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Effects of Magneto Hydrodynamic Fluids in a narrow Porous rough Journal Bearing

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Abstract: *This Paper investigates the influence of Magneto hydrodynamic (MHD) fluid on rough short porous journals bearing, operating under conventional hydrodynamic regime. Using Christensen theory, average Reynolds equations are derived and expression for pressure and load carrying capacity is carried out. It is found that suitable combinations of roughness parameter, permeability parameter and Hartmann number increases the bearing performance.*

Keywords: *Porous, journal bearing, roughness, Hartmann number.*

1. Introduction

The basic concept of MHD is that the magnetic fields induce a current in a moving conducting fluid, then each particle experiences a force that depends on the magnetization of the material and strength of the applied field. It changes the fluid as a magnetic fluid namely, hydrodynamic magnetic fluid, magneto gas dynamics etc. Analysis of infinitely long journal bearing in the presence of magnetic field for the case of electrically conducting fluid was presented by Kuzma [1]. N S Patel et al [2] have made an attempt to study and analyze the performance of a magnetic- fluid - based hydrodynamic short journal bearing. Tze-Chi and Hsin [3] presented the performance of lubrication of short journal bearing by considering surface roughness and magnetic field and showed that load carrying capacity increases and reduces the friction coefficient. Bujurke and kudenetti [4] studied the surface roughness effect in MHD lubrication flow between the rectangular plates and found that the bearing performances are improved. Nada and Osman [5] investigated the problem on finite hydrodynamic journal bearings lubricated by magnetic fluid considering the effect of couple stress fluid. Gururajan & Prakash [6 -10], have studied the surface roughness effect on journal bearings with Newtonian fluid and found that roughness effect increases the bearing performance and also investigated that performance of bearing characteristics decreases with slip. Rajashekar and Biradar Kashinath [11] have studied the effect of surface roughness on MHD Couple Stress Squeeze-Film Characteristics between a sphere and a porous plane surface. Recently, Kalavathi et al. [12-15] examined the surface roughness effect in an infinitely narrow, long and finite journal bearing surface with heterogeneous slip/no-slip surface. Authors found that the effect of surface roughness increases the performance of bearing. They also studied the effect of MHD on narrow porous journal bearing with a heterogeneous slip/no-slip surface and found that suitable combination of MHD, roughness and permeability parameters increases the bearing performance.

In this paper, effect of Hartmann number on an infinitely short journal bearing is carried out by using Christensen stochastic model. The generalized Reynolds equation is derived and the expressions for pressure and load carrying capacity for both the types of roughness patterns like (i) longitudinal and (ii) transverse are obtained.

2. ANALYSIS

The geometrical configuration of a journal bearing is shown in the Fig. 1, Here, 'R' is the radius of bearing, U is the rotating velocity, e is the eccentricity of the journal centre. The space between bearing and the journal is filled with a magnetic fluid. Since the bearing is infinitely short $\frac{\partial p}{\partial z} \gg \frac{\partial p}{\partial x}$.

Considering the assumptions of hydro dynamic theory, equations for the oil flow are given by

$$\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2}{\lambda} u = \frac{1}{\lambda}\frac{\partial p^*}{\partial x}, \quad (1)$$

$$\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2}{\lambda} w = \frac{1}{\lambda}\frac{\partial p^*}{\partial z}, \quad (2)$$

$$\frac{\partial p^*}{\partial y} = 0 \quad (3)$$

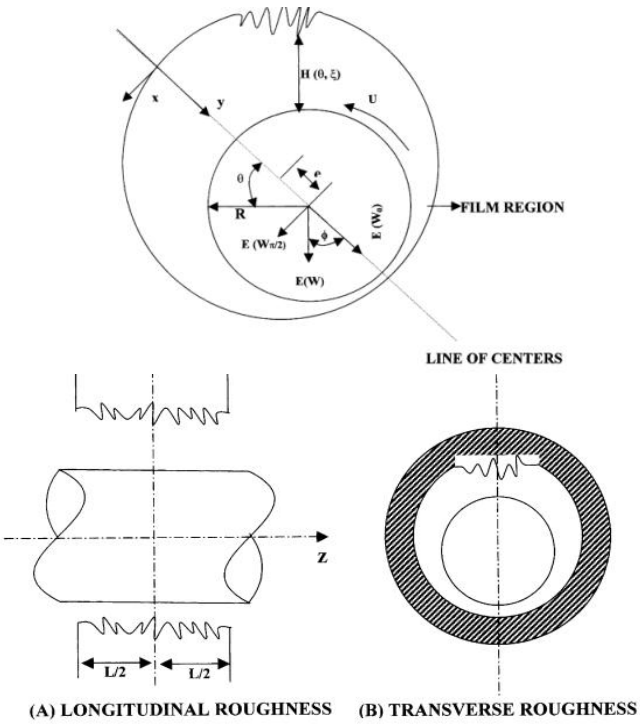

Fig.1 *Bearing Geometry and Journal bearing configuration*

Non-dimensionalising $M_0 = \frac{B_0 h_0}{\sqrt{\frac{\sigma}{\lambda}}}$ called Hartmann Number, where B_0 is applied magnetic field in y-direction, σ is conductivity of fluid, and λ is viscosity of fluid, h_m is the smooth part of the film geometry. Then equations (1), (2) and (3) are written as

$$\frac{\partial^2 u}{\partial y^2} - \frac{M_0^2}{h_0^2} u = \frac{1}{\lambda}\frac{\partial p^*}{\partial x}, \quad (4)$$

$$\frac{\partial^2 w}{\partial y^2} - \frac{M_0^2}{h_0^2} w = \frac{1}{\lambda}\frac{\partial p^*}{\partial z}, \quad (5)$$

$$\frac{\partial p^*}{\partial y} = 0 \quad (6)$$

Here, u, v, w are circumferential, radial and axial velocity components respectively. p^* is pressure component. x, y, z are Cartesian coordinates.

continuity equation is given by

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (7)$$

Boundary conditions for the velocity components by considering slip and porous media are mentioned below

At $y = 0,\ u = 0,\ v = -V_0,\ w = 0$ (8)

At $y = H, u = U,\ v = 0,\ w = 0$. (9)

where H is the film thickness, V_0 is velocity component in porous media, and is given by

$$V_0 = \frac{\varphi}{\lambda}\left[\frac{\partial p^*}{\partial y}\right]_{y=0} \tag{10}$$

where, φ is permeability.

The bearing wall thickness H_0 assumed to be small [7] and showed that

$$\left[\frac{\partial p^*}{\partial y}\right]_{y=0} \approx -H_0\left[\frac{\partial^2 p^*}{\partial x^2} + \frac{\partial^2 p^*}{\partial z^2}\right] \tag{11}$$

Substituting (11) in to (10) we have

$$V_0 = -\frac{\varphi}{\lambda} H_0\left[\frac{\partial^2 p^*}{\partial x^2} + \frac{\partial^2 p^*}{\partial z^2}\right] \tag{12}$$

Solving eq. (4) and eq. (5) for u and w, and using the boundary conditions of eq. (8) and eq. (9), we obtain

$$u = \frac{1}{\lambda}\frac{h_0^2}{M_0^2}\frac{\partial p^*}{\partial x}\left\{cosh\left(\frac{M_0}{h_0}y\right) - 1\right\} + U\frac{sinh\left(\frac{M_0}{h_0}y\right)}{sinh\left(\frac{M_0}{h_0}H\right)} + \frac{1}{\mu}\frac{h_0^2}{M_0^2}\frac{\partial p}{\partial x}\frac{\left\{1-cosh\left(\frac{M_0}{h_0}y\right)\right\}}{sinh\left(\frac{M_0}{h_0}H\right)} sinh\left(\frac{M_0}{h_0}y\right) \tag{13}$$

and

$$w = \frac{1}{\lambda}\frac{h_0^2}{M_0^2}\frac{\partial p^*}{\partial z}\left\{cosh\left(\frac{M_0}{h_0}y\right) - 1\right\} + U\frac{sinh\left(\frac{M_0}{h_0}y\right)}{sinh\left(\frac{M_0}{h_0}H\right)} + \frac{1}{\mu}\frac{h_0^2}{M_0^2}\frac{\partial p}{\partial z}\frac{\left\{1-cosh\left(\frac{M_0}{h_0}y\right)\right\}}{sinh\left(\frac{M_0}{h_0}H\right)} sinh\left(\frac{M_0}{h_0}y\right) \tag{14}$$

Substituting eq. (13) and eq. (14) into continuity equation (7) and integrating across the film thickness H, we obtain

$$\frac{1}{\lambda}\frac{{h_0}^3}{{M_o}^3}\frac{\partial}{\partial x}\left[\left\{\left(sinh\left(\frac{M_0}{h_0}H\right) - \frac{M_0}{h_0}H\right) + \frac{\left\{1-cosh\left(\frac{M_0}{h_0}y\right)\right\}}{sinh\left(\frac{M_0}{h_0}H\right)}\left(cosh\left(\frac{M_0}{h_0}H\right) - 1\right)\right\}\frac{\partial p^*}{\partial x}\right]$$

$$+\frac{1}{\lambda}\frac{{h_0}^3}{{M_o}^3}\frac{\partial}{\partial z}\left[\left\{\left(sinh\left(\frac{M_0}{h_0}H\right) - \frac{M_0}{h_0}H\right) + \frac{\left\{1-cosh\left(\frac{M_0}{h_0}y\right)\right\}}{sinh\left(\frac{M_0}{h_0}H\right)}\left(cosh\left(\frac{M_0}{h_0}H\right) - 1\right)\right\}\frac{\partial p^*}{\partial z}\right]$$

$$= U\frac{h_0}{M_o}\frac{\partial}{\partial x}\left(cosh\left(\frac{M_0}{h_0}H\right) - 1\right) - (V_H - V_0)\ . \tag{15}$$

Since the journal surface is non-porous, $V_H = 0$. The velocity component V_0 across porous media is given by eq. (12). Substituting for V_H and V_0 in eq. (15), simplifying and non-dimensionalising, the modified Reynolds equation is given by

$$\frac{\partial}{\partial x}\left[\left\{\alpha(M^*, H^*) + \psi\, {M^*}^3\right\}\frac{\partial p^*}{\partial x}\right] + \frac{\partial}{\partial z}\left[\left\{\alpha(M^*, H^*) + \psi\, {M^*}^3\right\}\frac{\partial p^*}{\partial z}\right] = \frac{\lambda\, U}{(\Delta r)^2}{M^*}^2\frac{\partial}{\partial x}[\beta(M^*, H^*)] \tag{16}$$

where, $\alpha\,(M^*, H^*) = \frac{-2 + 2cosh\,(M^*H^*) - M^*H^* sinh\,(M^*H^*)}{sinh(M^*H^*)}$, (17)

$$\beta(M^*, H^*) = \frac{1-cosh(M^*H^*)}{sinh(M^*H^*)}, \tag{18}$$

$$M^* = \frac{M_0}{h_m},\ h_m = \frac{h_0}{\Delta r},\ H^* = \frac{H}{\Delta r}, \psi = \frac{\varphi H_0}{(\Delta r)^2}\,. \tag{19}$$

where, M^* is non-dimensional Hartmann number

Mathematically, the local film geometry of lubricant is written as

$$H^* = \Delta r(1 + \varepsilon\, cos\theta) + h_s\left(x, z, \xi\right)$$

Here, $\Delta r(1+\varepsilon\, cos\theta)$ denotes the nominal smooth part of the film geometry, h_s is the part due to the surface asperities measured from the nominal level and is regarded as a randomly varying quantity with zero mean.

Taking expected values on both sides of eq. (16), we get

$$\frac{\partial}{\partial x}\left[E\left\{\alpha(M^*,H^*)+\psi\, {M^*}^3\right\}\frac{\partial p^*}{\partial x}\right]+\frac{\partial}{\partial z}\left[E\left\{\alpha(M^*,H^*)+\psi\, {M^*}^3\right\}\frac{\partial p^*}{\partial z}\right]=\frac{\lambda\, U}{(\Delta r)^2}M^{*2}\frac{\partial}{\partial x}[E(\beta(M^*,H^*)] \tag{20}$$

Here, E(·) is the expectancy operator, defined by

$$E(\blacksquare)=\int_{-\infty}^{+\infty}(\blacksquare)f(h_s)\, dh_s \tag{21}$$

and $f(h_s)$ is the probability density function for the stochastic variable h_s. In engineering field, nature of roughness striations on bearing is of Gaussian type. The Gaussian can be derived from the polynomial distributions. Such a density function is

$$\begin{aligned} f(h_s) &= \frac{35}{32C^7}\left(c^2-{h_s}^2\right)^3, \quad -c<h_s<c,\\ &= 0, \qquad elsewhere, \end{aligned} \tag{22}$$

The function eliminates at c = $\pm 3\sigma$, where σ is the standard deviation.

2.1 Longitudinal One-dimensional Roughness:

The one-dimensional longitudinal roughness pattern, can be manifest as

$$\frac{\partial}{\partial x}\left[E\left\{\alpha(M^*,H^*)+\psi {M^*}^3\right\}\frac{\partial}{\partial x}[E(p^*)]\right]+\frac{\partial}{\partial z}\left[\left\{\frac{1}{E\left(1/_{\alpha(M^*,H^*)}\right)}+\psi {M^*}^3\right\}\frac{\partial}{\partial z}\{E(p^*)\}\right]=\frac{\lambda\, U}{(\Delta r)^2}{M^*}^2 E\left(\frac{\partial}{\partial x}\{\beta(M^*,H^*)\}\right). \tag{23}$$

where, $H^*=\Delta r(1+\varepsilon\, cos\theta)+h_s(x,\xi)$

For the approximation of short journal bearing, the variation of pressure in circumferential direction is neglected in favour of axial variation. Hence eq. (23) reduced to

$$\frac{\partial}{\partial z}\left[\left\{\frac{1}{E\left(1/_{\alpha(M^*,H^*)}\right)}+\psi {M^*}^3\right\}\frac{\partial}{\partial z}\{E(p^*)\}\right]=\frac{\lambda\, U}{(\Delta r)^2}{M^*}^2\frac{\partial}{\partial x}[E\{\beta(M^*,H^*)\}]. \tag{24}$$

Film pressure boundary condition for infinitely short journal bearing is given by

$$E(p^*)=o \ at \ z=\pm\frac{L}{2}. \tag{25}$$

L is the length bearing length. On integrating eq. (24) and using eq. (25), we obtain an expression for pressure as

$$\bar{p}=\frac{E\,(p^*)\,(\Delta r)^2}{\lambda\, U\, L\, R^2}=\frac{1}{2}\,\varepsilon\, M^{*3}\,\frac{\frac{d}{d\theta}[E\{\beta(M^*,H^*)\}]}{\left\{\frac{1}{E(1/\alpha(M^*,H^*))}+\psi\, M^{*3}\right\}}\left(z^2-\frac{L^2}{4}\right) \tag{26}$$

where $\bar{z}=z/L,\ \theta=x/R,\ C=c/\Delta r.$ (27)

Load carrying capacity of the short journal bearing is obtained by integrating the pressure, taking the direction into account and by using Half Somerfield boundary conditions, the mean component acting along the line of centre is given by

$$E(W_0)=E(W)cos\phi=-LR\int_0^{\pi}E(p)\,cos\theta\ \ d\theta$$

and that acting along the normal to the line of center is given by

$$E\left(W_{\pi/2}\right)=E(W)\,sin\phi=LR\int_0^{\pi}E(p)\,sin\theta\ \ d\theta$$

Integrating eq. (26), the load components W_0^* and $W_{\pi/2}^*$ can be written as

$$W_0^* = \frac{E(W_0)(\Delta r)^2}{\lambda\, U\, L\, R^2} = \frac{M^{*3}}{12}\, \varepsilon \int_0^{\pi} \frac{\delta_1(M^*, H^*)}{\left\{\frac{1}{E(1/\alpha(M^*,H^*))} + \psi\, M^3\right\}} \times sin\theta \times cos\theta\, d\theta. \tag{28}$$

$$W_{\pi/2}^* = \frac{E(W_{\pi/2})(\Delta r)^2}{\lambda\, U\, L\, R^2} = -\frac{M^{*3}}{12}\, \varepsilon \int_0^{\pi} \frac{\delta_1(M^*, H^*)}{\left\{\frac{1}{E\{1/\alpha(M^*,H^*)\}} + \psi\, M^3\right\}} \times sin^2\theta\, d\theta. \tag{29}$$

where, $\delta_1(M^*, H^*) = E\left[\frac{cos\,h(M^*H^*)-1}{\{sin\,h(M^*H^*)\}^2}\right]$.

The resultant of non-dimensional load capacity is evaluated as

$$W^* = \left[(W_0^*)^2 + \left(W_{\pi/2}^*\right)^2\right]^{1/2} \tag{30}$$

2.2Transverse One-dimensional Roughness:

The one-dimensional transverse roughness pattern, can be manifest as

$$\frac{\partial}{\partial x}\left[\left\{\frac{1}{E(1/\,\alpha\,(M^*,H^*))} + \psi\, M^{*3}\right\}\frac{\partial}{\partial x}\{E(p^*)\}\right] + \frac{\partial}{\partial z}\left[\left\{E\left(\alpha(M^*,H^*) + \psi\, M^{*3}\right)\right\}\frac{\partial}{\partial z}\{E(p^*)\}\right]$$
$$= \frac{\lambda\, U}{(\Delta r)^2} M^{*2} \frac{\partial}{\partial x}\left[E\left\{\frac{\beta(M^*,H^*)}{\alpha(M^*,H^*)}\right\}\right] \tag{31}$$

where $H^* = \Delta r(1 + \varepsilon\, cos\theta) + h_s(x, \xi)$.

In accordance with narrow bearing theory, the eq. (31) reduces to

$$\frac{\partial}{\partial z}\left[\left\{E\left(\alpha(M^*,H^*) + \psi\, M^{*3}\right)\right\}\frac{\partial}{\partial z}\{E(p^*)\}\right] = \frac{\lambda\, u}{(\Delta r)^2} M^{*2} \frac{\partial}{\partial x}\left[\left\{E\left\{\frac{\beta(M^*,H^*)}{\alpha(M^*,H^*)}\right\}\right\}\right]. \tag{32}$$

On integrating eq. (32) and using boundary condition of eq. (25), we obtain an expression for pressure as

$$\bar{p} = \frac{E\,(p^*)\,(\Delta r)^2}{\lambda\, U\, L\, R^2} = \frac{\frac{d}{d\theta}\left[\left\{E\left\{\frac{\beta(M^*,H^*)}{\alpha(M^*,H^*)}\right\}\right\}\right]}{\left[E\left(\alpha(M^*,H^*) + \psi\, M^{*3}\right)\right]}\left(z^2 - \frac{L^2}{4}\right). \tag{33}$$

Integrating eq. (33), the load components are given as follows:

$$W_0^* = \frac{E(W_0)(\Delta r)^2}{\lambda\, U\, L\, R^2} = \frac{M^{*3}}{12}\, \varepsilon \int_0^{\pi} \frac{\delta_1(M^*, H^*)}{[E\{\alpha(M^*,H^*) + \psi\, M^{*3}\}]} \times sin\theta \times cos\theta\, d\theta. \tag{34}$$

$$W_{\pi/2}^* = \frac{E(W_{\pi/2})(\Delta r)^2}{\lambda\, U\, L\, R^2} = -\frac{M^{*3}}{12}\, \varepsilon \int_0^{\pi} \frac{\delta_1(M^*, H^*)}{[E\{\alpha(M^*,H^*) + \psi\, M^{*3}\}]} \times sin^2\theta\, d\theta. \tag{35}$$

where, $\delta_1(M^*, H^*) = E\left[\frac{cos\,h(M^*H^*)-1}{\{\,sin\,h(MH^*)\,\}^2}\right]$.

The non-dimensional load capacity W^* can be evaluated using eq. (30)

3. RESULTS AND DISCUSSION

The bearing characteristics depends on some parameters such as Hartmann number (M^*) roughness parameter (C), bearing eccentricity by the bearing ratio (ε), porosity by the permeability parameter (ψ). The study of surface roughness effects of MHD in porous narrow journal bearings are presented in graphs. The following are the range of values used for the preparation of results: $M^* = 0.0\ to\ 1$, $C = 0.1\ to\ 0.9$, $\varepsilon = 0.1\ to\ 0.9$ such that $(C + \varepsilon) \to 1$ and $\psi = 0\ to\ 1$.

The variation of load carrying capacity with permeability parameter (ψ) for different values of Hartmann number is shown in Fig. 2. It is observed that due to the effect of Hartmann number M^*, the load carrying capacity increases/decreases as compared to longitudinal/transverse pattern. The similar type of effect is seen in the Rajashekar and Biradar Kashinath [11]. Large permeability means there are more voids available in porous facing, for the quick escape of fluid and porous facing is main channel for the fluid discharge, therefore the modification of film thickness have negligible effect due to the presence of surface roughness. This result is also in accordance with the fact that for higher values of permeability the resistance offered by fluid film is very small. Therefore the roughness effect for a fixed value of C decreases with increase of ψ. It is highly pronounced for $M^* = 0.1$ and $\psi = 0.1$.

Load carrying capacity, W* versus C for different M^* is plotted in Fig. 3 with $\varepsilon = 0.5,\ \psi = 0.01$. It is observed that for increasing values of C, the load carrying capacity increases for longitudinal roughness as compared to transverse roughness. Also, it is highly significant for $M^* = 0.1$

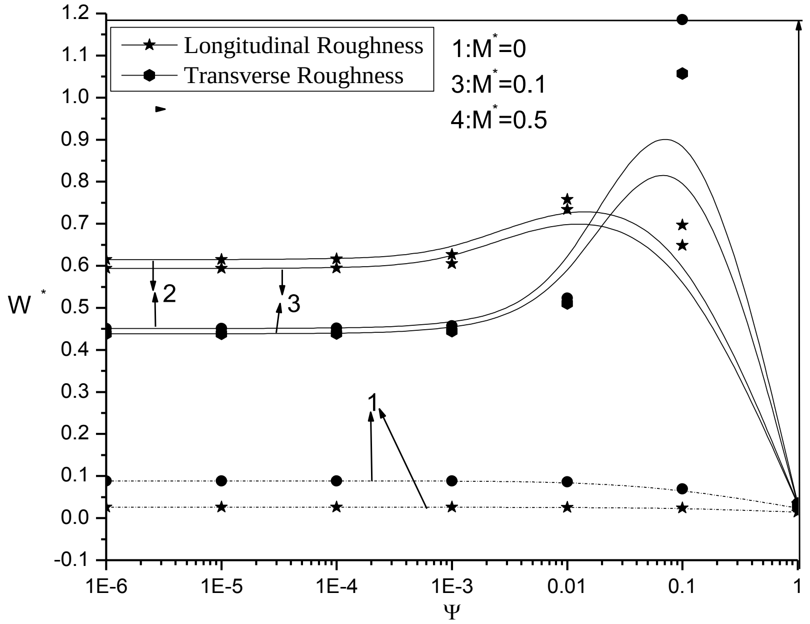

Fig. 2 Load Carrying capacity, W * versus Permiability parameter,ψ for various values of Hartmann Number,M^* with ε= 0.5 and C = 0.5

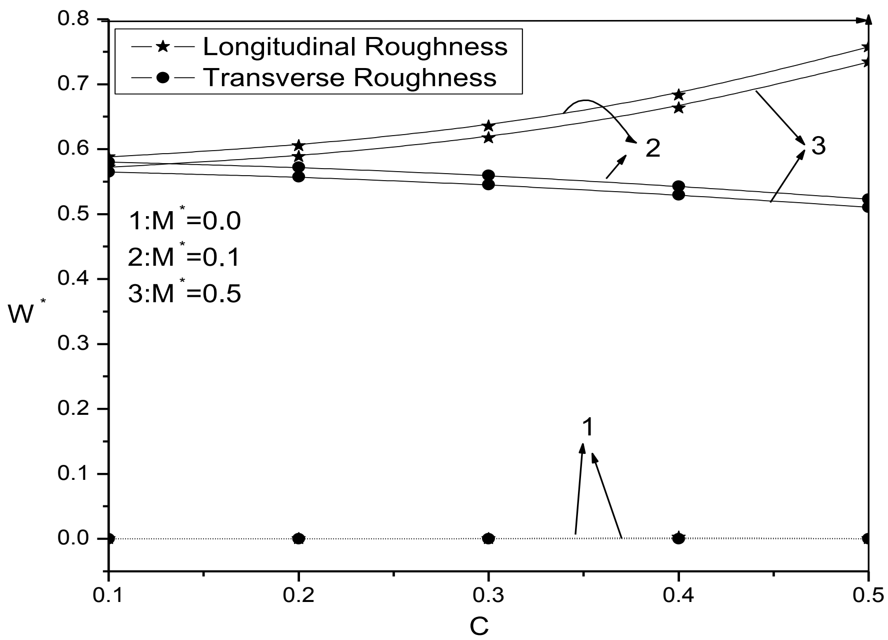

Fig. 3 Load Carrying capacity, W * versus Roughness parameter,C for various values of M^* with ε = 0.5 and ψ = 0.01

Figure 4 shows that the variation of non-dimensional mean load carrying capacity W^* with Hartmann number M^* as a function of C for both types of roughness patterns, it is observed that the effect of longitudinal/transverse patterns is to increase/decrease W^* as compared to smooth case (i.e., $C = 0$). Also, load carrying capacity for longitudinal roughness pattern as compared to the transverse roughness is high.

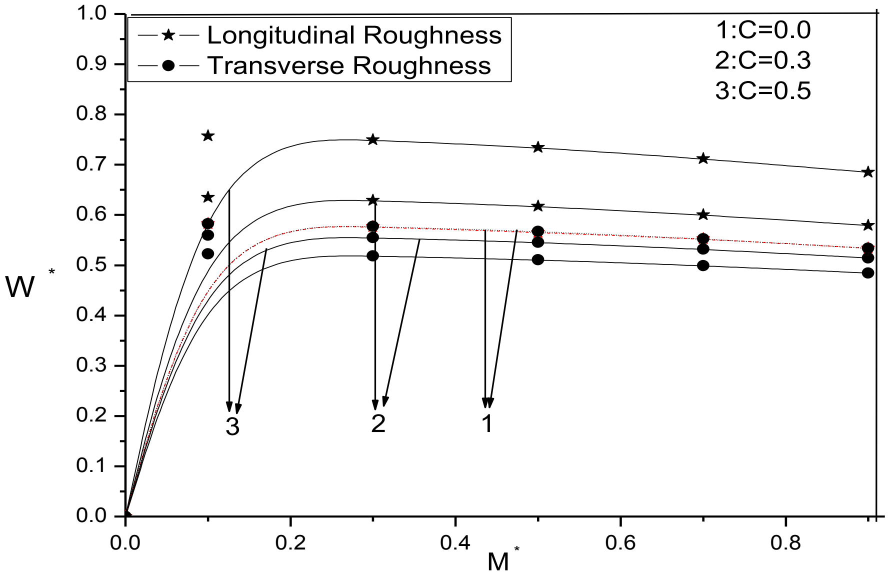

Fig. 4 Load Carrying capacity, W * versus Hartman number,M *
for various values of C with ε = 0.5 and ψ = 0.01

The variation of non-dimensional mean load carrying capacity W^* with Hartmann number for different values of ψ is shown in the Fig. 5, it is observed that the effect of permeability parameter ψ is to decrease load carrying capacity as compared to both types of roughness pattern. Addition of magnetic field increases load carrying capacity as compared to without magnetic field.

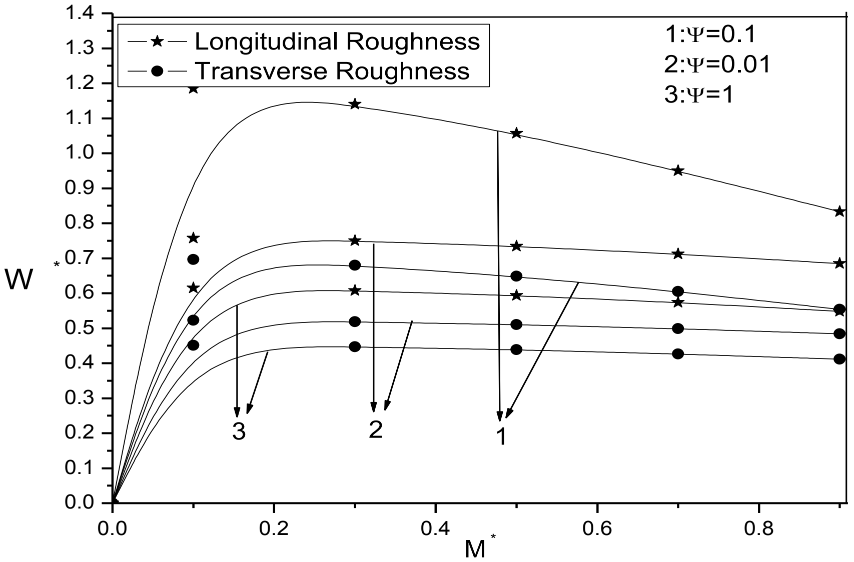

Fig. 5 Load Carrying capacity, W * versus Hartmann Number,M *
for various values of Hartmann Number,M * with ε= 0.5 and C = 0.5

4. Conclusion

Effects of magnetic field in a narrow porous rough journal bearing are studied using Christensen stochastic model. It is observed that the load carrying capacity increases for increasing values of roughness parameter C for longitudinal roughness whereas; it decreases for transverse roughness pattern. The load carrying capacity is found to increase for the values of Hartmann number $M^* = 0.1$ and permeability parameter, $\psi = 0.1$.

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