Tribology International 94 (2016) 288–305

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Dynamic characteristics of compliant journal bearings considering thermal effects

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ARTICLE INFO

Article history:
Received 4 April 2015
Received in revised form
7 July 2015
Accepted 9 August 2015
Available online 17 August 2015

Keywords:
Stiffness
Damping
Compliance
Thermal effects

ABSTRACT

A numerical THD model that takes into account mechanical and thermal deformations of a compliant lining is used to investigate the influence of compliance on dynamic characteristics of a two axial groove bearing. A detailed study on the contribution of mechanical and thermal deformation components of the compliant lining to the non-dimensional bearing stiffness and damping is carried out. Thermal deformation is found to increase horizontal stiffness K_{yy} and cross-coupled stiffness K_{xy} and slightly reduce journal critical mass. Mechanical deformation of the compliant lining is found to decrease damping, reduce vertical and cross-coupled K_{xy} stiffness. Radial clearance is found to increase stiffness, except its horizontal component, and decrease horizontal damping. Compliant lining is found to improve bearing stability.

1. Introduction

Hydrodynamic journal bearings are routinely used in a wide range of industrial machinery. Such bearings are relatively simple to manufacture and easy to install. They provide higher damping and take less space if compared to rolling element bearings. A general trend in machine elements is to increase power density by making components smaller and to reduce power consumption. One way to achieve lower power losses in a journal bearing is to use oils with better viscosity-temperature characteristics and higher oxidation stability as shown in [1]. Another promising approach is to substitute babbitt by a low friction compliant material. It was shown that a polytetrafluoroethylene (PTFE) facing on tilting pads improved thrust bearing full film operation [2–4]. PTFE is also capable of providing lower friction during short periods of boundary and mixed lubrication that occur during start-ups and shutdowns [5].

As explained in [6] a PTFE lining in a journal bearing improves steady state performance characteristics in comparison with a babbitted bearing. A compliant lining enhances bearing load carrying capacity, decreases maximum pressure and increases minimum oil film thickness while power losses and maximum film temperature remain similar or slightly increase [6]. A positive effect of bearing compliance is also known in foil gas bearings [7,8].

Since a PTFE lining is more elastic than babbitt, bearing dynamic characteristics will be affected. Stability of the plain journal bearings with compliant linings has been studied by several authors. Since nonlinear analysis is not the scope of the present paper, we only consider papers relevant to the linearized approach. Most of the published works refer to the work of Lund and Thomsen [9] when new numerical models are validated. In 1978 Lund and Thomsen [9] published an algorithm to evaluate linearized stiffness and damping coefficients for conventional plain journal bearings in the isoviscous conditions. Zhang et al. modified Lund's original approach to analyse a compliant lining bearing in the isothermal case in terms of journal critical mass and whirl ratio [10]. The dynamic deformation of the lining was shown to be important in the linear stability analysis. The same trend was also shown by [11,12]. Rao et al. [13] published an analytical approach for a quick estimation of linearized stiffness and damping for an iso-viscous problem. Results were verified by a comparison with Lund's data [9].

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http://dx.doi.org/10.1016/j.triboint.2015.08.018
0301-679X/

List of symbols

$B_{xx}, B_{yx}, B_{xy}, B_{yy}$	Damping coefficients (Ns/m)
C	bearing radial clearance (m)
E	PTFE Young's modulus (Pa)
h	oil film thickness (m)
k_0	effective bearing stiffness (N/m)
$K_{xx}, K_{yx}, K_{xy}, K_{yy}$	stiffness coefficients (N/m)
M_{crit}	critical journal mass (kg)
p	oil film pressure (Pa)
r	journal radius (m)
s	compliant lining thickness (m)
t	time (s)
W	load carrying capacity (N)
y	cross-film coordinate (m)
z	axial coordinate (m)
δ	deformation of the compliant lining (m)
ε	eccentricity (m)
θ	circumferential coordinate (rad)
ϑ	instability whirl frequency (rad/s)
μ	oil viscosity (Pas)
ν	Poisson's ratio (-)
φ	attitude angle (rad)
Ω	journal speed (RPM)

Constants and non-dimensional parameters

B_r	$\frac{\mu_0 \cdot \omega^2 \cdot R^2}{K_h \cdot T_0}$
B_{xx}	$\overline{B}_{xx}\frac{W}{\omega C}$
e	ε/C
$\overline{h}$	h/C
K_{xx}	$\overline{K}_{xx}\frac{W}{C}$
$\overline{r}$	r/R
$\overline{t}$	$t\omega$
$\overline{y}$	y/h
$\overline{z}$	z/L
η	R/L
θ	x/R
$\overline{\mu}$	μ/μ_0
$\overline{v}$	$v/\omega h$
ω	$\pi\Omega/30$

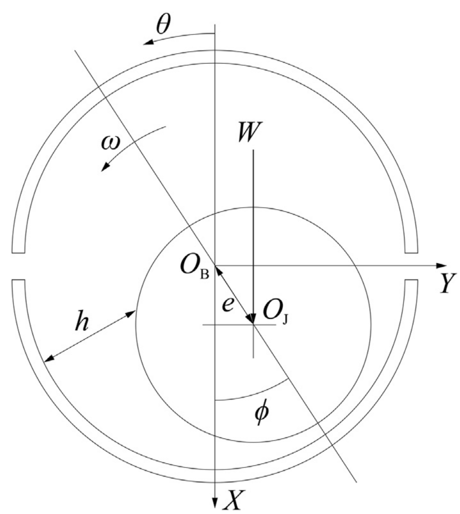

Fig. 1. Bearing geometry.

Recently, several authors published hydrodynamic and elastohydrodynamic studies of bearings with compliant linings, confirming the importance of the dynamic deformation in the stability analysis [14,15]. The compliant lining was shown to increase minimum film thickness, decrease stiffness, damping, load carrying capacity and attitude angle at a fixed relative eccentricity [14]. The cross-coupling damping coefficients were shown to be different if compliant lining is implemented [15]. This was also observed in the earlier works [10–12].

Durany et al. [16] used a thermohydrodynamic model to analyse dynamic behaviour of a plain journal bearing. Mechanical deformation of the bearing was not considered. Journal critical mass was shown to be increased if difference between shaft and bearing temperatures was positive and increased. At the same time, if shaft temperature was lower then that of the bearing, the journal critical mass was shown to be lower then that in the hydrodynamic model.

While journal bearing dynamic analysis has been extensively done for iso-viscous conditions with and without the effect of elasticity, a proper thermoelastohydrodynamic analysis seems to be missing. Moreover, the thermal effects were shown to have a visible influence on the linearized dynamic characteristics of the plain journal bearings [16].

The goal of this work is to analyse the effect of lining compliance on the stiffness, damping and stability of a plain cylindrical bearing using a thermoelastohydrodynamic bearing model. This work is a continuation of the work reported in [6].

2. Model description

The numerical model consists of two parts: a static analysis to obtain the journal equilibrium position and a dynamic analysis to evaluate stiffness and damping coefficients. Since the first part is well described in [17], we present only a short summary here. The