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MAGNETIC FLUID BASED SQUEEZE FILM BETWEEN ROUGH POROUS INFINITELY LONG PARALLEL PLATES WITH POROUS MATRIX OF VARIABLE FILM THICKNESS

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Abstract

An endeavor has been made to study and analyze the performance of a squeeze film between infinitely long porous rough parallel plates with porous matrix of variable film thickness in the presence of a magnetic fluid lubricant. The bearing surfaces are assumed to be transversely rough. The stochastic film thickness characterizing the random roughness is considered to be asymmetric with non-zero mean and variance. A magnetic fluid is used as the lubricant and the external magnetic field is oblique to the lower plate. The associated Reynolds' equation is solved by making use of appropriate boundary conditions. Then expressions for pressure distribution, load carrying capacity and response time are obtained. The results are presented graphically. It is found that the performance of the bearing system improves considerably due to the magnetic fluid lubricant. But it is also observed that the composite roughness of the bearing surfaces induces an adverse effect on the performance of the bearing system. However, the negative effect can be considerably compensated by the magnetic fluid lubricant in the case of negatively skewed roughness. In addition, it is seen that the load carrying capacity increases with increasing values of the parameter associated with the variable film thickness. This investigation tends to suggest that the roughness must be given due consideration while designing the magnetic fluid based bearing system even though, the thickness of porous matrix is suitably chosen.

Key Words

Squeeze film, Magnetic fluid, Roughness, variable film thickness, Reynolds' equation, Load carrying capacity.

1. THE INTRODUCTION

The squeeze film behavior between non-porous parallel plates was investigated by Archibald [4]. The method adopted by Archibald [4] was simplified by Prakash and Viz [26] incorporating Morgan-Cameron approximation to uncouple the modified Raynolds' equation while the porous facing thickness was assumed small and constant. It is an established fact that the introduction of a sintered porous bush in the bearing results in loss of mechanical strength and reduction of film pressure and consequently, in load carrying capacity.

Efforts were directed to improve the performance of a porous bearing by making use of electromagnetic pumping of lubricant (Sinha and Gupta[27]) and using a magnetic fluid lubricant (Verma [31]). Agrawal [1] discussed the effect of magnetic fluid lubricant by considering no slip condition. Bhat and Deheri [6, 7] analyzed the performance of a magnetic fluid based squeeze film between curved annular disks and curved circular plates and observed that its performance with the magnetic fluid as a lubricant was relatively better than with a conventional lubricant. Patel and Deheri [18] investigated the magnetic fluid based squeeze film between curved annular plates taking the surfaces determined by hyperbolic functions. Simultaneously, Patel and Deheri [20] discussed the behavior of magnetic fluid based squeeze film between two curved circular plates lying along the surfaces governed by secant functions.

All these studies assumed the porous wall thickness to be uniform. However, in practice, in some cases the porous facing may not be of uniform thickness due to various manufacturing reasons, for instance, the non uniform applications of pressure while sintering and the non homogeneous mixing of the bearing materials. The non uniformity of thickness of porous bush gives rise to an additional degree of freedom for its design. Prajapati [24] studied the hydrodynamic lubrication of an inclined porous slider bearing with variable porous matrix thickness. Further, the behavior of squeeze film between porous circular plates with porous matrix of variable thickness was investigated by Prajapati [23].

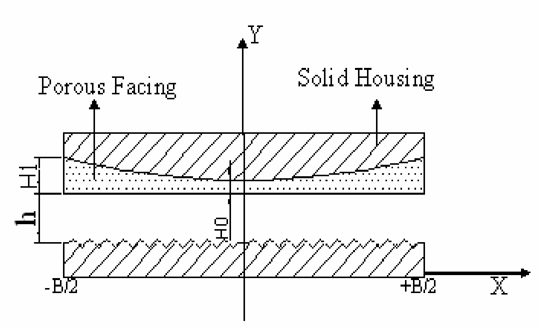
In all these above investigations the bearing surfaces were taken to be smooth. However, after having some run in and wear the bearing surfaces develop roughness especially, in bearing working with small film thickness. Several studies were devoted to analyze the effect of surface roughness (both transverse as well as longitudinal) (Davies [12], Burton [8], Michell [17], Tonder [29], Tzeng and Saibel [30], Christensen and Tonder [9-11], Berthe and Godet [5]). Modifying and developing the approach of Tzeng and Saibel [30] Christensen and Tonder [9-11] presented a comprehensive general analysis for both transverse as well as longitudinal surface roughness. Subsequently, this approach of Christensen and Tonder [9-11] formed the basis of the analysis to study the effect of surface roughness in a number of investigations (Ting [28], Prakash and Tiwari [25], Prajapati [21,22], Guha [15], Gupta and Deheri [16], Andharia et. al. [2,3]). Patel and Deheri [19] dealt with the performance of a squeeze film formed by a magnetic fluid in rough annular plates. Deheri, Patel and Patel [14] studied the behavior of a magnetic fluid based squeeze film between infinitely long transversely rough rectangular plates. Although, the effect of roughness is adverse in general, the investigations of Patel and Deheri [19] and Deheri, Patel and Patel [14] suggested that negatively skewed roughness resulted in a better performance of the bearing system.

Thus, it was deemed appropriate to make an investigation on the performance of a magnetic fluid based squeeze film between porous rough infinitely long parallel plates with porous matrix of variable film thickness.

2. THE ANALYSIS

The configuration of the bearing system is given below.

It concerns with the laminar axis symmetric flow of an incompressible fluid between two infinitely long parallel plates, lower one is fixed while the upper plate has a porous facing of variable porous matrix thickness backed by a solid wall. The upper plate approaches the lower one normally with velocity $\dot{h} = \frac{dh}{dt}$. The porous wall thickness is assumed to vary linearly with its values at $x = 0$ as H_0 while this value is H_1 at $x = \frac{B}{2}$. Hence the porous wall thickness H is given by



Geometry of the bearing system

$$H = H_0 + (H_1 - H_0)\left(\frac{2x}{B}\right) \tag{1}$$

The Z-axis is taken normal to the lubricant film. The bearing surfaces are assumed to be transversely rough. The thickness $h(x)$ of the lubricant film is

$$h(x) = \bar{h}(x) + h_s$$

where $\bar{h}(x)$ is the mean film thickness and h_s is the deviation from the mean film thickness characterizing the random roughness of the bearing surfaces. h_s is considered to be stochastic in nature and governed by the probability density function

$$f(h_s),\ -c \le h_s \le c$$

where c is the maximum deviation from the mean film thickness. The mean α, the standard deviation σ and the parameter ε which is the measure of symmetry of the random variable h_s are defined by the relationships

$$\alpha = E(h_s) \tag{2}$$

$$\sigma^2 = E\left((h_s - \alpha)^2\right) \tag{3}$$

and

$$\varepsilon = E\left((h_s - \alpha)^3\right) \tag{4}$$

where E denotes the expected value defined by

$$E(R) = \int_{-c}^{c} R\, f(h_s)\, dh_s \tag{5}$$

Assuming axially symmetric flow of the magnetic fluid between the parallel plates under and oblique magnetic field $\bar{M}$ whose magnitude M is a function of x vanishing at ±B/2, the modified Reynolds' equation governing the film pressure is obtained as [6, 13, 14]

$$\frac{\partial}{\partial x}\left[g(h)\frac{\partial}{\partial x}\left(p - 0.5\mu_0\bar{\mu}M^2\right)\right] = 12\mu\dot{h} \tag{6}$$

where

$$M^2 = \left(\frac{B}{2} - x\right)\left(\frac{B}{2} + x\right),$$

$$g(h) = h^3 + 3\sigma^2 h + 3h^2 a + 3ha^2 + 3\sigma^2 a + a^3 + \varepsilon + 12\varphi H,$$

μ is the absolute viscosity of the lubricant, μ_0 is the permeability of the free space and $\bar{\bar{\mu}}$ is the magnetic susceptibility.

Integrating the above equation with respect to the concerned boundary conditions

$$P(\pm 1/2) = 0 \tag{7}$$

we get the expression for non-dimensional pressure as

$$P = \frac{\mu^*\left(\frac{1}{4} - X^2\right)}{2} - \frac{12X}{b} + \frac{12\ \ln(a + bX)}{b\ \ln\left(\frac{2a+b}{2a-b}\right)} - \frac{6\ \ln\left(\frac{4a^2 - b^2}{4}\right)}{b\ \ln\left(\frac{2a+b}{2a-b}\right)} \tag{8}$$

where

$$a = 1 + 3\sigma^{*2} + 3a^* + 3a^{*2} + 3\sigma^{*2} a^* + a^{*3} + \varepsilon^* + 12\psi,$$

$$b = 24\psi A, \qquad \mu^* = -\frac{\mu_0\bar{\mu}h^3}{\mu\dot{h}}, \qquad X = \frac{x}{B},$$

$$\sigma^* = \frac{\sigma}{h}, \qquad a^* = \frac{a}{h}, \qquad \varepsilon^* = \frac{\varepsilon}{h^3},$$

$$\psi = \frac{\phi h}{H^3}, \qquad A = \frac{H_1}{H_0} - 1$$

The load carrying capacity in dimensionless form comes out to be $W = \int_{-1/2}^{1/2} P\, dX$

$$= \frac{\mu^*}{12} + \frac{12a}{b^2} - \frac{12}{b\ \ln\left(\frac{2a+b}{2a-b}\right)} \tag{9}$$

If the time taken for the plate to move from the film thickness $h=h_0$ to $h=h_1$ is Δt then the dimensionless squeeze time ΔT is given by

$$\Delta T=-W\int_{\bar h_1}^{\bar h_2}\frac{d\bar h}{G(h)} \tag{10}$$

where $$G(h)=\bar h^3+3\sigma^{*2}\bar h+3\bar h^2\alpha^*+3\sigma^{*2}\alpha^*+\alpha^{*3}+\varepsilon^*+12\psi$$

and $$\bar h_1=\frac{h_1}{h_0},\ \bar h_2=\frac{h_2}{h_0},\ \bar h=\frac{h}{h_0}$$

3. RESULTS AND DISCUSSION

It is clearly seen that equation (8) determines the pressure distribution while equation (9) gives the distribution of load carrying capacity. Further, equation (10) accounts for response time. All these performance characteristics depend on various parameters such as magnetization parameter μ^*, porosity parameter ψ, thickness ratio parameter A and the roughness parameters σ^*, α^* and ε^*. Taking the thickness ratio parameter A to be zero the results for uniform porous matrix thickness are obtained. Further, taking the roughness parameters to be zero one gets the analysis of the behavior of magnetic fluid based between infinitely long smooth parallel plates. This study reduces to the performance of the squeeze film between infinitely long smooth parallel plates by setting the magnetization parameter μ^* as zero. Lastly, further choosing thickness ratio parameter to be zero one can find the performance of squeeze film between two porous infinitely long parallel plates. From equations (8) and (9) it is clear that pressure gets increased by $\dfrac{\mu^*\left(\frac{1}{4}-X^2\right)}{2}$ while, the increase in load carrying capacity is $\dfrac{\mu^*}{12}$.

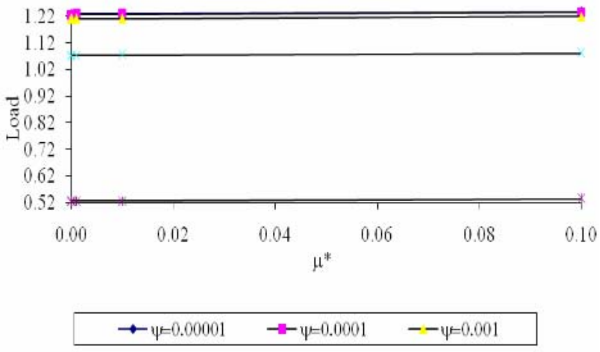


Figure: 1 Variation of load carrying capacity with respect to μ^* and ψ

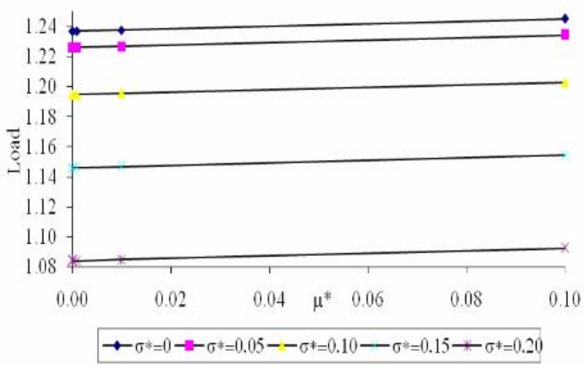


Figure: 2 Variation of load carrying capacity with respect to μ^* and σ^*

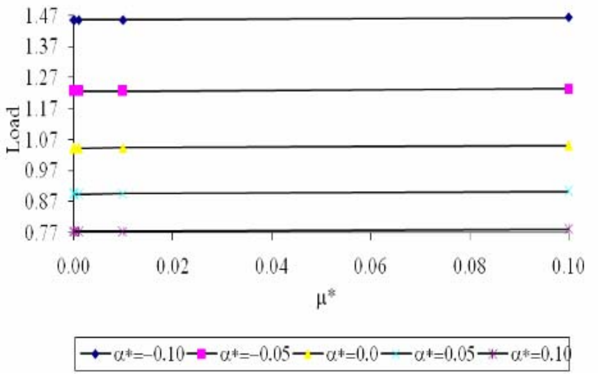


Figure: 3 Variation of load carrying capacity with respect to μ^* and α^*

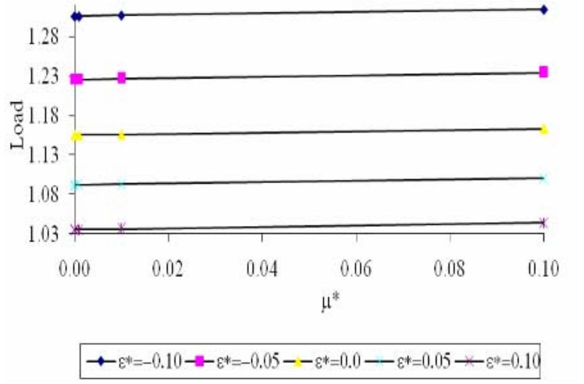


Figure: 4 Variation of load carrying capacity with respect to μ^* and ε^*

Figures (1-5) present the variation of load carrying capacity with respect to the magnetization parameter μ* for different values of porosityψ, standard deviation σ*, variance α*, skewness ε* and the thickness ratio parameter A respectively. It is clearly seen from these figures that the load carrying capacity increases significantly with respect to the increasing values of the magnetization parameter. Besides, figure (5) indicates that the combination of the magnetization parameter and the thickness ratio parameter introduces a strong positive effect on the performance of the bearing system as compared to the other cases.

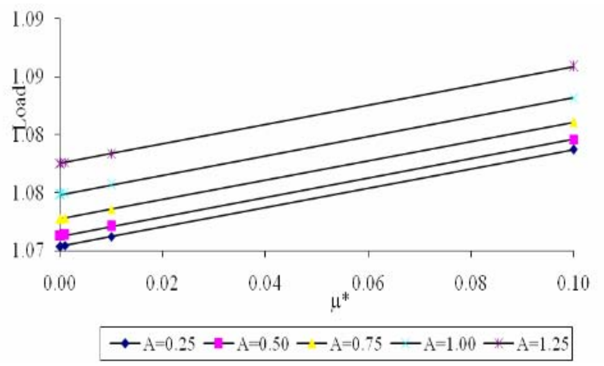


Figure: 5 Variation of load carrying capacity with respect to μ* and A

We have the effect of porosity on the performance of the bearing system in Figures (6-9). The bearing performance suffers due to porosity and particularly the combined effect of porosity and standard deviation is considerably adverse. [Figure (6)]

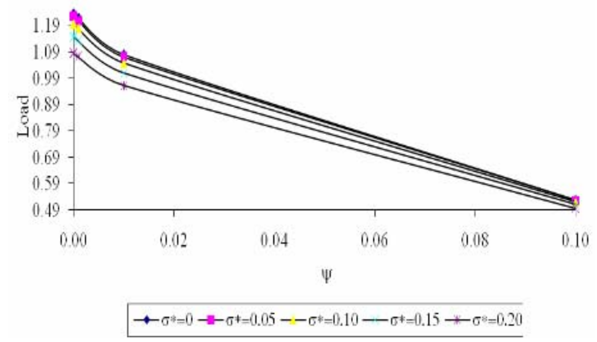


Figure: 6 Variation of load carrying capacity with respect to ψ and σ*

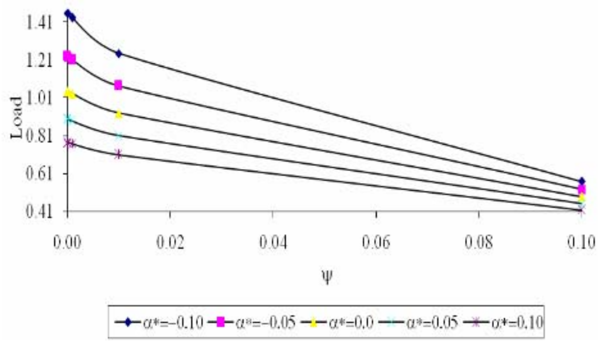


Figure: 7 Variation of load carrying capacity with respect to ψ and α*

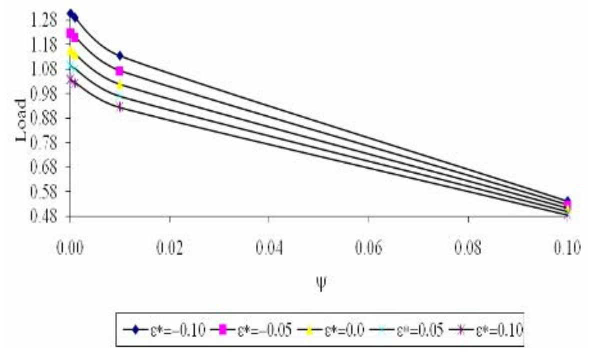


Figure: 8 Variation of load carrying capacity with respect to ψ and ε*

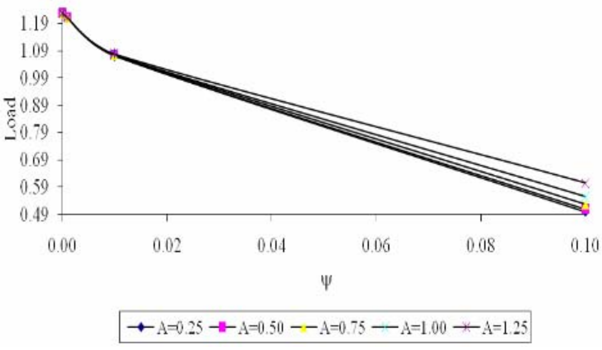


Figure: 9 Variation of load carrying capacity with respect to ψ and A

Figures (10-12) depict the variation of load carrying capacity with respect to the standard deviation associated with roughness. It is manifest that standard deviation has a considerably adverse effect on the performance of the squeeze film bearing. Further, Figure (12) makes it clear that the rate of decrease due to the standard deviation increases while there is a negligible increase due to the thickness ratio parameter.

The effect of variance is shown in Figures (13-14). It is easily observed that the load carrying capacity decreases due to variance (+ve) while the negative variance and the thickness ratio parameter increase the load carrying capacity. Besides, Figure (15) determines the combined effect of skewness and thickness ratio parameter. It is found that the skewness follows the path of the variance so far as load carrying capacity is concerned. However, the effect of thickness ratio parameter with respect to the variance is almost negligible, while it is slightly better in the case of skewness.

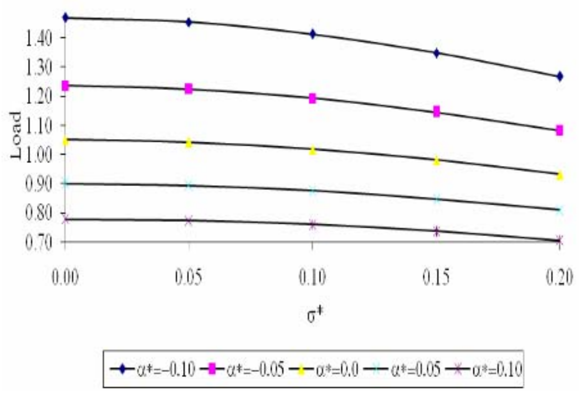


Figure: 10 Variation of load carrying capacity with respect to σ* and α*

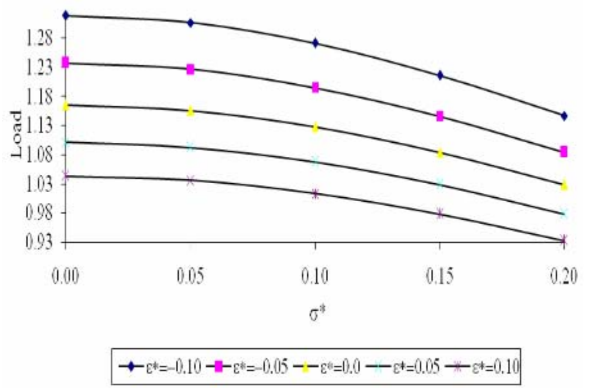


Figure: 11 Variation of load carrying capacity with respect to σ* and ε*

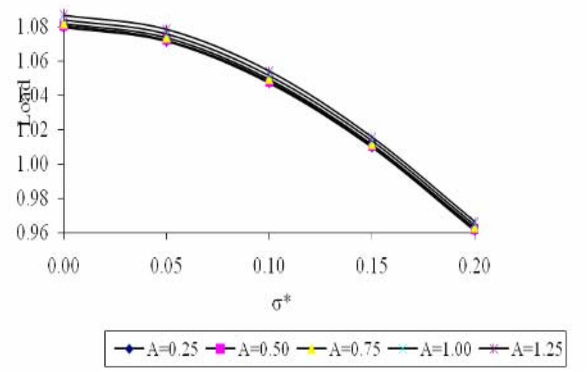


Figure: 12 Variation of load carrying capacity with respect to σ* and A

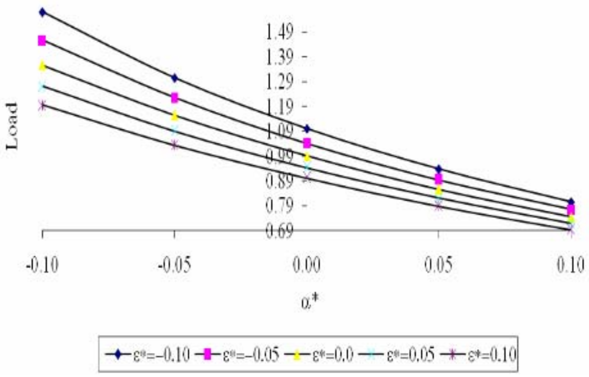


Figure: 13 Variation of load carrying capacity with respect to α* and ε*

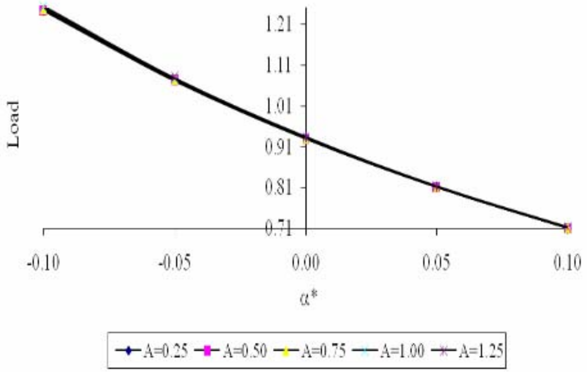


Figure: 14 Variation of load carrying capacity with respect to α* and A

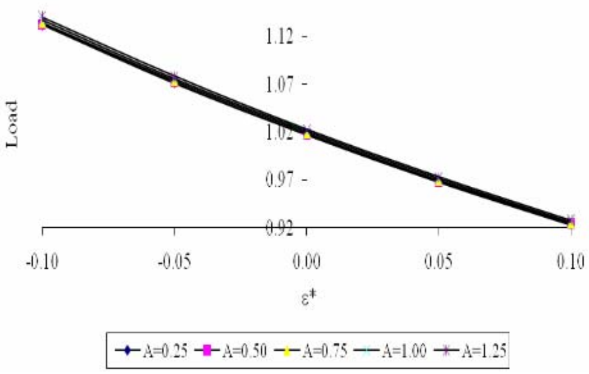


Figure: 15 Variation of load carrying capacity with respect to ε* and A

Lastly, in order to get the effect of the thickness ratio parameter one can have look at Figures (5, 9, 12, 14 and 15). It is observed from these figures that the load carrying capacity increase with respect to increasing values of thickness ratio parameter. Further, it is noticed that the effect of thickness ratio parameter is relatively sharp when large values of porosity are involved. Here the combined effect of variance and thickness ratio parameter mostly dominates that of the combined effect of skewness and thickness ratio parameter in increasing the load carrying capacity Figures (14-15). Moreover, there is a significant observation that with a proper selection of the values of μ* and A the porous magnetic fluid based squeeze film bearing with variable porous matrix thickness can be made to perform considerably better than a conventional porous bearing with an uniform porous matrix thickness in the case of negatively skewed roughness. Equation (10) clearly suggests that the trends of the response time are similar to that of the load carrying capacity.

4. CONCLUSIONS

This investigation makes it clear that the negative effect induced by the porosity, standard deviation and positive variance can be compensated up to a considerable extent by properly choosing the magnetization parameter and the thickness ratio parameter in the case of the negatively skewed roughness. In addition, besides providing an additional degree of freedom from design point of view the thickness ratio parameter plays an important role in reducing the adverse effect caused by transverse roughness and porosity. Therefore, while designing the bearing system we are required to account for roughness, even if, there is a strong magnetic field and suitable value of the thickness ratio parameter is chosen.

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NOMENCLATURE

h	Uniform film thickness
p	Pressure distribution
w	Load carrying capacity
H	Porous wall thickness
P	Dimensionless pressure
W	Load carrying capacity in dimensionless form
H_0	Porous wall thickness at $r = 0$
H_1	Porous wall thickness at $r = a$
ϕ	Permeability of the porous matrix
Δt	Response time
ΔT	Dimensionless response time
σ	Standard deviation
α	Variance
ε	Measure of Symmetry
σ^*	Standard deviation in dimensionless form
α^*	Non dimensional variance
ε^*	Dimensionless measure of Symmetry

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