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Effects of External Circuit on MHD Squeeze Film Lubrication between Porous Conducting Plates

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Abstract: This paper presents theoretically the effect of transverse magnetic field on the squeeze film between two electrically conducting porous plates in the presence of the magnetic field in the free space. The expressions for the MHD squeeze film pressure, load-carrying capacity and squeeze film time are obtained. The results are presented graphically for different values of operating parameters. It is observed that the pressure, load capacity and time of approach are predominant for larger values of Hartmann number and conductivity, and for smaller values of permeability and external current parameters, as compared to the corresponding classical cases.

Key words: MHD, External current, Squeeze film, Conductivities, Porous plates.

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I. INTRODUCTION

The concept of porous media has been widely used in industry for a long time. Porous material has been used in lubrication applications such as journal bearing, composite slider bearing. If the bearing is porous and porous medium is impregnated with oil, no exterior lubrication or further lubrication is required for the life time of machine.The lubricant penetrates into the pores and remains effective throughout the bearing life. Hydrodynamic lubrication of porous metal bearing was first studied by Morgan [1]. The effect of squeeze film and hydromagnetic squeeze film on porous rectangular plates has been analysed by Wu [2] and Sinha et al. [3] in their articles respectively. Prakash and Vij [4] studied that porosity causes decrease in load carrying capacity of inclined slider bearing. The porosity inversely influences the bearing characteristics but it can be overcome by numerous design and maintenance advantages. Cusano [5] found that the bearing performance can be improved by using porous housings of different permeabilities. Syeda Tasneem Fathima et al. [6] have shown from their investigation that the magnetic field increases the frictional force and load carrying capacity in porous media for both plane and parabolic slider bearings. Syeda Tasneem Fathima et al. [7] have also studied hydromagnetic couplestress squeeze film lubrication of porous plates having different geometry and found that the impact of porous facing lubricated with couplestress fluid in presence of transverse magnetic field strengthen load carrying capacity.

Due to the large electrical conductivity of liquid metals such as Mercury and Sodium, the possibilities of electromagnetic pressurization from the application of an external magnetic field have been explored and investigated. Shukla and Prasad [8] investigated the performance of hydromagnetic squeeze films between two conducting non-porous surfaces and shown that an increase in load capacity, pressure and time of approach are possible by increasing either the strength of the magnetic field, or conductivities of surfaces, or both. Vadher et al. [9] studied the hydromagnetic squeeze film lubrication between conducting porous transversely rough triangular plates and it was found that the negative effect introduced by the roughness and porosity could be neutralized up to certain extent by the positive effect of magnetization parameter in the case of negatively skewed roughness. Soundalgekar [10] has studied the effects of external circuit on a MHD slider bearing and concluded that an increase in external magnetic field leads to an increase in pressure and load capacity of the bearing. The effect of external magnetic field in the case of hydromagnetic squeeze film has been discussed by Soundalgekar and Amrute [11]. They have found that the presence of external magnetic field is to increase the pressure and to decrease the load and squeezing time considerably.

The objective of this paper is to study the effects of external current on the hydromagnetic squeeze film behaviour of porous conducting plates. Results are compared with the corresponding non-porous case [11].

II. MATHEMATICAL FORMULATION AND SOLUTION OF THE PROBLEM

Figure. 1 shows the configuration of the bearing system.

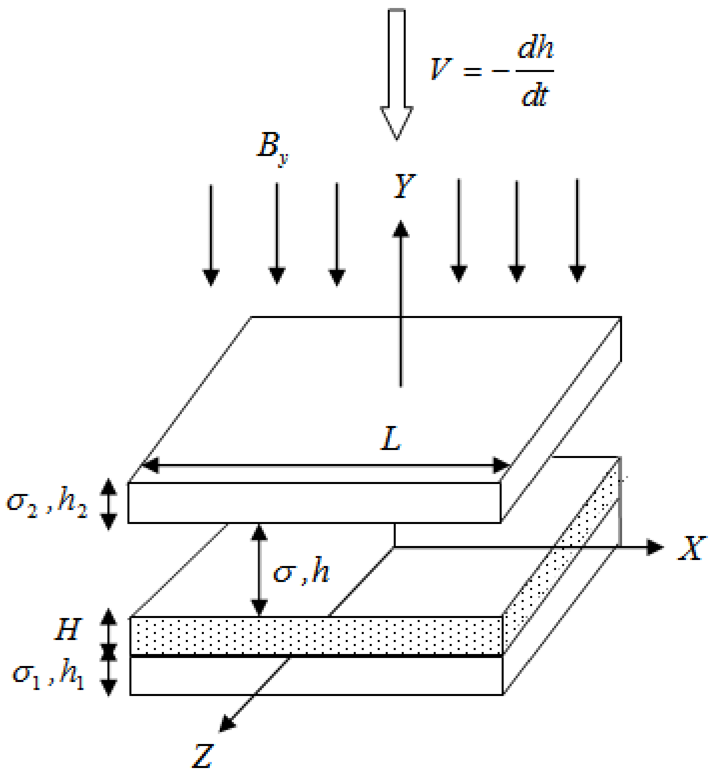

Fig. 1 Squeeze film between porous conducting surfaces in the presence of external magnetic field.

The basic governing equations for the hydro-magnetic flow are:

$$\frac{\partial^2 u}{\partial y^2} - \frac{M^2}{{h_2}^2} u = \frac{ME_z}{h_2}\sqrt{\frac{\sigma}{\mu}} + \frac{1}{\mu}\frac{\partial p}{\partial x} \tag{1}$$

$$\frac{\partial p}{\partial y} = 0 \tag{2}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{3}$$

$$\frac{\partial H_x}{\partial y} = -\sigma E_z - \frac{M\sqrt{\sigma\mu}}{h_2} u \tag{4}$$

For the porous region:

$$\bar{u} = \frac{-k}{\mu\left(1 + \frac{kM^2}{m{h_2}^2}\right)}\left(\frac{\partial P}{\partial x} + \frac{ME_z\sqrt{\sigma\mu}}{h_2}\right) \tag{5}$$

$$\bar{v} = \frac{-k}{\mu}\frac{\partial P}{\partial y} \tag{6}$$

$$\frac{\partial \bar{u}}{\partial x} + \frac{\partial \bar{v}}{\partial y} = 0 \tag{7}$$

The relevant boundary conditions for the velocity and induced magnetic field are

$$u = 0 \text{ at } y = 0, h \tag{8}$$

$$\frac{dH_x}{dy} - \frac{H_x}{\Phi_1 h_2} = -\frac{H_{x_0}}{\Phi_1 h_2} \text{ at } y = 0 \tag{9}$$

$$\frac{dH_x}{dy}+\frac{H_x}{\Phi_2 h_2}=\frac{H_{x_1}}{\Phi_2 h_2} \quad \text{at } y=h \tag{10}$$

The solution of equations (1) and (4) using conditions (8) to (10) are

$$u=\frac{h_2^{\,2}}{M^2}\left(\frac{1}{\mu}\frac{\partial p}{\partial x}+\frac{ME_z}{h_2}\sqrt{\frac{\sigma}{\mu}}\right)f_1\left(h,M.y\right) \tag{11}$$

$$H_x=-\sigma E_z\left(y+\Phi_1 h_2\right)-\frac{h_2\sqrt{\sigma\mu}}{M}\left(\frac{1}{\mu}\frac{\partial p}{\partial x}+\frac{ME_z}{h_2}\sqrt{\frac{\sigma}{\mu}}\right)f_2\left(h,M,y\right)+H_{x_0} \tag{12}$$

$$E_z=\frac{\dfrac{h_2}{M\sqrt{\sigma\mu}}\dfrac{\partial p}{\partial x}\left[h-f_3\left(h,M\right)\right]-\dfrac{\left(H_{x_1}-H_{x_0}\right)}{\sigma}}{\Phi_1 h_2+\Phi_2 h_2+f_3\left(h,M\right)} \tag{13}$$

Where

$$f_1\left(h,M.y\right)=\frac{\cosh\dfrac{M}{2h_2}\left(2y-h\right)}{\cosh\dfrac{Mh}{2h_2}}-1, \qquad f_2\left(h,M,y\right)=\frac{\sinh\dfrac{M}{2h_2}\left(2y-h\right)}{\dfrac{M}{h_2}\cosh\dfrac{Mh}{2h_2}}-y+\frac{h_2}{M}\tanh\frac{Mh}{2h_2}$$

$$f_3\left(h,M\right)=\frac{2h_2}{M}\tanh\frac{Mh}{2h_2}$$

Eliminating E_z between equations (11) and (13), we get the expression for velocity

$$u=\frac{h_2^{\,2}}{M^2}\left(\frac{\dfrac{1}{\mu}\dfrac{\partial p}{\partial x}\left(\Phi_1 h_2+\Phi_2 h_2+h\right)-\dfrac{M}{h_2\sqrt{\sigma\mu}}\left(H_{x_1}-H_{x_0}\right)}{\Phi_1 h_2+\Phi_2 h_2+f_3\left(h,M\right)}\right)f_1\left(h,M,y\right) \tag{14}$$

The volume flow rate is

$$Q=b\int_o^h u\,dy \tag{15}$$

Substituting (14) in (15) and integrating, we obtain

$$Q=\frac{bh_2^{\,2}}{M^2}\left(\frac{\dfrac{1}{\mu}\dfrac{\partial p}{\partial x}\left(\Phi_1 h_2+\Phi_2 h_2+h\right)-\dfrac{M}{h_2\sqrt{\sigma\mu}}\left(H_{x_1}-H_{x_0}\right)}{\Phi_1 h_2+\Phi_2 h_2+f_3\left(h,M\right)}\right)\left[f_3\left(h,M\right)-h\right] \tag{16}$$

But the external magnetic field and the net current I_y are related by

$$I_y=H_{x_1}-H_{x_0} \tag{17}$$

If the conducting path is solely in the lower region, then $H_{x_0}=0$ so that $I_y=H_{x_1}$. Hence eqn. (16) becomes,

$$Q=\frac{bh_2^{\,2}}{M^2}\left(\frac{\dfrac{1}{\mu}\dfrac{\partial p}{\partial x}\left(\Phi_1 h_2+\Phi_2 h_2+h\right)-\dfrac{MI_y}{h_2\sqrt{\sigma\mu}}}{\Phi_1 h_2+\Phi_2 h_2+f_3\left(h,M\right)}\right)\left[f_3\left(h,M\right)-h\right] \tag{18}$$

Integration of the continuity equation (3) over the film thickness h gives,

$$\frac{\partial\left(Q/b\right)}{\partial x}=-\left(v_h-v_0\right) \tag{19}$$

Since the upper plate is non-porous

$$v_h=-V=dh/dt \tag{20}$$

The velocity component in y - direction is continuous at the plate interface, hence

$$v_0 = \left(\bar{v}\right)_{y=0} = -\frac{k}{\mu}\left(\frac{\partial P}{\partial y}\right)_{y=0} \tag{21}$$

Substituting (20) and (21) in (19) we get

$$\frac{\partial\left(Q/b\right)}{\partial x} = -\frac{dh}{dt} - \frac{k}{\mu}\left(\frac{\partial P}{\partial y}\right)_{y=0} \tag{22}$$

Equations (5)-(7) yields

$$\frac{\partial}{\partial x}\left(\frac{\partial P}{\partial x} + \frac{ME_z\sqrt{\sigma\mu}}{h_2}\right) + C^2\frac{\partial}{\partial y}\left(\frac{\partial P}{\partial y}\right) = 0 \tag{23}$$

Where $C = \left(1 + \frac{kM^2}{mh_2^{\,2}}\right)^{1/2}$

The relevant boundary conditions for the pressure field are

i) For the fluid film region:

$$p = 0 \text{ at } x = L/2 \tag{24}$$

ii) At the interface:

$$\frac{\partial P}{\partial x} = \frac{\partial p}{\partial x} \text{ and } \frac{\partial P}{\partial y} = 0 \text{ at } y = -H \tag{25}$$

Integrating equation (23) and using the condition (25), we get from equation (22), the volume flow rate as

$$Q = -\frac{bh_2^{\,2}\left[f_3\left(h,M\right) - h\right]\frac{dh}{dt}x}{h_2^{\,2}\left[f_3\left(h,M\right) - h\right] - \frac{kHM^2}{C^2}} \tag{26}$$

Hence from equations (18) and (26) using boundary condition (24) we get the non-dimensional pressure as

$$p^* = \frac{M^2}{\left(\Phi + h^*\right)}\left[\frac{\Phi + f_4\left(h^*,M\right)}{f_4\left(h^*,M\right) - h^* - \frac{\psi M^2}{C^2}}\left(\frac{x^{*2}}{2} - \frac{1}{8}\right) + I\left(x^* - \frac{1}{2}\right)\right] \tag{27}$$

Where $\Phi = \Phi_1 + \Phi_2$, $f_4\left(h^*,M\right) = \frac{2}{M}\tanh\frac{Mh^*}{2}$

The load per unit width is given by

$$W = b\int_{-L/2}^{L/2} p\, dx \tag{28}$$

The dimensionless load carrying capacity is

$$W^* = -\frac{M^2}{12\left(\Phi + h^*\right)}\left[\left(\frac{\Phi + f_4\left(h^*,M\right)}{f_4\left(h^*,M\right) - h^* - \frac{\psi M^2}{C^2}}\right) + 6I\right] \tag{29}$$

The non-dimensional time of approach is

$$t^* = \int_1^{h_1^*}\frac{M^2}{12\left(\Phi + h^*\right)}\left[\left(\frac{\Phi + f_4\left(h^*,M\right)}{f_4\left(h^*,M\right) - h^* - \frac{\psi M^2}{C^2}}\right) + 6I\right]dh^* \tag{30}$$

III. RESULTS AND DISCUSSION

Expressions for the non-dimensional pressure, the load carrying capacity and time of approach are determined respectively by equations (27), (29) and (30). These bearing characteristics depend on the parameters such as Hartmann number M, porosity ψ, external current I and conductivities Φ. Taking $\psi = 0$, corresponds to non-permeable case [11].

3.1. Squeeze film pressure

Fig. 2 represents the effect of porosity on film pressure p^* for different values of external current I. It is noticed that, the pressure decreases for larger values of ψ. Also pressure is assumed to be maximum at $I = 0.0$. Fig. 3 and Fig. 4 represents the variation of film pressure with respect to x^* for various values of magnetization parameter M and conductivity parameter Φ respectively. It is clear from these figures that, the pressure is high in the plates for larger M and Φ. Also pressure is more when $\psi = 0.0$ compared to $\psi \neq 0.0$.

3.2. Load carrying capacity

Fig. 5 depicts the variation of load verses porosity for different values of external current. It is found that the load carrying capacity decreases considerably with increase of porosity and external current. The graphs in Fig. 6 and Fig. 7 gives the load profile for several values of M, Φ and ψ. It is transparent from these figures that load carrying capacity increases significantly with respect to magnetic field M and conductivity Φ.

3.3. Squeeze film time

The variation of non-dimensional time t^* with porosity ψ is shown in Fig. 8. It is evident from this figure that, as ψ increases, the squeezing time decreases. As $\psi \to 0$ it reduces to non-porous case. Fig. 9 and Fig. 10 describes the variation of t^* as a function of $1-h_1^*$ for different values of M and Φ respectively. These figures clearly show that, increase in the values of M and Φ lengthens the non-dimensional squeezing time considerably.

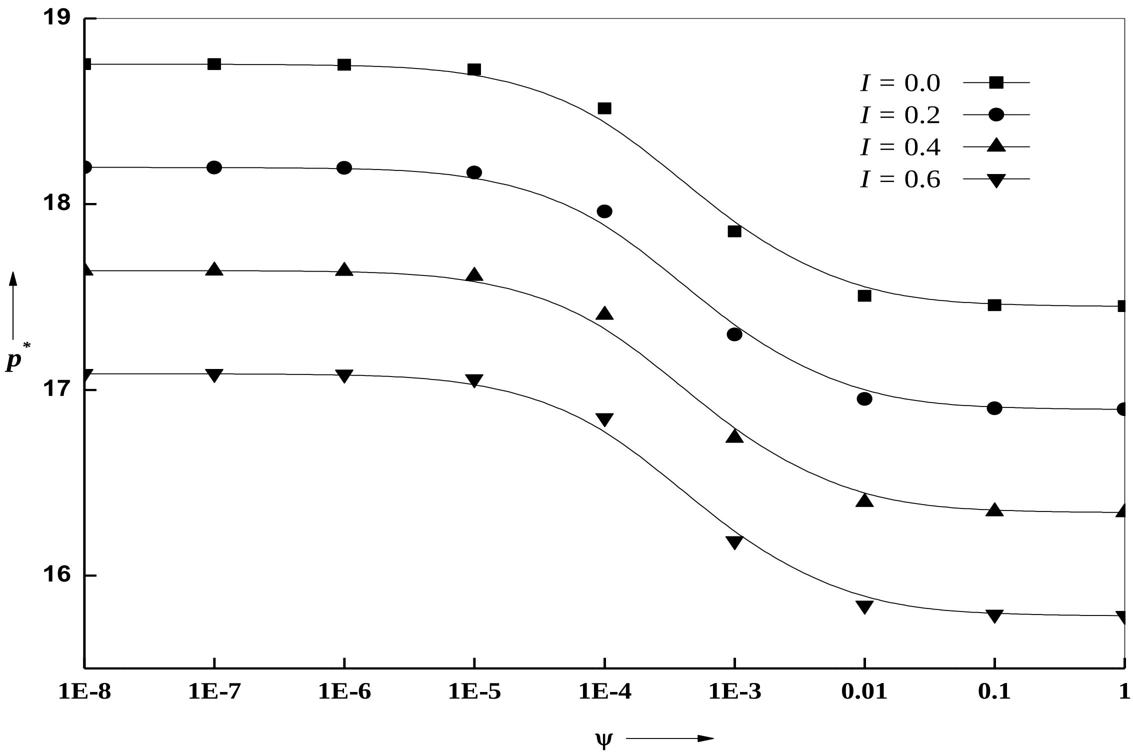

Fig. 2 Variation of dimensionless pressure p^* with ψ for different values of I at $H^* = 0.02$, $m = 0.6$, $M = 5$, $\Phi = 4$, $h^* = 0.5$ and $x^* = 0$.

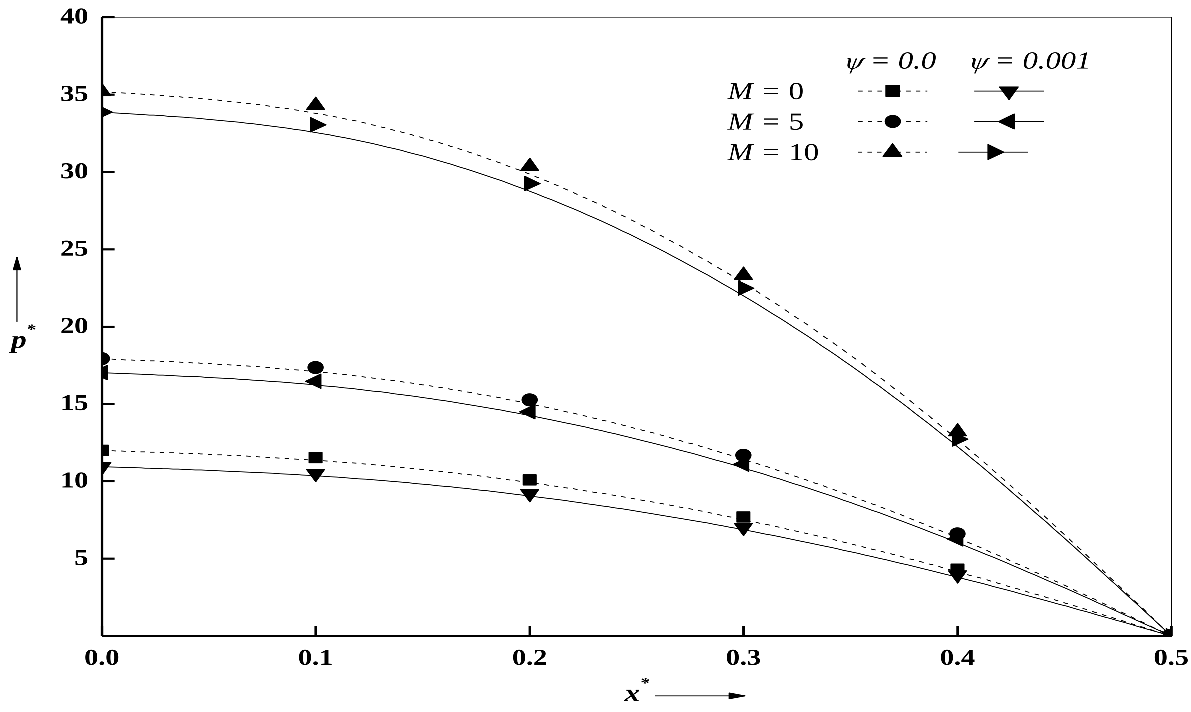

Fig. 3 Variation of dimensionless pressure p^* with x^* for different values of M and ψ at $H^* = 0.02$, $m = 0.6$, $I = 0.3$, $\Phi = 4$ and $h^* = 0.5$.

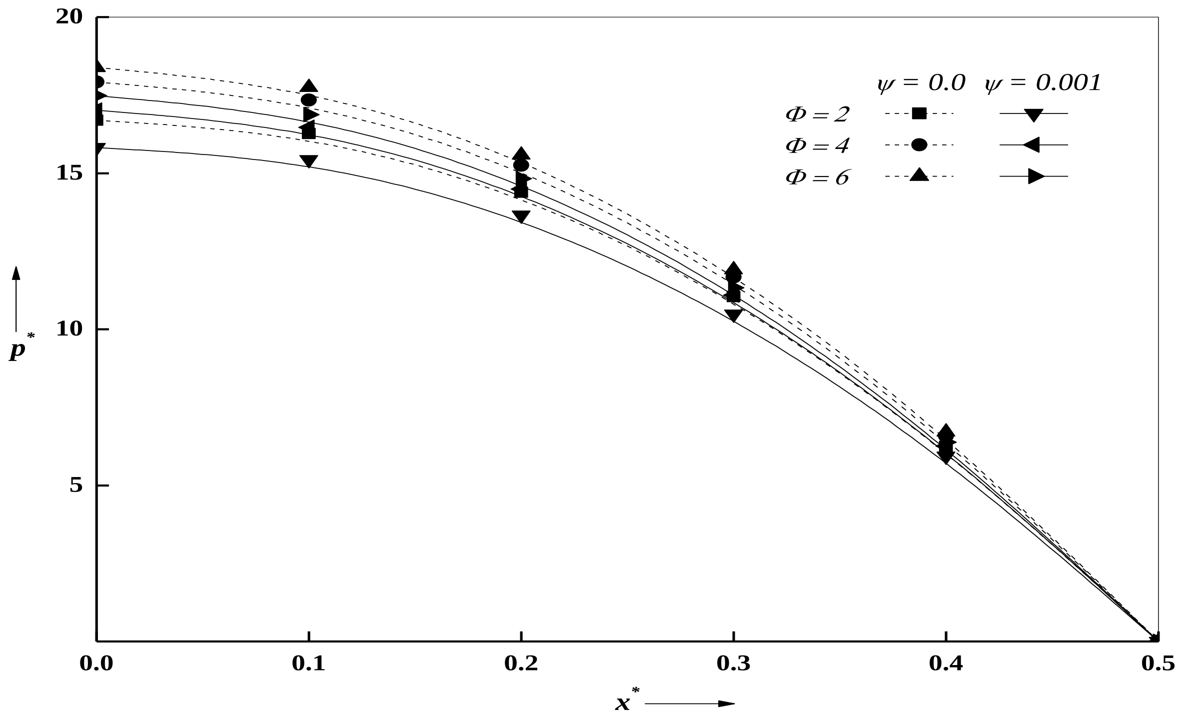

Fig. 4 Variation of dimensionless pressure p^* with x^* for different values of Φ and ψ at $H^* = 0.02$, $m = 0.6$, $I = 0.3$, $M = 5$ and $h^* = 0.5$.

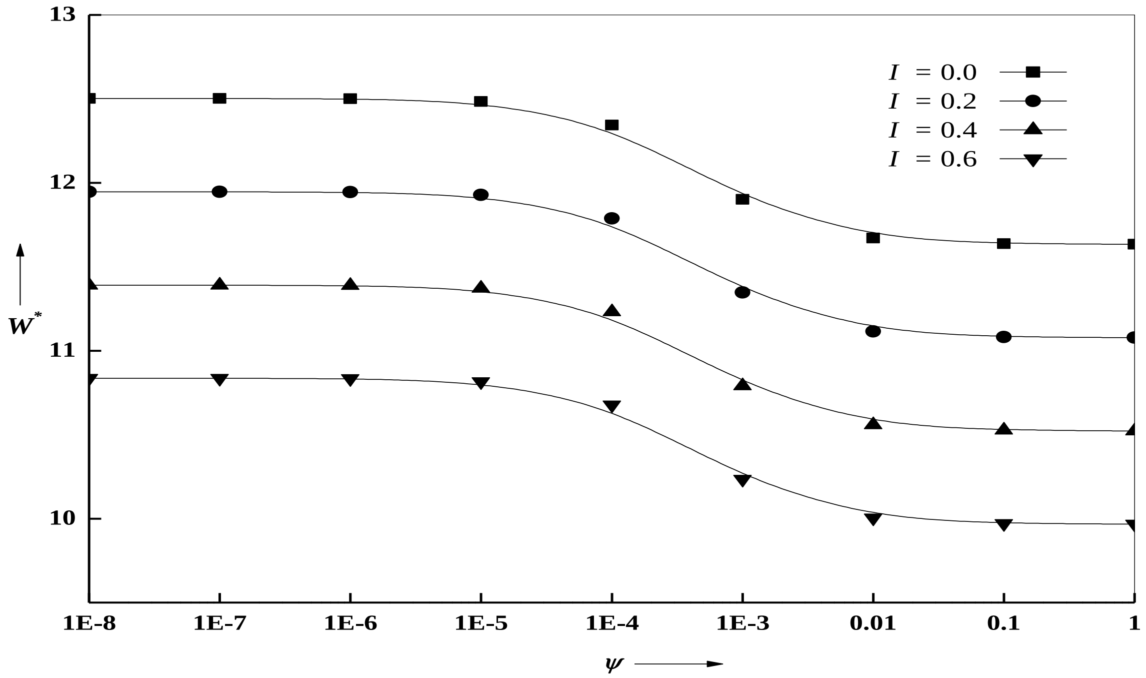

Fig. 5 Variation of dimensionless load W^* with ψ for different values of I at $H^* = 0.02$, $m = 0.6$, $M = 5$, $\Phi = 4$ and $h^* = 0.5$.

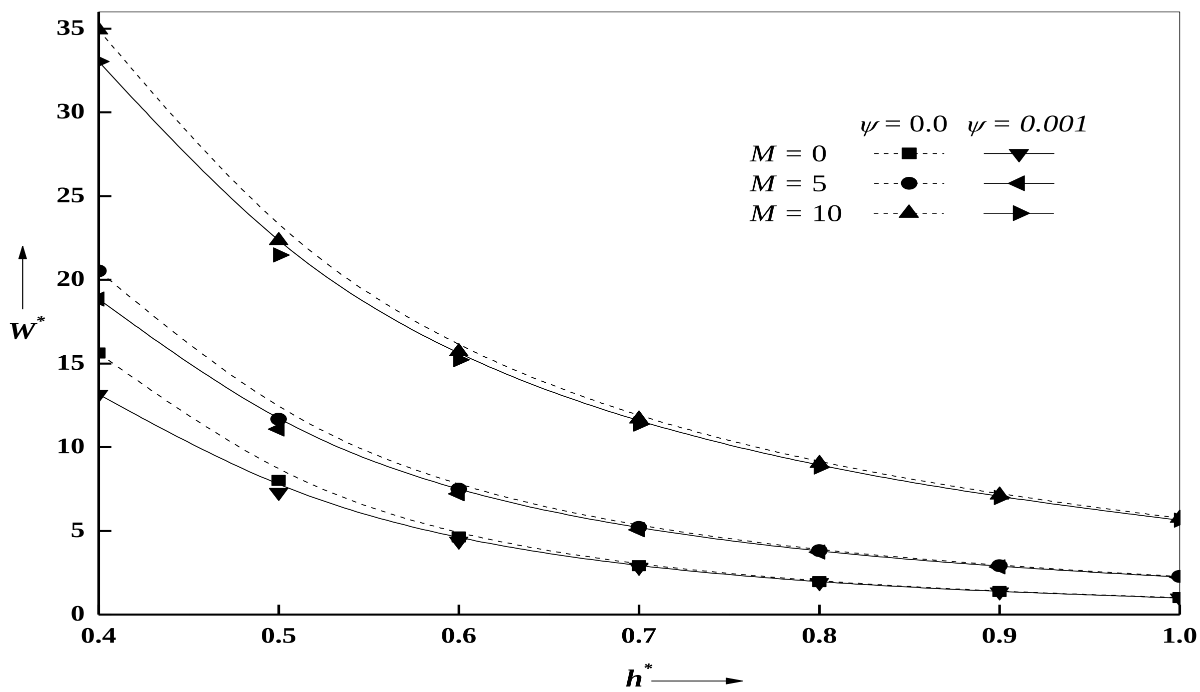

Fig. 6 Variation of dimensionless load W^* with h^* for different values of M and ψ at $H^* = 0.02$, $m = 0.6$, $I = 0.3$ and $\Phi = 4$.

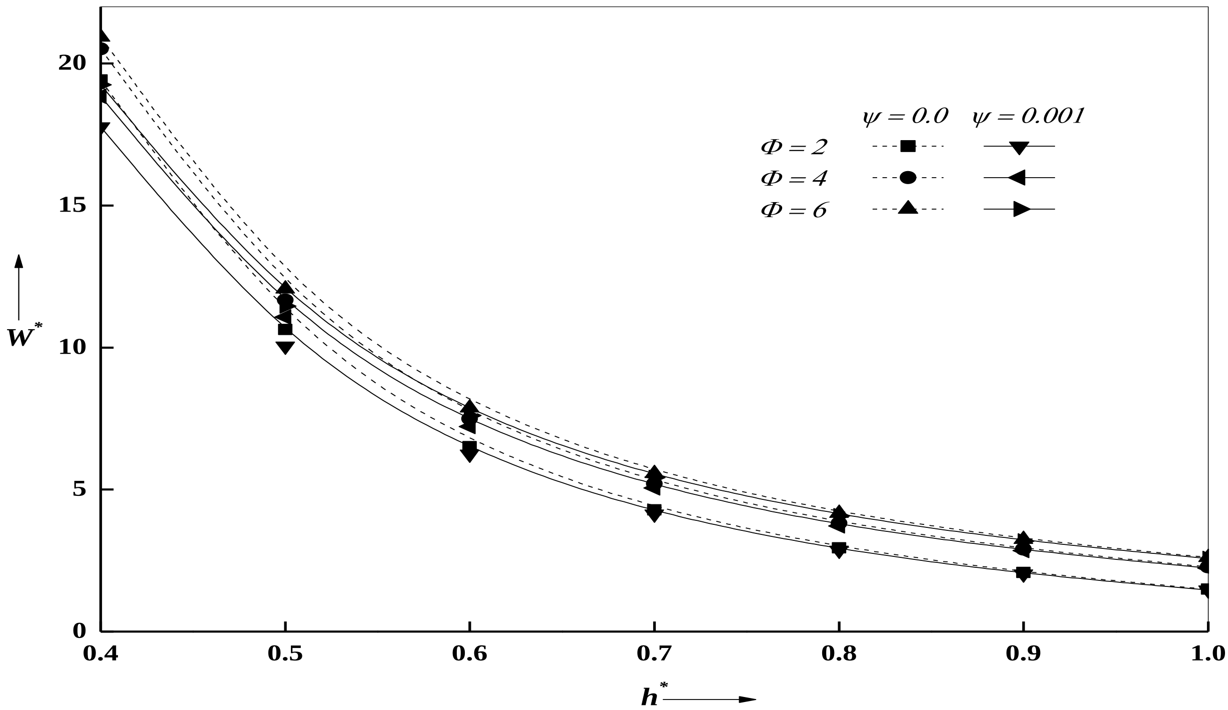

Fig. 7 Variation of dimensionless load W^* with h^* for different values of Φ and ψ at $H^* = 0.02$, $m = 0.6$, $I = 0.3$ and $M = 5$.

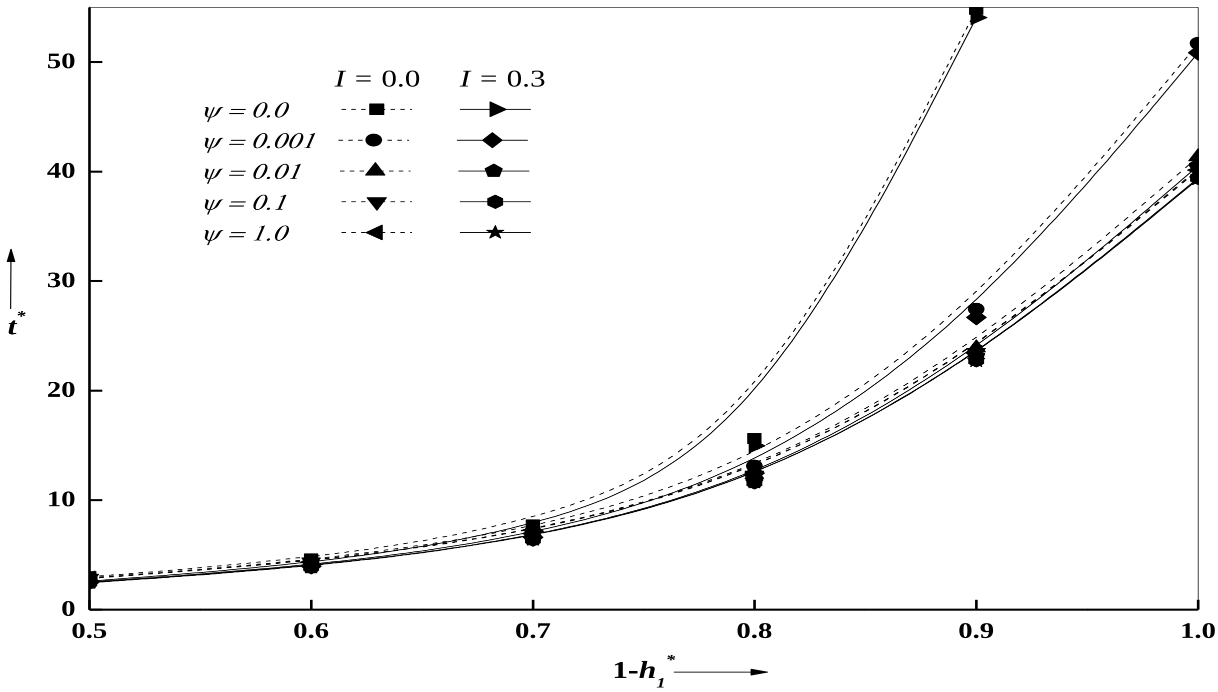

Fig. 8 Variation of dimensionless squeeze film time t^* with $1-h_1^*$ for different values of ψ and I at $H^* = 0.02$, $m = 0.6$, $M = 5$ and $\Phi = 4$.

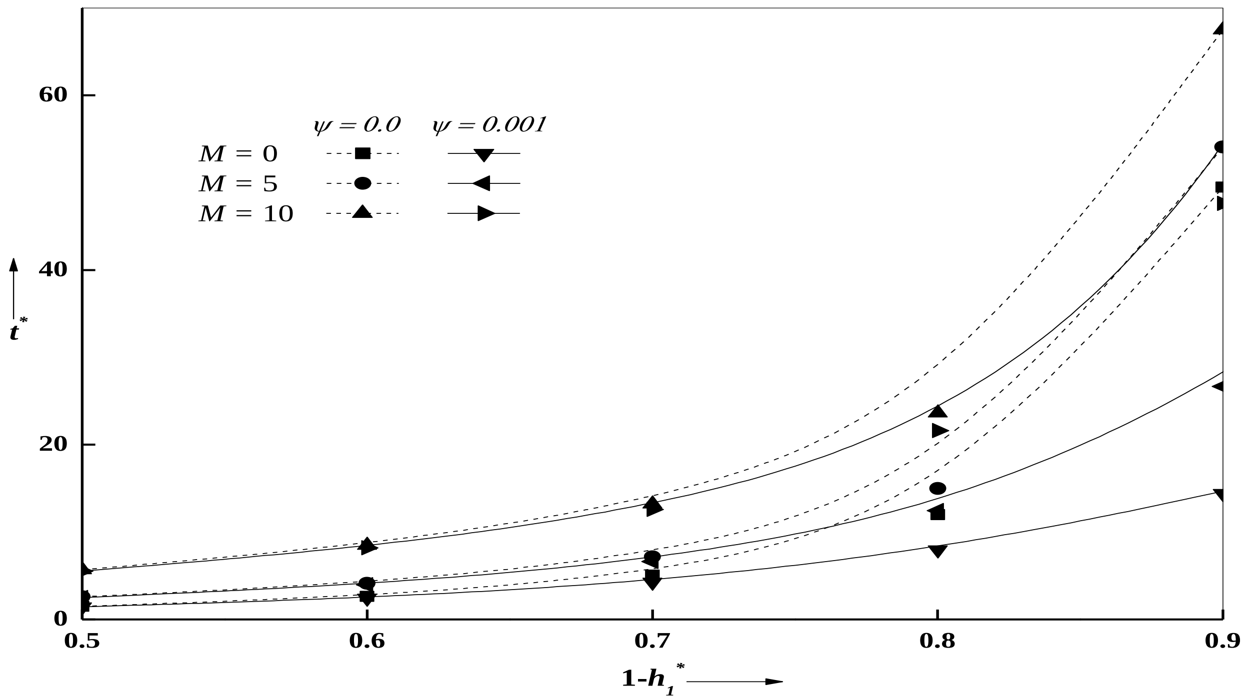

Fig. 9 Variation of dimensionless squeeze film time t^* with $1-h_1^*$ for different values of M and ψ at $H^* = 0.02$, $m = 0.6$, $I = 0.3$ and $\Phi = 4$.

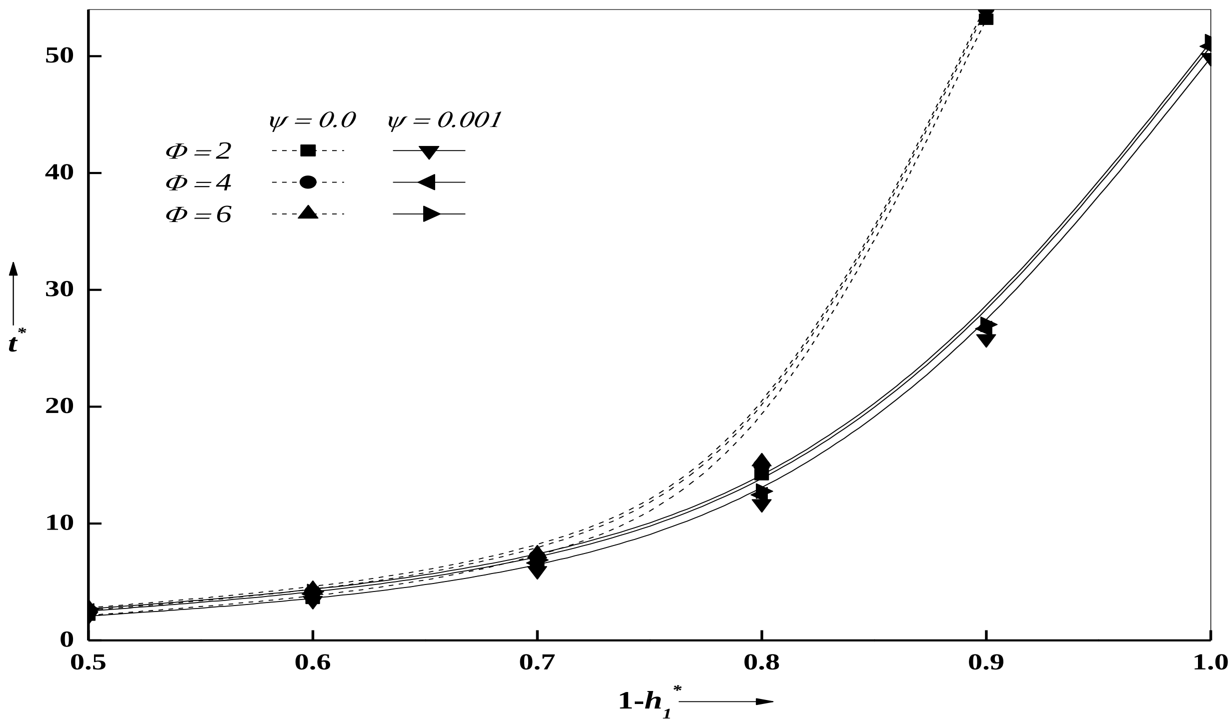

Fig. 10 Variation of dimensionless squeeze film time t^* with $1-h_1^*$ for different values of Φ and ψ at $H^* = 0.02$, $m = 0.6$, $I = 0.3$ and $M = 5$.

IV. CONCLUSION

The effects of MHD squeeze film motion between porous conducting plates in the presence of external magnetic field are presented in this article. As $\psi \to 0$, the squeeze film characteristics reduces to that of non-permeable case [11]. It is found that the negative effect induced by porosity can be overcome completely by the positive effect of magnetization and conductivities. Also the presence of external magnetic field delays the time of approach and decreases the pressure and load carrying capacity of the bearing.

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Nomenclature

b	Width of the bearing
L	Length of the bearing
x	Coordinate axis parallel to the length of the bearing in the lower plate
y	Coordinate axis perpendicular to X -axis
B_y	Applied magnetic field in Y -direction
h	Film thickness
h^*	Non-dimensional film thickness $\left(h/h_2\right)$
h_1	Minimum film thickness (when time $t=0$)
h_2	Film thickness after time Δt
h_1^*	Non-dimensional film thickness after time Δt
H^*	Thickness of porous facing $\left(H/h_2\right)$
M	Hartmann Number $\left(B_y h_2 \sqrt{\sigma/\mu}\right)$
ψ	Permeability parameter $\left(kH/h_2^3\right)$
k	Permeability of porous facing
m	Porosity

E_z	Electric field in the Z -direction
H_x	Induced magnetic field in the X -direction
H_{x_0}	Magnetic field in the lower free space
H_{x_1}	Magnetic field in the upper free space
I_y	External current $\left(H_{x_1} - H_{x_0}\right)$
I	Non-dimensional external current $\left(I_y h_2 / LVM\sqrt{\mu\sigma}\right)$
u	Velocity of the fluid in X -direction
V	Velocity of approach of upper surface $\left(-dh/dt\right)$
p	Pressure in the film region
p^*	Non-dimensional fluid film pressure $\left(ph_2^3 / \mu L^2 V^*\right)$
Q	Mass flow rate per unit length
W	Load capacity of the squeeze film
W^*	Non-dimensional load capacity $\left(Wh_2^3 / \mu bL^3 V\right)$
t	Time of approach of the upper plate
t^*	Non-dimensional time $\left(-Wh_2^2 t / \mu bL^3\right)$
σ	Electrical conductivity of the fluid
σ_1	Electrical conductivity of lower plate
σ_2	Electrical conductivity of upper plate
μ	Viscosity of lubricant
Φ_1	Electrical conductance ratio for the lower plate $\left(\sigma_1 h_1 / \sigma h\right)$
Φ_2	Electrical conductance ratio for the upper plate $\left(\sigma_2 h_2 / \sigma h\right)$

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