Performance Analysis of Porous Journal Bearing with Surface Roughness and Thermal Effects

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Abstract : The influence of surface roughness on performance characteristics of porous journal bearing is studied by considering thermal effect. The modified Reynolds equation governing the pressure field within fluid-film is developed using Patir and Cheng flow factors and Darcy equation to include the 3D surface roughness and thermal effects. The energy equations for both fluid-film and porous media are also derived. The modified Reynolds and energy equations are simultaneously solved using finite element method. The performance characteristics are obtained by using the matched pressure field that obtained from the simultaneous solution of Reynolds equation. The load carrying capacity, fluid-film stiffness, damping coefficients and stability threshold speed margin of smooth and rough porous journal bearings were shown to reduces as permeability of porous matrix increases. The reduced performance characteristics of porous journal bearing due to increased permeability were shown to be compensated by the proper roughness. Stationary roughness and transverse roughness pattern combination was shown to provide maximum enhancement for the circumferential and axial pressure distribution, load carrying capacity, fluid-film stiffness and damping coefficients.

1. INTRODUCTION

The conventional plane metal journal bearings are replaced by porous journal bearings due to their favorable self-lubricating properties. From last few decades, considerable amount of research works have been made in the area of porous journal bearings. Notably among these, some available studies [1-3] considered the influence of couple stress fluids, flexibility of porous liner and thermal effects on porous bearing performances without considering roughness effects. Only few studies [4-7] exhibit the influence of roughness on porous journal bearing performances using stochastic Reynolds equation which is limited to one-dimensional roughness patterns. Since these are the limiting cases of roughness found in real engineering surfaces, consideration of area distributed 3D surface roughness effects on porous journal bearing performances is most essential. Further, the studies [4-7] have been considered the surface roughness effect without considering thermal effects. Therefore, the present study considered the combined influence of surface roughness and thermal effects on performance characteristics of porous journal bearing.

2. Mathematical Models

For the fluid-film region of porous journal bearing system, the modified form of Reynolds equation is derived using Patir and Cheng [8] flow factors and Darcy equation. It is expressed in non-dimensional form as

$$\frac{\partial}{\partial\alpha}\left[\phi_x\left(\bar{h}^3\bar{F}_2+\frac{\bar{k}}{\bar{\mu}}\frac{\bar{F}_1}{\bar{F}_0}\bar{h}\right)\frac{\partial\bar{p}}{\partial\alpha}\right]+\frac{\partial}{\partial\beta}\left[\phi_y\left(\bar{h}^3\bar{F}_2+\frac{\bar{k}}{\bar{\mu}}\frac{\bar{F}_1}{\bar{F}_0}\bar{h}\right)\frac{\partial\bar{p}}{\partial\beta}\right]=\Omega\frac{\partial}{\partial\alpha}\left[\left(1-\frac{\bar{F}_1}{\bar{F}_0}\right)\bar{h}_T\right]+\frac{\Omega}{\Lambda}\frac{\bar{F}_1}{\bar{F}_0}\frac{\partial\phi_s}{\partial\alpha}+\Omega\frac{\partial\bar{h}_T}{\partial\bar{t}} \quad (1)$$

The 3D energy equation in fluid domain is expressed in non-dimensional form as

$$\bar{h}^2\left[\bar{u}\frac{\partial\bar{T}_f}{\partial\alpha}+\bar{v}\frac{\partial\bar{T}_f}{\partial\beta}+\frac{\tilde{w}}{\bar{h}}\frac{\partial\bar{T}_f}{\partial\bar{z}}\right]=\bar{P}_f\left[\frac{\partial^2\bar{T}_f}{\partial\bar{z}^2}\right]+\bar{D}_f\bar{\mu}\left[\left(\frac{\partial\bar{u}}{\partial\bar{z}}\right)^2+\left(\frac{\partial\bar{v}}{\partial\bar{z}}\right)^2\right] \quad (2)$$

For a thin walled porous bush, the energy equation is expressed in non-dimensional form as

$$\bar{p}_p\left[\bar{u}^*\frac{1}{\bar{r}}\frac{\partial\bar{T}_p^*}{\partial\alpha}+\bar{v}^*\frac{\partial\bar{T}_p^*}{\partial\beta}\right]=\bar{k}_{ep}\left[\frac{\partial^2\bar{T}_p^*}{\partial\bar{r}^2}+\frac{1}{\bar{r}}\frac{\partial\bar{T}_p^*}{\partial\bar{r}}+\frac{1}{\bar{r}^2}\frac{\partial^2\bar{T}_p^*}{\partial\alpha^2}+\frac{\partial^2\bar{T}_p^*}{\partial\beta^2}\right]$$

3. Results and Discussion

The results showing the influence of surface roughness and thermal effects are computed for the following non-dimensional operating and geometric parameters of the porous bearing.

Aspect ratio, $\lambda = 1.0$; Eccentricity, ε = 0.6; Speed parameter, Ω = 17.404; Permeability parameters, $\bar{k}$ =1E-0.8 to 1E+00; Pecklet number for porous bush and fluid-film, $\bar{P}_p$ =1464.478 and $\bar{P}_f$ =1.675; Fluid film thickness ratio, $\Lambda\bar{h}$ =3. As seen from Fig. 1, the circumferential pressure increases as the permeability parameter increases in stationary, $\overline{V}_{rj} = 0$ (i.e. smooth journal and rough porous bush) type rough bearings with transverse roughness pattern ($\gamma = 1/6$) when thermal effect is considered. The opposite trend is observed in moving, $\overline{V}_{rj} = 1$ (i.e. rough journal and smooth porous bush) and two-sided, $\overline{V}_{rj} = 0.5$ (both journal and porous bush rough) with the same transverse roughness pattern. However, when thermal effect is not considered the circumferential pressure of both smooth and rough bearings reduces as the permeability of bearing increases (Figure not presented). Stationary roughness type bearings with transverse roughness pattern provides maximum enhancement to the circumferential pressure distribution.

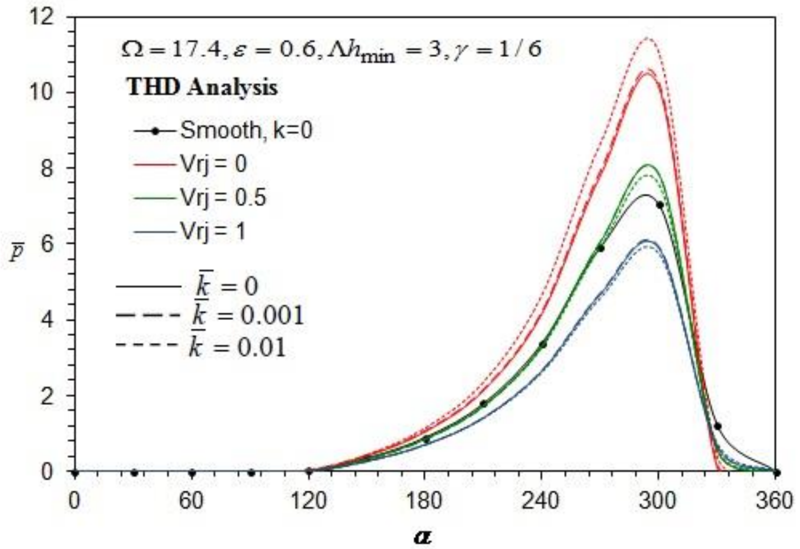

Fig. 1- Circumferential pressure distribution

Fig. 2 shows the variation of load carrying capacity with permeability parameter. Except moving type rough bearing with isotropic ($\gamma = 1$) and longitudinal ($\gamma = 6$) roughness pattern combination, all other roughness combinations considered in this study provides enhanced load carrying capacity than that of a smooth bearing for all values of permeability parameters considered. These roughness combinations provide the same load carrying capacity as that of smooth bearing provides at permeability 0.001 even for higher permeability parameters also (i.e. at point A and B). The reduction in load carrying capacity of a smooth porous journal bearing due to permeability can be compensated by the two-sided type and stationary type rough bearings that having either transverse or longitudinal roughness patterns.

As shown in Fig. 3, the fluid-film stiffness coefficient ($\overline{S}_{xx}$) is constant up to permeability parameter 0.01 and then reduces as permeability parameter increases above 0.01 for all the surface roughness orientation and variance ratios. The stationary and two sided type bearings are observed provide the same value of $\overline{S}_{xx}$ as that of smooth porous bearing provides at permeability 0.01 even for higher permeability parameter values also. The stationary type bearing provides maximum enhancement of $\overline{S}_{xx}$ as compared to two-sided type roughness irrespective of its roughness orientations. The other fluid-film stiffness and damping coefficients were found to show similar trend as that of $\overline{S}_{xx}$. The stability threshold speed was found to increases as the permeability parameter increases in both smooth and rough bearings (these results are not shown).

4. Conclusions

1. When thermal effect is not considered, the performance of both smooth and rough porous journal bearings reduces as the permeability of porous matrix increases while opposite trend is observed in smooth and stationary rough bearing when thermal effect is considered.
2. The proper roughness combinations provide the same performance characteristics as that of smooth bearing provide with smaller permeability even at higher permeability parameters.

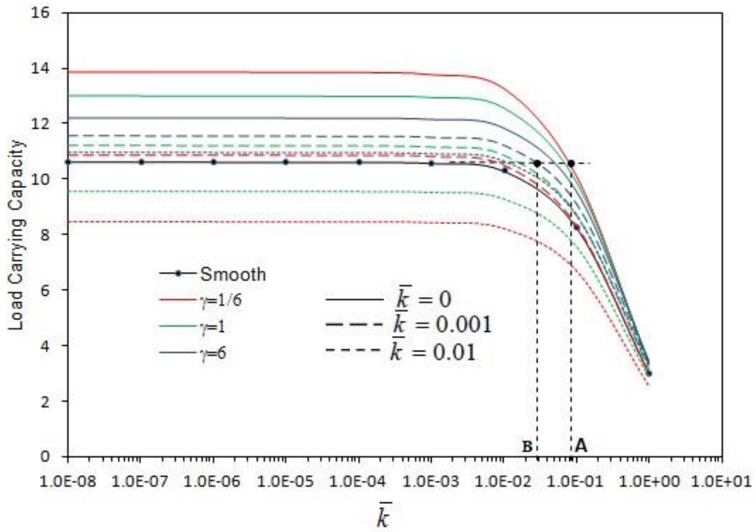

Fig. 2- Load carrying capacity

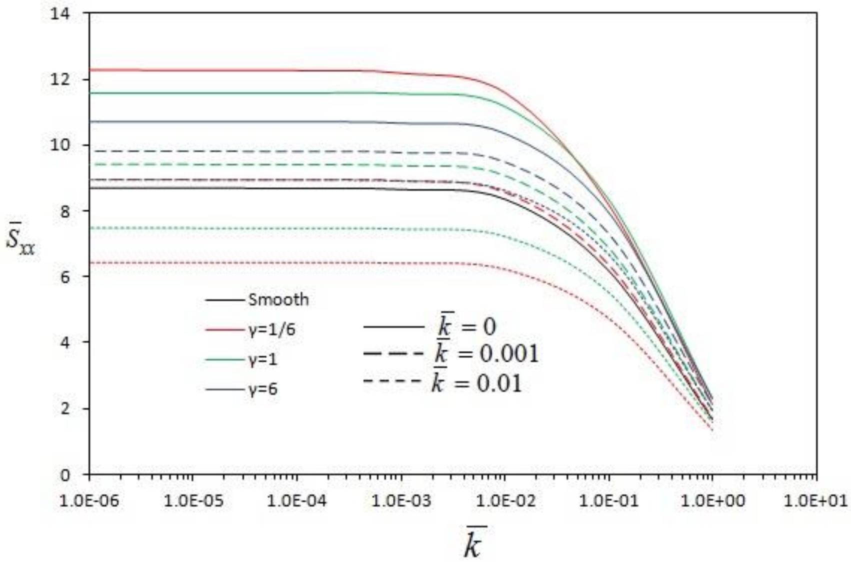

Fig. 3- Fluid-film stiffness coefficient

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