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Two lobe non-recessed roughened hybrid journal bearing – A comparative study

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ABSTRACT

The present paper examines the influence of surface roughness on the performance of two lobe hybrid journal bearing. The performance characteristics of two lobe journal bearings compensated with different types of flow control devices such as orifice, capillary, constant flow valve and slot restrictors, have been presented for different forms of roughness patterns such as transverse, longitudinal, isotropic and smooth surface. The results of the study indicate that roughness orientation significantly affects the performance of bearing system. Further, results indicates that, a proper selection of roughness pattern parameter, offset factor and compensating device is essential to enhance the bearing performance.

1. Introduction

Over the last couple of decades, non-recessed circular hybrid journal bearings have gained tremendous popularity over recessed bearings due to their improved performance characteristics at low and high speed. As a result of this, hole entry and slot entry hybrid journal bearings are widely employed in many engineering applications [1–4].

The performance of externally pressurized bearing is greatly dependent on the type of flow control device as it supplies the lubricant under pressure. Consequently, different restrictors such as orifice, constant flow valve, capillary, slot entry etc. have been developed and employed in bearing systems. However, under stringent and critical operating condition, the bearings are often subjected to variations in stiffness and load. Under such circumstances, choice of a suitable flow controlling device becomes critical. Further, the accuracy in manufacturing of restrictors for hole entry and slot entry bearing plays vital role because of required precision in tolerance on the restrictor dimensions. Many studies concerning the influence of different flow control devices on bearing performance have been reported in the published literature [1–2,5–6]. The available studies mainly concern about the circular recessed/non-recessed and non-circular multirecess hybrid journal bearing systems and noticeably point out that the selection and type of compensating device play a vital role in enhancing of the bearing performance. The circular journal bearings are prone to oil whirl instability. However, this problem can be suppressed by the use of multilobes in bearing designs [7,9–16]. Among the different types of multilobe journal bearings, two lobe journal bearing configuration is more popular owing to its better damping and anti-whirl capabilities. As a result of this, several experimental and theoretical studies related to two lobe bearing configurations have been reported in the published literature [9,11–14]. Lund and Thomsen [9] exhaustively studied the elliptical hydrodynamic journal bearing and provided vital information on the values of length to diameter ratios. Malik [12] presented an analytical study of lobed journal bearing and provided the design data, considering various aspects over the broad range of load condition. More recently, Rahmatabadi et al. [15] carried out the study of two lobe, three lobe and four-lobe hydrodynamic bearings operated with micropolar lubricants. It was reported that the use of micropolar lubricant enhances the static performance characteristics. These days, many studies concerning multilobe hybrid journal bearing systems have been reported in the published literature [16–21,22–24]. An experimental study on water lubricated multi-recessed bearing was carried out by San Andres [16]. He investigated the combined effect of geometric asymmetry and recess position on the dynamic coefficients and whirl frequency. Ghosh and Satish [17,18] carried out a study to determine the dynamic performance characteristics of 3-lobe and 4-lobe recessed hybrid journal bearings for different values of offset factors using the small amplitude perturbation method. The result of their study indicates that the non-circular hybrid bearings with a ratio of maximum to minimum clearance ratio greater than one provide improved stability than the circular bearing configuration.

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Nomenclature

a_b bearing land width, mm
c radial clearance, mm
e journal eccentricity, mm
E Young's modulus of elasticity, $\mathrm{N\,mm^{-2}}$
F fluid film reaction $(\partial h/\partial t \neq 0)$, N
F_x, F_z components of fluid film reactions in X and Z direction $(\partial h/\partial t \neq 0)$, N
F_o fluid film reaction $(\partial h/\partial t = 0)$, N
C_1 clearance due to circumscribed circle on the bearing, mm
C_2 clearance due to inscribed circle on the bearing, mm
g acceleration due to gravity, $\mathrm{m\,s^{-2}}$
h_L local fluid-film thickness
$\overline{h}$ nominal fluid-film thickness, (h/c)
$\overline{h}_{TL}$ average fluid-film thickness, (h_{TL}/c)
$h_{\min}$ minimum fluid film thickness, mm
L bearing length, mm
R_J, R_L, R_b radius of journal, lobe and bearing, mm
r_c radius of capillary, mm
d_o orifice diameter, mm
p pressure, $\mathrm{N\,mm^{-2}}$
Q bearing flow, $\mathrm{mm^3\,s^{-1}}$
S_{ij} stiffness coefficients $(i, j = X, Z)$, $\mathrm{N\,mm^{-1}}$
C_{ij} damping coefficients $(i, j = X, Z)$, $\mathrm{N\,s\,mm^{-1}}$
$\lambda_{0.5x,y} = 0.5$ correlation lengths of the x and y profile, mm
t time, s
ω_I $(g/c)^{1/2}$, $\mathrm{rad\,s^{-1}}$
D journal diameter, mm
W_o external load, N
μ dynamic viscosity of lubricant, $\mathrm{N\,s\,m^{-2}}$
ρ density of lubricant, $\mathrm{Kg\,mm^{-3}}$
z combined roughness height, $(z = z_J + z_b)$, μm
z_J, z_b roughness height in journal and bearing, μm
σ RMS value of combined roughness, $\sigma = (\sigma_J^2 + \sigma_b^2)^{1/2}$, μm
σ_J RMS value of journal surface roughness, μm
σ_b RMS value of bearing surface roughness, μm
$\overline{C}_{S2}$ restrictor design parameter
erf error function, $erf(x) = 2/\pi \int_0^x \exp(-y^2)dy$
n number of rows of holes/slots
k number of holes/slots per row
V_r variance ratio
Y_S radial length of slot, mm
Z_S axial width of slot, mm
X, Y, Z Cartesian coordinates
X_J, Z_J coordinates of steady state equilibrium journal center from geometric center of bearing, mm
SOLV program subroutine module used to solve modified system of equation
JECP program subroutine module for equilibrium journal center position
SDPC program subroutine module used to compute static and dynamic performance characteristics

Greek symbols

λ aspect ratio
φ altitude angle
O_j, O_{Li} journal center, lobe center
ω_J journal rotational speed, $\mathrm{rad\,s^{-1}}$
ω_{th} threshold speed, $\mathrm{rad\,s^{-1}}$
p_s lubricant supply pressure $\mathrm{N\,mm^{-2}}$

Non-dimensional parameters

$\overline{a}_b = a_b/L$ land width ratio
$\beta^* = p^*/p_s$ concentric design pressure ratio
$\overline{C}_{ij} = C_{ij}\left(c^3/\mu R_J^4\right)$;
$(\overline{F}, \overline{F}_o) = (F, \overline{F}_o)/p_s R_J^2$;
$(\overline{h}) = (h)/c$;
$\overline{p}, \overline{p}_c, \overline{p}_{\max} = (p, p_c, p_{\max}/p_s)$;
$\overline{C}_{S2} = \frac{1}{12}(\pi r_c^4/8c^3 l_c)$ for capillary restrictor
$\overline{C}_{S2} = \overline{Q}_c$ for constant flow valve restrictor
$\overline{C}_{S2} = \frac{1}{12}\left(3\pi d_o^2 \mu \psi_d/c^3\right)(2/\rho p_s)^{1/2}$ for orifice restrictor
$\psi_d =$ coefficient of discharge for orifice restrictor
$\overline{C}_{SR} = \frac{\pi}{36}\frac{SWR}{\lambda}\frac{k}{\overline{a}_b}\frac{a_b}{Y_s}\left[\frac{Z_s}{c}\right]^3$ for slot restrictor
SWR slot width ratio of a slot-entry bearing, $SWR = \frac{a_s}{(a_s)_{\max}} = \frac{a_s n}{\pi D}$;
$\overline{Q} = Q(\mu/c^3 p_s)$;
$\overline{Q}_{slot} = \frac{1}{12\eta}(\overline{p}_c - p)\frac{a_s Z_s{}^3}{Y_s}$;
$\overline{S}_{ij} = S_{ij}(c/p_s R_J^2)$;
$\overline{W}_o = W_o/p_s R_J^2$;
$\overline{z}, \overline{z}_J, \overline{z}_b = (z, z_J, z_b)/c$;
$(\overline{X}_J, \overline{Z}_J) = (X_J, Z_J)/c$;
$\overline{t} = t(c^2 p_s/\mu R_J^2)$;
$\overline{X}^i{}_L, \overline{Z}^i{}_L = (X^i{}_L, Z^i{}_L)/c$;
$\overline{V}_{rj}, \overline{V}_{rb} = ((\sigma_j, \sigma_b)/\sigma)^2$;
$\Lambda = c/\sigma$ surface roughness parameter
$\gamma = \lambda_{0.5x}/\lambda_{0.5y}$ surface pattern parameter
ϕ_{xL}, ϕ_{yL} pressure flow factors
ϕ_{sL} shear flow factor
Φ_s shear flow factor related to a single surface
$\alpha, \beta = (X, Y)/R_J$ circumferential and axial coordinates
$\varepsilon = e/c$ eccentricity ratio
$\delta = C_1/C_2$ offset factor
$\overline{\omega}_{th} = \omega_{th}/\omega_I$
$\Omega = \omega_J(\mu R_J^2/c^2 p_s)$ Speed parameter

Matrices

$N_i, N_j =$ shape functions
$[\overline{F}]$ assembled fluidity matrix
$\{\overline{p}\}$ nodal pressure vector
$\{\overline{Q}\}$ nodal flow vector
$\{\overline{R}_H\}$ column vectors due to hydrodynamic terms
$\{\overline{R}_{X_J}\}, \{\overline{R}_{Z_J}\}$ global right hand side vector due to journal center velocities.

Subscripts and superscripts

b bearing
J journal
R restrictor
s supply
l lobe
i lobe number
min minimum
max maximum
x, y, z components in ***X***, ***Y***, and ***Z*** directions
. first derivative w.r.t time
r reference value
$*$ concentric operation
.. second derivative w.r.t time
— non-dimensional parameter