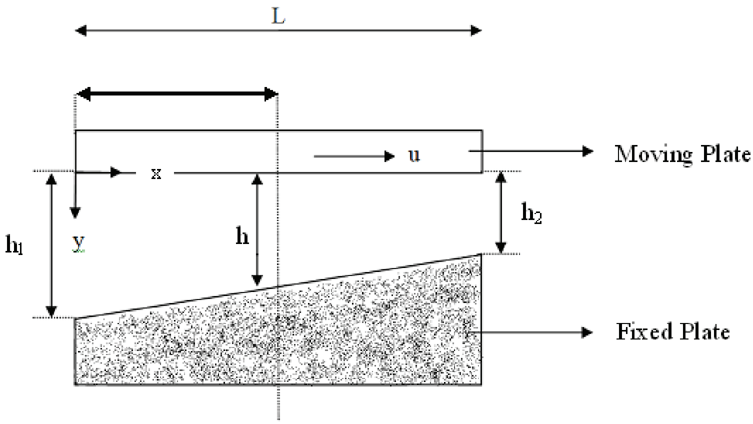

Figure 1. Geometrical configuration of the bearing system

In the X-direction the slider moves with the uniform velocity u. L is the length of the bearing and the breadth B lies in the Z-direction, wherein, B << L. The pressure gradient $\partial p / \partial z$ is much larger than the pressure gradient $\partial p / \partial x$ as the dimension B is very small. Therefore, $\partial p / \partial x$ can be neglected. The lubricant film is considered to be isoviscous, incompressible and the flow is laminar. Under the usual assumptions of hydromagnetic lubrication the modified Reynolds' equation governing the lubricant film pressure is obtained as (Patel and Deheri, 2004), (Vadher et al., 2008), (Patel et al., 2010).

$$\frac{d^2p}{dz^2} = \frac{6u\frac{dh}{dx}}{\frac{h^3}{\mu}(-C)\cdot D} \tag{1}$$

where

$$h = h_2\left\{1 + m\left(1 - \frac{x}{L}\right)\right\}$$

$$C = \left[\frac{2}{M^3}\{\tanh(M/2) - (M/2)\} - \frac{\psi}{c^2}\right]$$

$$D = \left[\frac{\phi_0 + \phi_1 + 1}{\phi_0 + \phi_1 + \frac{\tanh(M/2)}{(M/2)}}\right]$$

Solving this equation with the associated boundary conditions,

$$p = 0 \text{ at } z = \pm(B/2)$$

and

$$\frac{dp}{dz} = 0 \ \text{ at } z = 0 \tag{2}$$

one gets the expression for pressure distribution as,

$$p = \frac{3umh_2\left(\frac{B^2}{4} - z^2\right)}{L\frac{h^3}{\mu}(C)\cdot D} \tag{3}$$

where

$$m = \frac{h_1 - h_2}{h_2}$$

In view of the following non-dimensional quantities,

$$P = \frac{h_2^3 p}{\mu u B^2} \qquad Z = \frac{z}{B} \qquad X = \frac{x}{L}$$

the distribution of pressure in dimensionless form can be obtained as,

$$P = \frac{\frac{3mh_2}{L}\left(\frac{1}{4} - Z^2\right)}{C\cdot D\cdot E^3} \tag{4}$$

where

$$E = \{1 + m(1 - X)\}$$

Hence the dimensionless load carrying capacity is found to be,

$$W = \frac{h_2^3 w}{\mu u B^4} = \int_{-\frac{1}{2}}^{\frac{1}{2}} \int_0^1 P(X,Z)\,dX\,dZ$$

$$= \frac{\frac{m(m+2)}{(m+1)^2}}{\frac{4B}{h_2}(-C)\cdot D} \tag{5}$$

At the lower plane of the moving plate the frictional force $\bar{F}$ per unit width is derived as,

$$\bar{F} = \int_{-1/2}^{1/2} \bar{\tau}\,dZ \tag{6}$$

where

$$\bar{\tau} = \left(\frac{h_2}{\mu u}\right)\tau \quad \text{is dimensionless shearing stress.}$$

while

$$\tau = \frac{dp}{dz}\left(y - \frac{h}{2}\right) + \frac{\mu u}{h} \tag{7}$$

Simplification of equation (7) leads to,

$$\bar{\tau} = \frac{dP}{dZ}\frac{B}{h_2}E\left(Y - \frac{1}{2}\right) + \frac{1}{E} \tag{8}$$

where

$$Y = \frac{y}{h}$$

For the moving plate (Y = 0) the dimensionless shearing stress takes the form,

$$\bar{\tau} = \frac{3mZ}{\frac{L}{h_2}(-C)\cdot D\cdot E^2} + \frac{1}{E} \tag{9}$$

Therefore, the frictional force in non-dimensional form is given by,

$$\bar{F}_0 = \frac{1}{E} \tag{10}$$

In addition, at the fixed plate (Y = 1) one finds that,

$$\bar{\tau} = -\frac{3mZ}{\frac{L}{h_2}(-C)\cdot D\cdot E^2} + \frac{1}{E} \tag{11}$$

Finally, the frictional force in dimensionless form is obtained as,

$$\bar{F}_1 = \frac{1}{E} \tag{12}$$

3.0 RESULTS AND DISCUSSIONS

It is clearly seen from Equations (4) and (5) that the non-dimensional pressure and load carrying capacity are dependent on various parameters such as magnetization M, porosity ψ, conductivity $\phi_0 + \phi_1$, aspect ratio m and ratios L/h_2 and B/h_2. However, the Equations (10) and (12) suggest that the friction depends on the aspect ratio m and obviously X = x/L. It is manifest that the friction is independent of hydromagnetization M. Taking the conductivity $\phi_0 + \phi_1$ to be zero in the limiting case of $M \rightarrow 0$; the present analysis turns in essentially, the discussions of (Basu et al., 2005) in the absence of porosity. It is noticed that conductivity $\phi_0 + \phi_1$ increases the load carrying capacity for fixed values of magnetization M, porosity ψ, aspect ratio m and the ratio B/h_2. In addition, the distribution of load carrying capacity comes through the factor,

$$\left[\frac{\phi_0 + \phi_1 + \frac{\tanh(M/2)}{(M/2)}}{\phi_0 + \phi_1 + 1}\right] \tag{13}$$

For large values of M this approaches to,

$$\left[\frac{\phi_0 + \phi_1}{\phi_0 + \phi_1 + 1}\right] \tag{14}$$

as $\tanh(M/2) \rightarrow 1$. It is observed that as conductivity $\phi_0 + \phi_1$ increases the load carrying capacity increases. Here it is pertinent to see that the bearing can support a load even when there is no flow. Lastly, a comparison of this investigation with the discussion of (Patel and Deheri, 2004) reveals that the load carrying capacity is comparatively reduced here. Probably, this is due to the fringing phenomena which occur when the plates are electrically conducting.

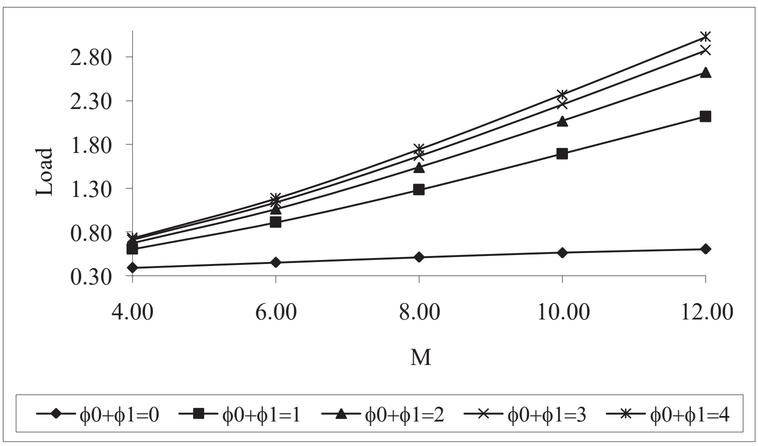

Figure 2. Variation of load carrying capacity with respect to M and $\phi_0+\phi_1$.

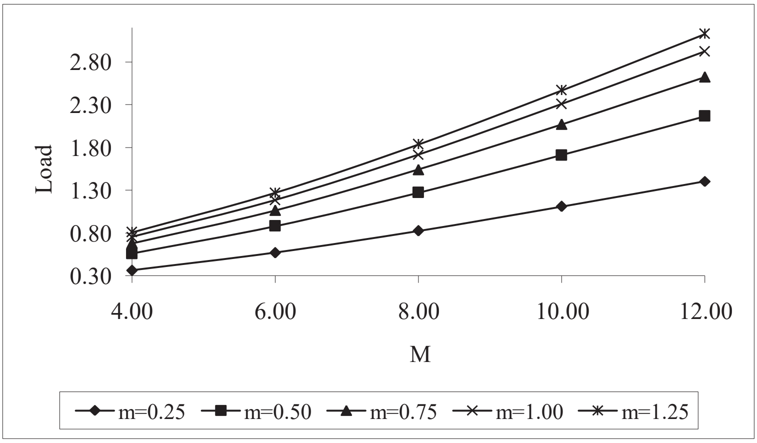

Figure 3. Variation of load carrying capacity with respect to M and m.

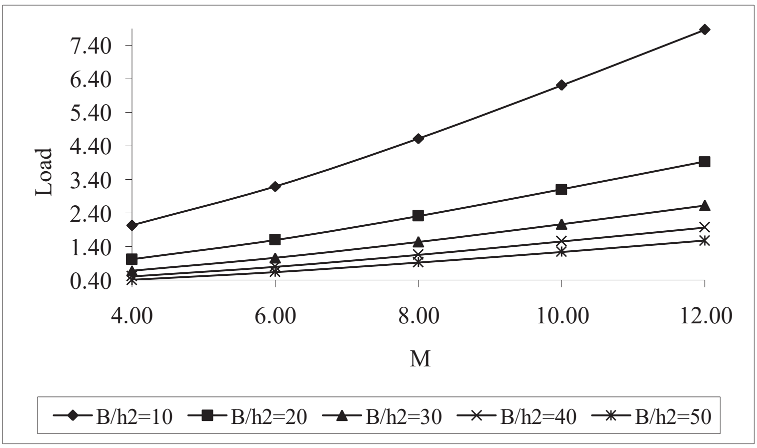

Figure 4. Variation of load carrying capacity with respect to M and B/h_2.

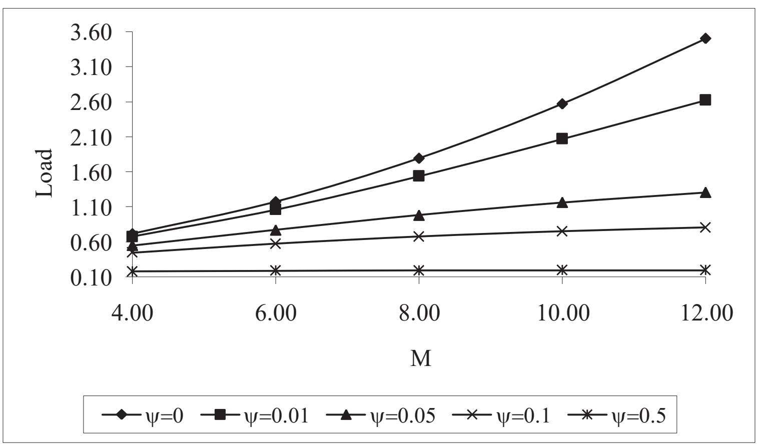

Figure 5. Variation of load carrying capacity with respect to M and ψ.

Figures 2 to 5 depict the variation of load carrying capacity with respect to the magnetization parameter M for various values of conductivity $\phi_0 + \phi_1$, aspect ratio m, the ratio B/h_2 and porosity ψ. It is noticed that the load carrying capacity gets increased with increasing values of magnetization parameter M. It is also seen that the conductivity $\phi_0+\phi_1$ has an important role in improving the performance of the bearing system. The porosity ψ has a sharp adverse effect on the performance of the bearing system. Figure 3 indicates that the load carrying capacity increases substantially with the increasing values of the aspect ratio m. Besides, the load carrying capacity decreases with the increasing values of the ratio B/h_2. In addition, the combined effect of magnetization M and the ratio B/h_2 is more sharp as compared to the other combinations.

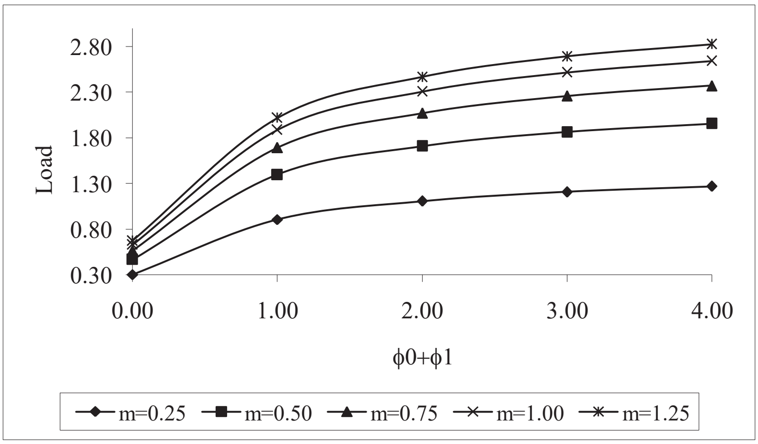

Figure 6. Variation of load carrying capacity with respect to $\phi_0+\phi_1$ and m.

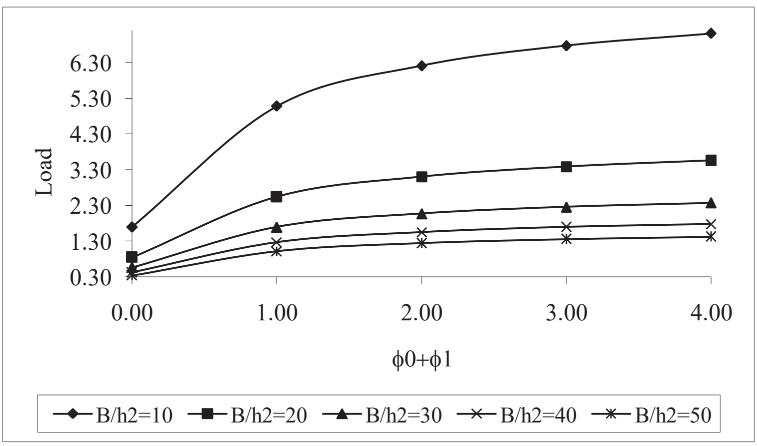

Figure 7. Variation of load carrying capacity with respect to $\phi 0+\phi 1$ and B/h_2.

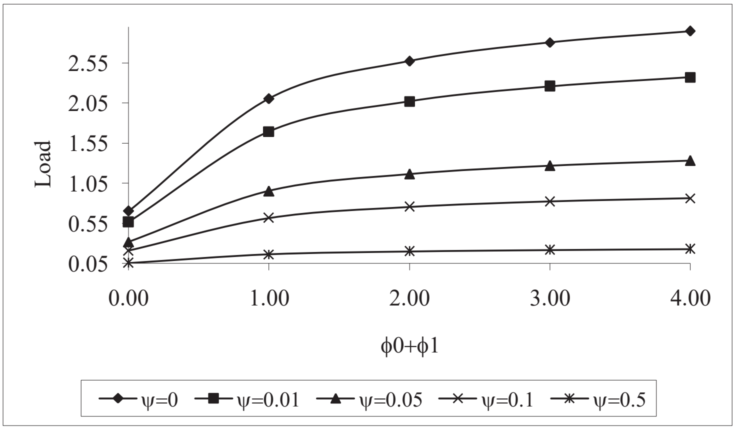

Figure 8. Variation of load carrying capacity with respect to $\phi_0+\phi_1$ and ψ.

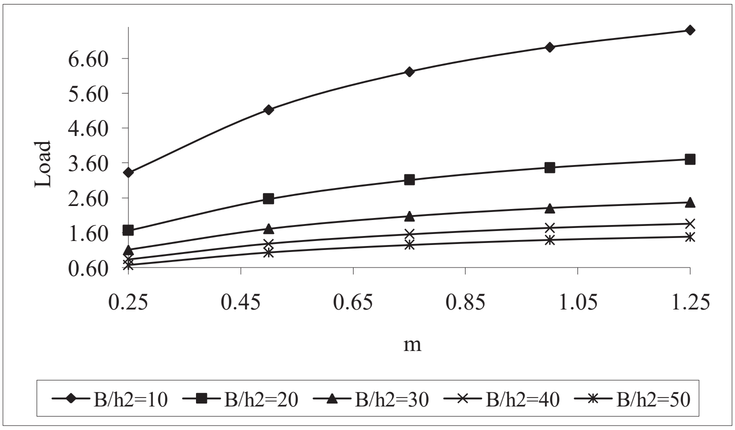

Figure 9. Variation of load carrying capacity with respect to m and B/h_2.

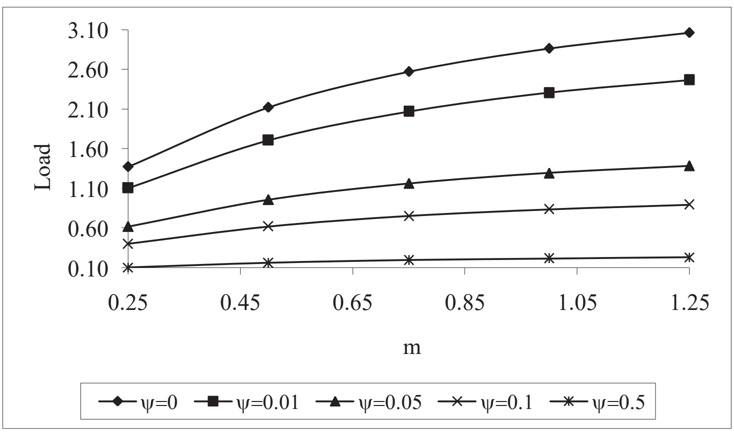

Figure 10. Variation of load carrying capacity with respect to m and ψ.

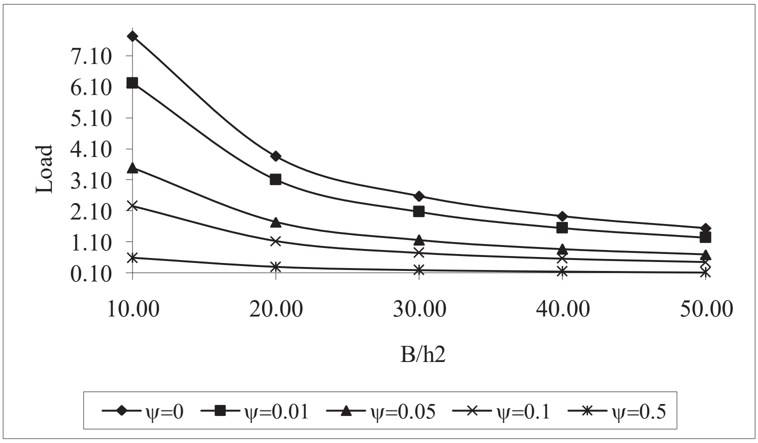

Figure 11. Variation of load carrying capacity with respect to B/h_2 and ψ.

The effect of conductivity $\phi_0+\phi_1$ on the load carrying capacity is presented in Figures 6 to 8. These figures suggest that the conductivity $\phi_0+\phi_1$ increases the load carrying capacity and this increase is more for smaller values of aspect ratio m, the ratio B/h_2 and porosity ψ. However, the load carrying capacity is substantially more in the case of the ratio B/h_2. Figures 9 and 10 deal with the effect of aspect ratio m on the variation of load carrying capacity. It is manifest that aspect ratio m increases the load carrying capacity and this increase is more in the case of the ratio B/h_2. Lastly, Figure 11 says that the combined effect of the ratio B/h2 and porosity ψ is significantly adverse as the load carrying capacity is more decreased at the initial stages.

A close scrutiny of these figures reveals that the negative effect of porosity ψ and the ratio B/h2 can be compensated up to certain extent by the positive effect of magnetization M and conductivity $\phi_0+\phi_1$ by choosing suitably the aspect ratio m. It is found that the increased load carrying capacity due to the conductivity $\phi_0+\phi_1$ gets further increased due to hydromagnetization. This is crucial for overcoming the negative effect of the ratio B/h_2 and porosity ψ. A comparison of this investigation with the study of (Patel et al., 2010) tends to suggest that the overall performance is relatively better here. As can be seen from Equations (10) and (12) for friction at the both plates, the friction remains unaltered.

4.0 CONCLUSIONS

It is concluded that the effect of hydromagnetization is comparatively sharp unlike some of the previous studies (Vadher et al., 2008), (Patel et al., (2010). The analysis incorporated here modifies and extends the earlier analysis concerning the performance of a magnetic fluid based squeeze film in a short bearing and also presents at least an additional degree of freedom to compensate the adverse effect of porosity. Furthermore, this investigation offers some scopes for the extension of the life period of the bearing system through the observations that the bearing with a magnetic fluid can support a load even when there is no flow unlike the case of a conventional lubricant.

NOMENCLATURE

H	Fluid film thickness at any point (mm)
h_1	Maximum film thickness (mm)
h_2	Minimum film thickness (mm)
B	Breadth of the bearing (mm)
L	Length of the bearing (mm)
m	Aspect ratio
u	Uniform velocity in X – direction
p	Lubricant pressure (N/mm^2)
P	Dimensionless pressure
w	Load carrying capacity (N)
W	Non-dimensional load carrying capacity
μ	Lubricant viscosity ($N.s/mm^2$)
τ	Shear stress (N/mm^2)
$\bar{\tau}$	Dimensionless shear stress
F	Frictional force (N/mm^2)
$\bar{F}$	Dimensionless frictional force
$\bar{F}_0$	Dimensionless frictional force (at moving plate)
$\bar{F}_1$	Dimensionless frictional force (at fixed plate)
s	Electrical conductivity of the lubricant
M	$= B_0 h \left(\frac{s}{\mu}\right)^{1/2}$ = Hartmann number
K	Permeability ($col^2 kgm/s^2$)
H_0	Thickness of the porous facing
m*	Porosity of the porous matrix
ψ	$= \frac{m^* H_0}{h^3}$ = Porosity
B_0	Uniform transverse magnetic field applied between the plates.

c^2 $= 1 + \dfrac{KM^2}{h^2 m*}$

$h_0^{'}$ Surface width of the lower plate (m)

$h_1^{'}$ Surface width of the upper plate (m)

s_0 Electrical conductivity of lower surface (mho)

s_1 Electrical conductivity of upper surface (mho)

$\phi_0(h)$ $= \dfrac{s_0 h_0^{'}}{sh}$ = Electrical permeability of the lower surface

$\phi_1(h)$ $= \dfrac{s_1 h_1^{'}}{sh}$ = Electrical permeability of the upper surface

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