ISSN 1330–0008
CODEN FIZAE4

EFFECT OF SLIP VELOCITY IN A POROUS SECANT-SHAPED SLIDER BEARING WITH A FERROFLUID LUBRICANT

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Received 6 July 2002; revised manuscript received 6 January 2003
Accepted 7 April 2003 Online 20 September 2003

We analysed a bearing with a secant shaped slider and with the stator having a porous facing backed by a solid wall, using a magnetic fluid lubricant flowing as per Jenkins model. Computed values of the bearing characteristics are displayed in tabular form. The load capacity, friction on the slider and the coefficient of friction decreased with increasing values of the slip parameter. The load capacity decreased and friction as well as the coefficient of friction increased with increasing values of the material parameter. However, the position of the centre of pressure did not significantly alter owing to the changes in slip parameter. But it slowly shifted towards the inlet when the material parameter increased.

PACS numbers: 81.40.Pq, 46.55.+d UDC 531.78
Keywords: magnetic fluid, lubrication, porous, secant shaped slider, Jenkins model, slip

1. *Introduction*

Prakash and Vij [1] and Ajwalia [2] studied slider bearings with conventional lubricants by taking the slider to be plane and secant-function shaped, respectively. Agrawal [3] and Bhat and Patel [4] extended the above analysis using a magnetic fluid lubricant. A magnetic fluid is a suspension of solid magnetic particles, like ferric oxide particles coated with a suitable surfactant, in a carrier liquid like diester. When an external magnetic field gradient is used, the particles within the liquid experience a force and move through the liquid imparting a drag to it causing it to flow, even in zero gravity regions. This property makes a ferrofluid useful in space ships. The advantage of a magnetic fluid lubricant over the conventional one is that the former can be retained at a desired location by an external magnetic field. Ram and Verma [5] extended the analysis of Ref. [3] using Jenkins model to describe the lubricant flow. Recently Shah and Bhat [6,7] and Patel and Deheri [8] studied the effect of magnetic fluid lubricant on the squeeze films between curved porous rotating circular plates, two curved annular plates and between two secant shaped plates, respectively. All the above investigators assumed that there was no slip at the interface of film region and porous region.

Beavers and Joseph [9] showed that such assumption need not hold at the nominal boundary of a naturally permeable material like foam. Sparrow et al. [10] gave simplified boundary conditions in the above case.

Cameron and McEttles [11] mention that secant shape wins over the linear or exponential shape and is a most useful introduction to the parabolic or journal shape. Moreover, owing to elastic, thermal or uneven wear effects an exponential or linear shape is likely to take a secant shape.

So we developed and studied the mathematical model of the effect of slip velocity on a porous secant shaped slider bearing with a ferrofluid lubricant, using Jenkins flow of fluid which takes care of material constant.

2. Analysis

The bearing shown in Fig. 1 consists of a stator lying along the x-axis and having a porous matrix of uniform thickness H^*, and a secant shaped slider moving with a uniform velocity U in the x-direction. The bearing has length A and breadth C, with $A \ll C$. The film thickness h is defined by

$$h = h_1 \sec\frac{\pi(A-x)}{2A}, \qquad 0 < x \leq A, \tag{1}$$

where h_1 is the minimum value of h. The applied magnetic field $\vec{B}$ is inclined to the x-direction at an angle ϕ which is determined as in Ref. [5] and its magnitude B is given by

$$B^2 = Kx(A-x), \tag{2}$$

K being a quantity chosen to suit the dimensions of both sides. Such a magnetic field was used in Refs. [3] and [5] because it attained a maximum at the middle of the bearing. Consequently, the magnetic pressure also was maximum there. According to Ref. [5], the basic equation governing the lubricant flow in the film region is

$$\frac{\partial^2 u}{\partial z^2} = \frac{1}{\zeta\left[1-\rho\alpha^2\overline{\mu}B/(2\zeta)\right]}\frac{\partial}{\partial x}\left(p-\frac{1}{2}\mu_0\overline{\mu}B^2\right), \tag{3}$$

where u, ζ, ρ, α^2, $\overline{\mu}$, p and μ_0 are, respectively, the x-component of the velocity of the film fluid, fluid viscosity, fluid density, material constant, magnetic susceptibility of the fluid particles, film pressure and the magnetic permeability of free space.

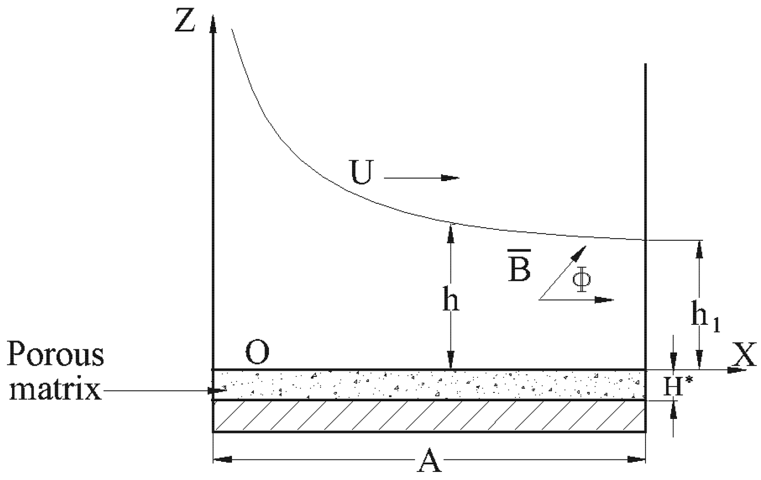

Fig. 1. Secant-shaped porous slider bearing.

We solve Eq. (3) under the conditions [10]

$$u = \left(\frac{1}{s}\frac{\partial u}{\partial z}\right)_{z=0} \tag{4}$$

when $z = 0$, and $u = U$ when $z = h$, s being the slip constant. The value of u obtained is substituted in the integral from of the continuity equation for film fluid.

By assuming that the z-components of velocities of fluid in the film and porous regions are continuous at the surface $z = 0$, we obtain Reynolds type equation

$$\frac{\mathrm{d}}{\mathrm{d}x}\left\{\left[12kH^* + \frac{h^3(4+sh) - 3\rho\alpha^2\overline{\mu}ksh^2B/\zeta}{(1+sh)\big[1-\rho\alpha^2\overline{\mu}B/(2\zeta)\big]}\right]\frac{\mathrm{d}}{\mathrm{d}x}\big(p - \frac{1}{2}\mu_0\overline{\mu}B^2\big)\right\}$$
$$= 6\zeta U\frac{\mathrm{d}}{\mathrm{d}x}\left(\frac{h(2+sh) - \rho\alpha^2\overline{\mu}ksB/\zeta}{1+sh}\right), \tag{5}$$

k being the permeability of porous matrix. Using Eqs. (1), (2) and the dimensionless quantities

$$X = \frac{x}{A}, \qquad \Psi = \frac{kH^*}{h_1^3}, \qquad \overline{h} = \frac{h}{h_1}, \qquad \overline{s} = sh_1,$$
$$\beta^2 = \frac{\rho\alpha^2\overline{\mu}\sqrt{K}A}{2\zeta}, \qquad \overline{p} = \frac{h_1^2 p}{\zeta UA}, \qquad \mu^* = \frac{\mu_0\overline{\mu}KAh_1^2}{\zeta U}, \qquad \gamma^* = \frac{6k}{h_1^2}, \tag{6}$$

Eq. (5) takes the form

$$\frac{\mathrm{d}}{\mathrm{d}X}\left\{D\frac{\mathrm{d}}{\mathrm{d}X}\left[\overline{p}-\frac{1}{2}\mu^* X(1-X)\right]\right\} = \frac{\mathrm{d}E}{\mathrm{d}X}\,. \tag{7}$$

Here

$$D = 12\Psi + \frac{\overline{h}^3(4+\overline{s}\overline{h}) - \gamma^*\beta^2\overline{s}\overline{h}^2\sqrt{X(1-X)}}{(1+\overline{s}\overline{h})(1-\beta^2\sqrt{X(1-X)})}, \tag{8}$$

$$E = \frac{6\overline{h}(2+\overline{s}\overline{h}) - 2\beta^2\overline{s}\gamma^*\sqrt{X(1-X)}}{1+\overline{s}\overline{h}} \tag{9}$$

and

$$\overline{h} = \sec\frac{\pi(1-X)}{2}, \qquad 0 < X \le 1. \tag{10}$$

3. Solutions

Since the pressure is negligible at the inlet and outlet of the bearing compared to the inside pressure, we use the boundary conditions

$$\overline{p} = 0, \qquad \text{when} \qquad X = 0, 1, \tag{11}$$

solve Eq. (7) and obtain the dimensionless pressure $\overline{p}$ as

$$\overline{p} = \frac{1}{2}\mu^* X(1-X) + \int_1^x \frac{E-Q}{D}\,\mathrm{d}X\,, \tag{12}$$

where

$$Q = \frac{\int_0^1 \frac{E}{D}\,\mathrm{d}X}{\int_0^1 \frac{1}{D}\,\mathrm{d}X}. \tag{13}$$

The load capacity W of the bearing, friction force F on the slider, coefficient of friction f and the x-coordinate $\overline{X}$ of the centre of pressure can be expressed in dimensionless forms as

$$\overline{W} = \frac{h_1^2 W}{\zeta U A^2 B} = \frac{\mu^*}{12} - \int_0^1 X\frac{E-Q}{D}\,\mathrm{d}X\,, \tag{14}$$

$$\overline{F} = \frac{h_1 F}{\zeta UAB} = \int_0^1 \left[\frac{\overline{s}}{1+\overline{s}\overline{h}} + \frac{\overline{h}(2+\overline{s}\overline{h})(E-Q)}{2D(1+\overline{s}\overline{h})(1-\beta^2\sqrt{X(1-X)}} \right] \mathrm{d}X \,, \tag{15}$$

$$\overline{f} = \frac{Af}{h_1} = \frac{\overline{F}}{\overline{W}} \,, \tag{16}$$

$$Y = \frac{\overline{X}}{A} = \frac{1}{\overline{W}} \left[\frac{\mu^*}{24} - \frac{1}{2} \int_0^1 X^2 \frac{E-Q}{D} \mathrm{d}X \right] . \tag{17}$$

4. Results and discussion

Dimensionless load capacity $\overline{W}$, friction $\overline{F}$, coefficient of friction $\overline{f}$ and the position of the centre of pressure Y are given by Eqs. (14)–(17) and their computed values for different values of the slip parameter $1/\overline{s}$ and the material parameter β^2 are displayed in Tables 1 – 4.

Table 1 shows that $\overline{W}$ decreases when $1/\overline{s}$ or β^2 increases. From Table 2, $\overline{F}$ decreases when $1/\overline{s}$ increases and it increases when β^2 increases. It is seen from

TABLE 1. Values of dimensionless load capacity $\overline{W}$ for different values of the slip parameter $1/\overline{s}$ and material parameter β^2 for $\Psi = 0.001$, $\mu^* = 1$, $\gamma^* = 0.3$.

$1/\overline{s}$	β^2				
	0.02	0.2	0.4	0.8	1.6
0.02	0.1984	0.1908	0.1821	0.1641	0.1236
0.03	0.1965	0.1890	0.1805	0.1628	0.1229
0.04	0.1948	0.1874	0.1790	0.1615	0.1223

TABLE 2. Values of dimensionless friction $\overline{F}$ for different values of $1/\overline{s}$ and β^2 for $\Psi = 0.001$, $\mu^* = 1$, $\gamma^* = 0.3$.

$1/\overline{s}$	β^2				
	0.02	0.2	0.4	0.8	1.6
0.02	0.7666	0.7717	0.7782	0.7945	0.8591
0.03	0.7602	0.7652	0.7716	0.7876	0.8513
0.04	0.7539	0.7589	0.7652	0.7810	0.8438

TABLE 3. Values of dimensionless coefficient of friction $\overline{f}$ for different values of $1/\overline{s}$ and β^2 for $\Psi = 0.001$, $\mu^* = 1$, $\gamma^* = 0.3$.

$1/\overline{s}$	β^2				
	0.02	0.2	0.4	0.8	1.6
0.02	3.865	4.045	4.272	4.840	6.953
0.03	3.868	4.048	4.274	4.838	6.925
0.04	3.871	4.050	4.274	4.834	6.897

TABLE 4. Values of dimensionless position of the centre of pressure Y for different values of $1/\overline{s}$ and β^2 for $\Psi = 0.001$, $\mu^* = 1$, $\gamma^* = 0.3$.

$1/\overline{s}$	β^2				
	0.02	0.2	0.4	0.8	1.6
0.02	0.5620	0.5605	0.5586	0.5538	0.5349
0.03	0.5612	0.5597	0.5578	0.5530	0.5344
0.04	0.5605	0.5590	0.5571	0.5523	0.5339

Table 3 that $\overline{f}$ increases when β^2 increases. When $1/\overline{s}$ increases, $\overline{f}$ increases or decreases depending on whether $\beta^2 < 0.4$ or $\beta^2 > 0.4$. Table 4 shows that the position Y of the centre of pressure does not change significantly owing to changes in $1/\overline{s}$. But the centre of pressure shifts towards the inlet when β^2 increases. The present analysis reduces to the analysis of Refs. [4] and [2] by setting $1/\overline{s} = \beta^2 = 0$ and $1/\overline{s} = \beta^2 = \mu^* = 0$, respectively.

5. Conclusions

The secant shaped slider stands separate from the inclined plane, exponential and convex shaped slider because the former is explicitly independent of the ratio of the maximum film thickness to the minimum film thickness while the latter are not. Moreover, we believe that the above obtained nature of various characteristics are more realistic because Jenkins model also includes property of the porous material.

Acknowledgements

The authors are grateful to the referee for his valuable comments.

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UČINAK BRZINE POSMIKA U POROZNOM LEŽAJU S KLIZAČEM U OBLIKU SEKANTE I S FEROFLUIDNIM MAZIVOM

Analiziramo ležaj s klizačem u obliku sekante u kojemu je stator porozan s čvrstom podlogom, a rabi magnetsko tekuće mazivo koje teče prema Jenkinsovom modelu. Izračunate vrijednosti značajki ležaja prikazuju se u tablicama. Nosivost, trenje klizača i koeficijent trenja smanjuju se pri povećanju parametra posmicanja, a nosivost i trenje smanjuju se pri povećanju parametra materijala. Položaj središta tlaka ne mijenja se bitno zbog promjena parametra posmicanja, ali se pomalo pomiče prema ulazu pri povećanju parametra materijala.