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A comparative study of full and partial textured hybrid orifice compensated circular thrust pad bearing system

Satish C. Sharma [a], Saurabh K. Yadav [b]

[a] Department of Mechanical and Industrial Engineering, Tribology Laboratory Indian Institute of Technology, Roorkee 247667, India
[b] Automobile Engineering Department, Graphic Era University, Dehradun, India

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This work concern with the performance of hybrid circular thrust pad bearing having partial and full textured surface, operating with power law lubricant has been studied. The governing Reynolds equation is non-linear with pressure. Finite element method with JFO boundary conditions has been implemented to obtain fluid film pressure on the bearing surface and cavitation zone. The numerically simulated results reveal that, among the different non-Newtonian lubricants, the dilatant one provides the minimum value of frictional power loss. Results show that surface texture and the behavior of lubricant significantly changes the frictional power loss and other performance parameters. It is expected that the result obtained will be very much quite useful for bearing designer and academic community.

1. Introduction

In the recent times, due to growing power prices and rising demand of energy efficient machinery, researchers have carried many studies to reduce friction coefficient or friction in bearing elements. Friction coefficient in the fluid film bearings is directly proportional to the frictional power consumption. The frictional power loss in the bearings results in rise of the lubricant oil temperature which may ultimately lead to failure of the bearing. During last decade, Laser Surface Texturing (LST) emerged as a viable option to reduce the friction coefficient in fluid film bearings [1–5]. This technique is used to create small cavities on the bearing surface which in turns acts as microbearing on the bearing surface. It has been observed by experimental and theoretical studies that these micro-dimples increase the load carrying capacity and have a positive influence on the coefficient of friction and wear resistance [2,4–8].

Influence of surface texture on the bearing performance has been studied by many researchers in recent years due to their potential ability to reduce friction coefficient, enhance fluid film reaction and reduce wear in bearings. The first study related to surface texture was published in 1966 by Hamilton [9]. The study however could not gain importance during the early days. Later in 1996, Etsion et al. [10] investigated the influence of surface texture on the fluid film pressure distribution. Since 1996 Etsion and co-workers [1,2,4–7] have been studying the influence of surface texture on the friction coefficient and load carrying capacity. Their study showed that each micro-dimple on the textured surface acts as a micro-hydrodynamic bearing and micro reservoir of lubricant. It was observed that the value of friction coefficient of bearing decreases significantly due to increase in fluid film thickness. In 2003 Brizmer et al. [2] analyzed the full textured and partial textured thrust bearing. They showed that the load carrying capacity of partial textured thrust bearing is more than load carrying capacity of full textured thrust bearing. It shows that optimum texturing is required to get the maximum hydrodynamic effect. Etsion and co-workers [2,4,11] carried out a study to generate the microdimples by using the Laser Texturing (LST) technique. They performed experiments by developing theoretical models to examine the effect of LST in thrust bearings. piston rings and mechanical seals etc. They showed that LST substantially reduced the friction coefficient when compared to smooth surfaces. Tala-Ighil et al. [12] theoretically analyzed hydrodynamic journal bearing by using cylindrical textured shape. Their results revealed that important bearing characteristics gets significantly improved by surface texturing. Brizmer and Kligeman [2] examined the potential use of laser surface texturing on the hydrodynamic thrust bearing system. They considered a regular geometry of microdimple with preselected diameter, area density and depth. In their investigation, it was observed that the optimum selection of parameter of LST give rise to the maximum fluid film reaction. Since the fluid film reaction of thrust bearing is an important criterion from the view point of design. Hence, many studies have been carried out to predict the effect of surface texture on load

E-mail addresses: sshmefme@iitr.ac.in (S.C. Sharma), saurabhme.iitr@gmail.com (S.K. Yadav).

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Nomenclature

Symbol	Name (Units)
A	Area (m^2)
r_p	Base radius of Dimple (m)
Q	Bearing flow (m^3/s)
X, Y, Z	Cartesian system of coordinates (m)
ρ_c	Effective lubricant density in cavitation region (kg/m^3)
ρ	Lubricant Density in fluid film region (kg/m^3)
$\overline{\delta}$	Dimensionless dimple radius (dimensionless)
h_p	Dimple depth (m)
C	Fluid film damping coefficient (N s/m)
p	Fluid film pressure (N/m^2)
S	Fluid film stiffness coefficient (N/m)
P_{fric}	Frictional Power loss (N m/s)
x_l, z_l	Local Cartesian coordinates of dimple (m)
h	Local fluid film thickness (m)
h_0	Minimum clearance (m)
n_p	Number of pockets (dimensionless)
r_o	Outer radius of thrust pad (m)
p_{oc}	Pocket pressure $(\frac{\partial h}{\partial t}) \neq 0$ (N/m^2)
h_r	Reference fluid film thickness (m)
μ_r	Reference viscosity of the lubricant (Pa-s)
Q_R	Restrictor flow (m^3/s)
F_0	Resultant fluid film reaction $(\frac{\partial h}{\partial t}) = 0$ (N)
F	Resultant fluid film reaction $(\frac{\partial h}{\partial t}) \neq 0$ (N)
p_s	Supply pressure (N/m^2)
t	Time (s)
n_t	Total number of finite elements (dimensionless)
n_l	Number of nodes in a quadrilateral element (dimensionless)
z	Coordinates along the fluid film thickness (m)
μ	Viscosity of the lubricant, (Pa-s)
a	Radius of capillary (m)
k	Power law index (dimensionless)
n	Total number of nodes (dimensionless)

Non-dimensional parameters

$\overline{C}$	$\frac{C h_f^3}{r_o^4 \mu}$
$\overline{C}_{s1}$	$\frac{3\pi d_o^2 \mu}{2h_r^3}.\Psi_d \left(\frac{2}{\rho.p_s}\right)^{1/2}$(Orifice)
$\overline{C}_{s2}$	$\overline{C}_{s1}/6$
$\overline{F}_0$	$F_0/r_o^2 p_s$
$\overline{F}$	$F/r_o^2 p_s$
$\overline{h}$	h/h_r
$\overline{h}_p$	h_p/h_r
$\overline{A}$	A_b/A_c
$\dot{\overline{h}}$	$\frac{\partial \overline{h}}{\partial \overline{t}}$
$\overline{p}$	p/p_s
$\overline{Q}_R$	$\frac{12\mu}{p_s h_r^3} Q_R$
$\overline{Q}$	$\frac{\mu}{p_s h_r^3} Q$
$\overline{\dot{\gamma}}$	$\dot{\gamma}/(h_r p_s / r_o \mu)$
$\overline{P}_{fric}$	$\frac{P_{fric} c}{p_s \omega_j r^2}$
$\overline{S}$	$\frac{12\mu}{p_s h_r^3} Q_r$
$\overline{r}_p$	r_p/r_o
$\overline{\Omega}$	$\frac{r_o^2 \mu \omega}{p_s \times h_r^2}$
Λ_{Cav}	ρ_c/ρ
α	X/r_o
β	Y/r_o
$\bar{t}$	$t/\left(\frac{\mu\, r_o^2}{h_r^2 p_s}\right)$
$\bar{z}$	z/h
$\overline{\mu}$	μ/μ_r

Subscripts and superscripts

–	Corresponding dimensionless parameter
0	Steady state equilibrium
b	Bearing
e	*eth* element
oc	Pocket
R	Restrictor
s	Supply

Finite element matrices

Symbol	Name (Type)
$[\overline{\mathbf{F}}]$	Global Fluidity Matrix (Square)
$\{\overline{\mathbf{p}}\}$	Fluid film pressure (Column)
$\{\overline{\mathbf{Q}}\}$	Nodal lubricant Flow Vector (Column)
$[\overline{\mathbf{R}}_t]$	Squeeze terms (Column)

carrying capacity. Etsion et al. [7] studied a laser textured hydrodynamic thrust bearing and showed that partial textured surface had more load carrying capacity than that of fully textured. Researchers have considered the optimization of micro-dimples parameters for automotive components including bearings and piston rings [4,6,7]. Some available studies showed that many other factors such as dimple orientation, dimple density and aspect ratio has a profound effect on the load carrying capacity and friction coefficient. Qui and Khonsari [13] studied fully textured hydrodynamic thrust bearing by using FDM and JFO boundary conditions. They studied the influence of surface roughness and dimple geometry on the performance of textured hydrodynamic thrust bearing. Wang et al. [14] studied the effect of dimple's shape and orientation on friction drag reduction and concluding that due to lack of effect of this, it may be attributed to the small contact area, compared with the dimple diameter.

The analysis of a bearing having a textured surface is a quite difficult task because the numerical simulation of the Reynolds equation requires a very fine FEM or FDM mesh near the dimple geometry and this type of mesh makes the computation difficult [13,15,16]. Therefore, many methods have been proposed by several researchers to minimize the computational time. Qui and Khonsari [13] analyzed full textured hydrodynamic thrust bearing. Due to symmetric boundary conditions, they considered only 1/38th model of the thrust pad. Kraker et al. [15] proposed a multiscale modeling method to analyze journal bearing. They