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Tribological design of a multistep journal bearing

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ABSTRACT

Journal bearings are machine elements with widespread application. The extent of their use, from the automobile engines to gas turbines, gives a significant incentive for improvement of their performance. Various approaches focusing on the journal bearing design have been used in the past in order to reduce power losses and increase load carrying capacity of journal bearings, including artificial texturing, axial and circumferential grooves and bushing specific shapes (e.g. three-lobe bearings). In this paper, the multistep journal bearing is examined. Its performance benefits are quantified. A maximum friction coefficient improvement of 38% is obtained with simultaneous 9.7% improvement of load capacity in comparison to the plain bearing. The specific operating conditions under which these benefits occur are established. The physical mechanism responsible for these improvements is discussed by correlating pressure, shear stress distribution, lubricant thickness and bushing geometry. The ultimate objective of this work is to suggest certain design principles that may adjust the improvement of the desired operating characteristics of the multistep journal bearing. The surface configuration of the bushing is relatively simple and is thus easy to be manufactured.

1. Introduction

Journal bearing design has always been of particular interest since this specific machine element has a wide variety of possible applications. Journal bearing static performance has been the issue of research many times in the past such as the work of Raimondi and Boyd [1]. Simmons [2] has studied the journal bearing problem with a number of new synthetic lubricants and polymer bearing materials. The simulation of the static performance of journal bearings with Newtonian and non-Newtonian lubricants using the Navier-Stokes equations is presented in the work of Gertzos et al. [3]. Moreover the use of CFD methods for the calculation of the static and dynamic characteristics of journal bearings has been investigated by Guo et al. [4]. The calculation of the stiffness and damping coefficients of a journal bearing using the Reynolds equation was presented by Lund and Thomsen [5]. Glienicke et al. [6] studied the static and dynamic performance of journal bearings with circular, lemon type and three-lobe bushing geometry using an analytical and an experimental approach. Sfyris and Chasalevris [7] presented an exact analytical solution of the Reynolds equation for the finite journal bearing.

Various methods of improvement of the journal bearing performance have been studied in previous research. Chasalevris and Dohnal [8] investigated the capability of a variable geometry journal bearing in reducing vibrations.

Pinkus [9] presented an analysis of the three lobe journal bearing. Leader et al. [10] executed an experimental study of the unbalance response and instability threshold of a four lobe journal bearing, while Flack et al. [11] presented simulation

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Nomenclature

R_b	bearing radius (mm)
C	radial clearance (μm)
R_j	journal radius
D	bearing diameter $D = 2 \cdot R_b$ (mm)
L	bearing length
W	bearing load
d	step depth
O_b	bearing center
O_j	journal center
$h(\theta)$	film thickness
e	eccentricity (μm)
$\vec{v}$	fluid velocity vector
F_{p_y}	force on the journal due to lubricant pressure on the y axis
F_{p_x}	force on the journal due to lubricant pressure on the x axis
F_{fr_i}	friction force
f_i	friction coefficient $f_i = \frac{F_{fr_i}}{W}$
S	Sommerfeld number (SI) $S = \mu \cdot \omega \cdot R_j \cdot L(R_j/C)^2/(\pi \cdot W)$
p^*	dimensionless pressure $p^* = (p - p_a) \cdot C^2/(\mu \cdot \omega \cdot R_j{}^2)$
n_{steps}	number of steps
Re	Reynolds number $Re = \rho \cdot \omega \cdot R_j \cdot C/\mu$

Subscripts

i	j for journal and b for bearing

Greek Symbols

ε	relative eccentricity $\varepsilon = e/C$
ρ	lubricant density (kg/m^3)
μ	lubricant viscosity (Pa s)
β	angle between two consecutive steps
γ	arc of step
ψ	orientation angle
ζ	secondary orientation angle
$\bar{\bar{\tau}}$	shear stress tensor

results concerning the pressure distribution in four-lobe bearings using the half-Sommerfeld and the Reynolds conditions in order to include cavitation into their calculations.

Roy and Laha [12] have investigated the static and dynamic performance of axially grooved journal bearings. Brito et al. [13] studied experimentally the influence of temperature and supply pressure on the performance of a two-axial groove hydrodynamic journal bearing. Roy and Kakoty [14] additionally have investigated the optimum location of groove in a journal bearing using genetic algorithms. Hargreaves and Reid [15] studied a three-pocket bushing configuration with a complex ramp and circular geometry. They have reported that the load carrying capacity would increase for certain bushing orientations. Chasalevris [16] presented an analytical solution for the evaluation of the static and dynamic characteristics of three lobe journal bearings. The pressure distribution as well as the stiffness and damping coefficients were calculated for various cases of bushing geometry orientation, relative to the load direction. The results show that some configurations of load direction are more favorable than others in terms of relative eccentricity.

Artificial texturing is another technique used for the improvement of the performance of a journal bearing. Brizmer and Kligerman [17] studied the performance of a surface textured journal bearing. Lu and Khonsari [18] investigated the effect of geometry and dimple configuration on the boundary lubrication of a textured journal bearing. They have shown that artificial texturing works as a lubricant reservoir, providing the journal bearing with lubricant under starvation conditions. Tala-Ighil et al. [19] performed an analysis of a journal bearing with various configurations of artificial texturing. They have reported a maximum improvement on friction coefficient of 1%.

A simpler alternative to the complicated geometry of the lemon type, three-lobe and four-lobe bearings could be a multi-step journal bearing. Instead of grooves of significant depth or numerous dimples with high density, a simpler geometry consisting of a section of the journal bearing with higher bearing radius would enable improved supply of lubricant in the lubricated area of the journal bearing. Hamrock and Anderson [20] performed research on the Rayleigh step journal bearing. Allaire and Flack [21] have studied different types of journal bearing design configurations including multilobe and multiple dam bearings. Ichikawa [22] studied the performance of a hydrostatic journal bearing with circumferentially