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Magnetic fluid based squeeze film between porous elliptical plates

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Nomenclature

a - semimajor axis, m;
b - semiminor axis, m;
p - lubricant pressure, P;
$P = -\frac{h_0^3\, p}{\mu \dot{h}_0\, \pi\, a\, b}$ - dimensionless pressure;
w - load carrying capacity;
$W = -\frac{h_0^3\, w}{\mu \dot{h}_0\, \pi^2 a^2 b^2}$ - dimensionless load carrying capacity;
Δt - response time;
$\Delta T = \frac{w\, h_0^2\, \Delta t}{2\, \mu\, \pi^2 a^2 b^2}$ - dimensionless response time;
$k = b/a$ - the aspect ratio;
ϕ - permeability of porous facing;
$\psi = \frac{\phi H}{h_0^3}$ - dimensionless porosity ;
μ - absolute viscosity of the lubricant, Pa.s;
$\bar{\mu}$ - magnetic susceptibility, m^3/kg;
μ_0 - permeability of the free space, N/A^2
$\mu^* = -\frac{h_0^3 \mu_0 \bar{\mu}}{\mu \dot{h}_0}$ - magnetization parameter;
$X = x/a$, $Z = z/a$;
$X_1 = x_1/a$, $Z_1 = z_1/b$;
$\bar{h}_1 = h_1/h_0$, $\bar{h}_2 = h_2/h_0$.

1. Introduction

Archibald [1] analyzed the performance of a squeeze film between various geometrical configurations. Later on Wu [2, 3] investigated a squeeze film behavior for mainly, two types of geometries namely, annular and rectangular. Prakash and Viz [4] developed some aspects of the analysis incorporated in Wu [2, 3] and obtained the load carrying capacity ultimately leading to time height relation for squeeze film between porous plates. This article considered various geometries like circular, annular, elliptical and rectangular. Besides, infinitely long rectangular plates and conical plates were also subjected to investigation. Further, a comparison was made between the squeeze film behavior of various geometries of equivalent surface area, other parameters remaining the same and it was found that circular plates had the highest transient load carrying capacity. Murti [5] dealt with the performance of the squeeze film between curved circular plates, describing the film thickness by an exponential expression. Murti's analysis was further developed by Gupta and Vohra [6] who discussed the squeeze film behavior between curved annular plates.

All the above studies considered the conventional lubricant. The application of magnetic fluid as a lubricant was investigated by Verma [7]. The magnetic fluid considered in this paper consisted of fine magnetic grains coated with a surfactant and magnetically passive solvent. Subsequently, Bhat and Deheri [8] studied the squeeze film behavior between porous annular disks using a magnetic field oblique to the lower disk. This analysis of Bhat and Deheri [9] was improved by them in 1992 to analyze the behavior of a magnetic fluid based squeeze film between curved circular plates. Patel and Deheri [10] discussed the performance of a magnetic fluid based squeeze film between curved annular plates. They [11] also considered magnetic fluid based squeeze film between two curved plates lying along the surfaces determined by secant functions. Recently, Deheri, Patel and Patel [12] investigated the magnetic fluid based squeeze film behavior between rotating rough annular plates.

In this article we seek to analyze the configuration of Prakash and Viz [4] regarding elliptical plates in the presence of a magnetic fluid lubricant.

2. Analysis

The configuration of the bearing system is presented in Fig. 1.

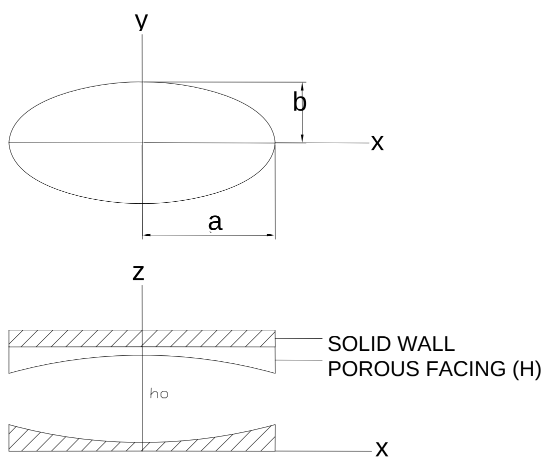

Fig. 1 Configuration of the bearing

It consists of two elliptical plates each of semimajor axis a and semiminor axis b. The upper plate has a porous facing of thickness H which is backed by a solid wall. It moves normally towards the lower plate with uniform velocity $\dot{h}_0 = \frac{dh_0}{dt}$ where h_0 is the central film thickness. Assuming axially symmetric flow of the magnetic fluid between the plates under an oblique magnetic field $\overline{M}$ whose magnitude vanishes at the boundary is given by

$$M^2 = ab\left(1 - \frac{x^2}{a^2} - \frac{z^2}{b^2}\right)$$

Now under the usual assumptions of hydrodynamic lubrication the associated Reynolds equation governing the film pressure p (Prakash and Viz [4], Bhat and Deheri [8], Patel and Deheri [10, 11]) comes out to be

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}\right)\left(p - \frac{\mu_0 \bar{\mu} M^2}{2}\right) = \frac{12\mu \dot{h}}{h^3 + 12\phi H}$$

Thus, the dimensionless film pressure P satisfies the equation

$$\left(\frac{\partial^2}{\partial X^2} + \frac{1}{k^2}\frac{\partial^2}{\partial Z^2}\right)\left(P - \frac{\mu^*\left(1 - X^2 - Z^2\right)}{2\pi}\right) = = -\frac{12}{\pi k\left(1 + 12\psi\right)} \tag{1}$$

Solving this equation with the concerned boundary conditions

$$P\left(X_1, Z_1\right) = 0 \quad ; \; X_1^{\,2} + Z_1^{\,2} = 1$$

we obtain the pressure distribution as

$$P = \left(\frac{\mu^*}{2\pi}\left(1 + \frac{1}{k^2}\right) + \frac{6}{\pi k\left(1 + \frac{1}{k^2}\right)\left(1 + 12\psi\right)}\right)\left(1 - X^2 - Z^2\right) \tag{2}$$

Then load carrying capacity of the bearing can be expressed in nondimensional form as

$$W = \frac{1}{\pi}\int_{X=-1}^{X=1}\int_{Z=-\sqrt{1-X^2}}^{Z=\sqrt{1-X^2}} P\, dX\, dZ =$$

$$= \left(\frac{\mu^*}{4\pi}\left(1 + \frac{1}{k^2}\right) + \frac{3}{\pi k\left(1 + \frac{1}{k^2}\right)\left(1 + 12\psi\right)}\right) \tag{3}$$

The time Δt taken by the upper plate to reach a film thickness h_2 starting from h_1 can be determined in dimensionless form from the equation

$$\Delta T = \frac{W}{6\alpha^2}\left[ln\left\{\frac{\left(1+\alpha\right)^2\left(\bar{h}^2 - \bar{h}\alpha + \alpha^2\right)}{\left(\bar{h}+\alpha\right)^2\left(1 - \alpha + \alpha^2\right)}\right\} + +2\sqrt{3}\, tan^{-1}\left\{\frac{\sqrt{3}\alpha\left(1 - \bar{h}\right)}{2\alpha^2 - \left(1 + \bar{h}\right)\alpha + 2\bar{h}}\right\}\right] \tag{4}$$

where $\alpha = \left(12\psi\right)^{1/3}$, $\psi = \frac{\phi H}{h_0^3}$ and $\bar{h} = \frac{h_1}{h_2}$.

3. Results and discussion

It is obvious from Eqs. (2) - (4) that the dimensionless pressure, load carrying capacity and response time depend on several parameters such as μ^*, ψ and the aspect ratio k. These parameters respectively, characterize the effect of magnetic fluid lubricant, porosity and dimensions of the bearing system. A close glance at these equations reveals that the dimensionless pressure and load carrying capacity get increased by

$$\frac{\mu^*}{2\pi}\left(1 + \frac{1}{k^2}\right), \text{ and } \frac{\mu^*}{4\pi}\left(1 + \frac{1}{k^2}\right)$$

respectively, as compared to that of the results of Prakash and Viz [4].

Figs. 2,3 present the variation of load carrying capacity with respect to magnetization parameter for various values of the aspect ratio and porosity respectively. These two figures indicate that the load carrying capacity increases with respect to the magnetization parameter while decreases with respect to porosity. Also, it is clearly seen that the increase of aspect ratio causes increased load

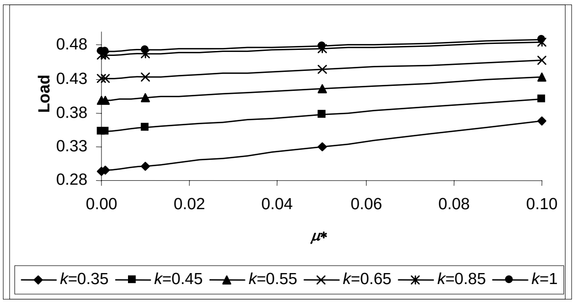

Fig. 2 Variation of load carrying capacity with respect to μ^* for various values of k where $\psi = 0.001$

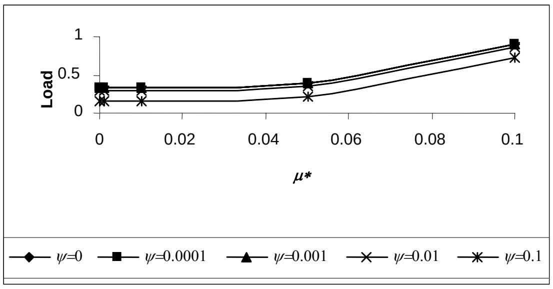

Fig. 3 Variation of load carrying capacity with respect to

μ^* for various values of ψ where $k = 0.4$

carrying capacity. Figs. 4, 5 deal with the variation of load carrying capacity with respect to the aspect ratio for various values of the magnetization parameter and porosity respectively. These two figures suggest that the load carrying capacity significantly increases with increasing magnetization parameter and aspect ratio while it decreases sharply with respect to the porosity. Lastly, in Figs. 6, 7 we have the distribution of load carrying capacity with respect to ψ for various values of μ^* and k respectively. Here also the load carrying capacity decreases considerably with respect to the porosity but the magnetization parameter marginally compensates this reduction. It is interesting to note that the porosity effects are negligible up to the order of approximately 0.001. This is probably due to the combined effect of magnetization and aspect ratio. In addition, it is observed that the response time follows the trends of load carrying capacity wherein, the aspect ratio plays a key role. This investigation reveals that the negative effect induced by the porosity can be neutralized to a considerable extent by the magnetization parameter for a suitable choice of the aspect ratio. Besides, this article tells that the aspect ratio must be given due consideration while designing the bearing system even at is the presence of magnetic fluid lubricant.

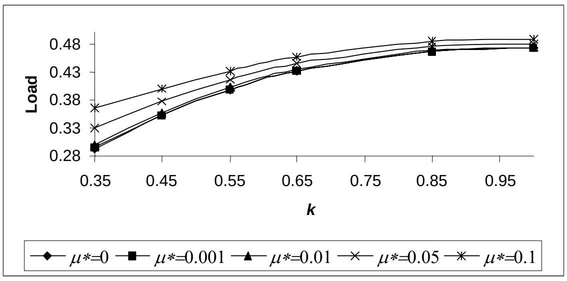

Fig. 4 Variation of load carrying capacity with respect to k for various values of μ^* where $\psi = 0.001$

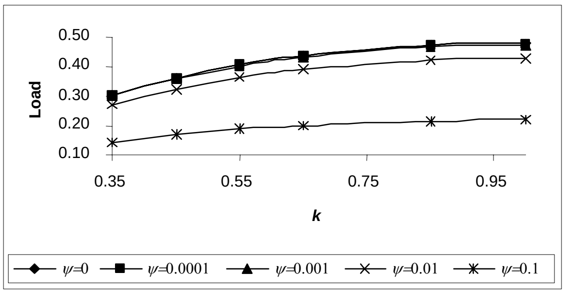

Fig. 5 Variation of load carrying capacity with respect to k for various values of ψ where $\mu = 0.01$

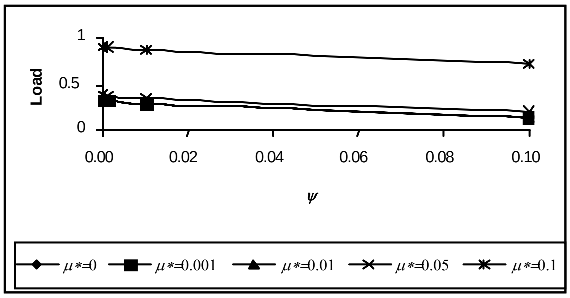

Fig. 6 Variation of load carrying capacity with respect to ψ for various values of μ^* where $k = 0.4$

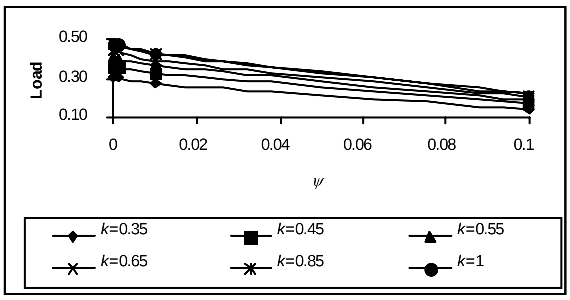

Fig. 7 Variation of load carrying capacity with respect to ψ for various values of k where $\mu = 0.01$

Acknowledgement

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MAGNETINIO SKYSČIO PLONASIENĖS PLĖVELĖS TARP ELIPSĖS FORMOS PLOKŠTELIŲ SUDARYMAS

R e z i u m ė

Straipsnyje tyrinėjamos ir analizuojamos plonasienės plėvelės, sudarytos tarp akytų elipsės formos plokštelių magnetiniu skysčiu, eksploatacines savybes. Čia kaip tepamoji medžiaga naudojamas magnetinis skystis, o išorinis magnetinis laukas yra pasviręs apatinės plokštelės atžvilgiu. Slėgio pasiskirstymui tarp plokštelių nustatyti, esant tam tikroms kraštinėms sąlygoms, buvo sprendžiamos Reinoldso lygtys. Tai panaudota nustatant sistemos laikomąją galią bei skaičiuojant jos reakcijos trukmę. Gauti rezultatai pateikti grafiškai. Pastebėta, kad sistemos laikomoji galia didėja didėjant įmagnetinimo parametrui, ypač esant pakankamai didelėms sistemos formos koeficiento vertėms. Akytumas iki tam tikrų verčių sistemos laikomąją galią veikia mažai, bet vėliau, jam didėjant, laikomoji galia labai sumažėja. Didėjant guolio formos koeficientui sistemos laikomoji galia didėja. Tai ypač ryšku esant santykinai didelėms įmagnetinimo parametro vertėms. Esant mažoms įmagnetinimo parametro vertėms vyrauja guolio formos koeficientas. Šis tyrimas rodo, kad guolio formos koeficientas yra be galo svarbus parametras net esant stipriam įmagnetinimo laukui. Straipsnyje parodoma, kad akytumo sukeltas neigiamas efektas gali būti kompensuojamas plačiame diapazone parenkant tinkamą guolio formos koeficiento ir įmagnetinimo parametro verčių kombinaciją.

Himanshu C. Patel, G. M. Deheri and Rakesh M. Patel

MAGNETIC FLUID BASED SQUEEZE FILM BETWEEN POROUS ELLIPTICAL PLATES

S u m m a r y

An attempt to study and analyze the performance of a magnetic fluid based squeeze film between porous elliptical plates has been made. The lubricant used here is a magnetic fluid and the external magnetic field is oblique to the lower plate. The associated Reynold's equation is solved with suitable boundary conditions in order to obtain pressure distribution. This is then used to get the load carrying capacity leading to the calculation of response time. The results are presented graphically. It is noticed that the load carrying capacity increases with respect to the magnetization parameter considerably for a sufficiently large range of aspect ratio. It is observed that although porosity effects are negligible up to a certain extent, load carrying capacity decreases significantly with respect to the porosity. Further, it is seen that the load carrying capacity increases with respect to the aspect ratio. This increase is quite considerable especially, when the magnetization parameter is relatively large. However, for lower values of the magnetization parameter the effect of aspect ratio dominates the effect of magnetization parameter. This investigation suggests that the aspect ratio has a very significant effect even if a strong magnetic field is applied. This article reveals that, the negative effect induced by the porosity can be compensated to a large extent by choosing a suitable combination of the aspect ratio and the magnetization parameter.

Гиманшу Ц. Пател, Г. М. Дегери, Ракеш М. Пател

СОЗДАНИЕ ТОНКОСТЕННОЙ ПЛЕНКИ МЕЖДУ ДВУМЯ ПОРИСТЫМИ ПЛАСТИНАМИ С ПОМОЩЬЮ МАГНИТНОЙ ЖИДКОСТИ

Р е з ю м е

В работе исследуется и анализируется эксплуатационные свойства тонкослойной пленки, образованной при помощи магнитной жидкости, находящейся между двумя пористыми пластинками эллиптической формы. Между пластинками в качестве смазочного материала используется магнитная жидкость и внешнее магнитное поле наклонено относительно нижней пластинки. С целью установления закона распределения давления между пластинками, при определенных граничных условиях решено уравнение Рейнольдса. Это было использовано при установлении несущей способности и времени реакции устройства. Полученные результаты представлены в графическом виде. Установлено, что несущая способность системы увеличивается при увеличении параметра намагничивания. Особенно это очевидно при больших значениях коэффициента формы системы. До определенного значения пористость пластинок на несущую способность системы оказывает незначительное влияние, однако при большем увеличении пористости упомянутый параметр уменьшается значительно. При увеличении коэффициента формы подшипника несущая способность системы увеличивается. Увеличение особенно проявляется при относительно больших значений параметра намагничивания. При малых значений параметра намагничивания доминирующую роль играет коэффициент формы подшипника. Исследование показывает, что коэффициент формы подшипника является особо важным параметром системы даже при сильном поле намагничивания. В статье раскрыт факт, что негативный эффект, вызванный пористостью, может быть компенсирован подбором комбинации коэффициента формы подшипника и параметра намагничивания одновременно.

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