Tribology International 52 (2012) 161–169

Contents lists available at SciVerse ScienceDirect

Tribology International

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

Integral transform solutions for the analysis of hydrodynamic lubrication of journal bearings

E.N. Santos [a], C.J.C. Blanco [b], E.N. Macêdo [c], C.E.A. Maneschy [a], J.N.N. Quaresma [c,*]

[a] School of Mechanical Engineering, Universidade Federal do Pará, UFPA, Campus Universitário do Guamá, Rua Augusto Corrêa, 01, 66075–110 Belém, PA, Brazil
[b] School of Environmental and Sanitary Engineering, Universidade Federal do Pará, UFPA, Campus Universitário do Guamá, Rua Augusto Corrêa, 01, 66075–110 Belém, PA, Brazil
[c] School of Chemical Engineering, Universidade Federal do Pará, UFPA, Campus Universitário do Guamá, Rua Augusto Corrêa, 01, 66075–110 Belém, PA, Brazil

ARTICLE INFO

Article history:
Received 2 December 2011
Received in revised form
6 March 2012
Accepted 22 March 2012
Available online 6 April 2012

Keywords:
Hydrodynamic lubrication
Journal bearings
Lubrication theory
Integral transforms

ABSTRACT

This work deals with analysis of hydrodynamic lubrication of radial journal bearings. The Reynolds equation was treated in order to obtain a hybrid numerical–analytical solution through the Generalized Integral Transform Technique (GITT) for the problem. A parametric analysis is done to investigate the influence of typical governing parameters for such a physical situation. Numerical results for engineering parameters such as pressure field, friction coefficient, axial flow rate and dimensionless load capacity were thus produced as functions of such parameters. Comparisons with results presented in the literature were also performed in order to verify the present results, as well as to demonstrate the consistency of the final results and the capacity of the GITT approach in handling journal bearing problems.

1. Introduction

The field for application of radial journal bearings is enormous, and includes shipbuilding, industrial machinery and equipment, transportation industry, among others. Research and simulation of physical phenomena involved in the operation of these bearings are very important technologies because they allow evaluation of the phenomena involved with their performance, such as the workload and coefficient of friction.

The analysis of journal bearings is probably the most important part of the classical hydrodynamic lubrication theory and, it is also most difficult and complex due to integration of the Reynolds equation. The journal bearings are used mainly for decreasing the friction existing between solid parts of rotating machines and weakening the load variations supported by them. The journal bearing must support the load carried with minimal lost energy and low wear [1,2].

Hydrodynamic lubrication has been studied by many researchers with different numerical techniques for solving the Reynolds equation either for isothermal or non-isothermal flows. Sivak and Sivak [3] obtained a numerical solution of the Reynolds equation by modified Ritz method. Tayal et al. [4] investigated the effect of nonlinearity on the performance of journal bearings with finite width by using the finite element method (FEM). Chandrawat and Sinhasan [5] presented a comparison between the Gauss-Seidel iterative method and the linear complementarity approach for determining the pressure field in the analysis of plain and two-axial groove journal bearings in laminar flow operation. Williams and Symmons [6] analyzed a procedure, based on the finite difference method together with a technique known as SIMPLE, to solve the Navier–Stokes equations for the steady three-dimensional flow of a non-Newtonian fluid into the journal bearing with finite-breadth. Sinhasan and Chandrawat [7] presented an elastohydrodynamic study of two-axial-groove journal bearings. Similarly, Sinhasan and Chandrawat [8] have included thermoelastohydrodynamic effects in journal bearings and the FEM has been used to solve the governing equations. Steady performance of a wedge-shaped hydrodynamic journal bearing was analyzed by El-Gamal [9], in which a method of perturbation was used to solve the Reynolds-like equation governing the pressure inside the bearing. Banwait and Chandrawat [10] analyzed non-isothermal plain journal bearing problems by using the linear complementarity and FEM approaches to solve the related governing equations. Blanco and Prata [11] have used the finite volume method (FVM) to simulate and optimize the thrust bearings. Stefani and Rebora [12] applied a finite-element approach to thermoelastohydrodynamic lubrication analysis applied to the problem of steadily loaded journal bearings. Their results proved be consistent with those from experimental and numerical works in the literature.

Various techniques for performance analysis of journal bearings also are presented in the literature. Among them, interesting approximations consider infinitely long bearing for simplifying the solution of the Reynolds equation. Warner [13] used a side

* Corresponding author. Tel.: +55 91 32017837; fax: +55 9132017848.
E-mail address: quaresma@ufpa.br (J.N.N. Quaresma).

0301-679X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.triboint.2012.03.016

Nomenclature

A_i	Coefficient defined in Eq. (13a)
B_i	Coefficient defined in Eq. (13b)
c	Radial clearance
C_f	Friction factor
C_i	Coefficient defined in Eq. (13c)
D	Journal diameter
D_i	Coefficient defined in Eq. (13d)
e	Eccentricity
E_i	Coefficient defined in Eq. (13e)
f	Coefficient defined in Eq. (A.1g)
$\tilde{F}$	Dimensionless friction force
$\bar{g}_i$	Coefficient defined in Eq. (8d)
h	Film thickness
$\tilde{h}$	Dimensionless film thickness
$\bar{h}_i$	Coefficient defined in Eq. (A.2e)
L	Bearing length
L_i	Coefficient defined in Eq. (A.2f)
NT	Truncation order for the pressure expansion
N_i	Normalization integral
p	Pressure field
P	Dimensionless pressure field
$P_{\max}$	Dimensionless maximum pressure
$\bar{P}_i$	Transformed potentials
$\tilde{Q}_s$	Dimensionless side leakage flow
R	Journal radius
u	Circumferential velocity component
U	Journal velocity
$\tilde{u}$	Dimensionless circumferential velocity component
v	Radial velocity component
w	Axial velocity component
$\tilde{w}$	Dimensionless axial velocity component
$\tilde{W}$	Dimensionless load carrying capacity
$\tilde{W}_1$	Dimensionless load component along the line of centers
$\tilde{W}_2$	Dimensionless load component perpendicular to the line of centers
x	Circumferential bearing coordinate
y	Radial bearing coordinate
Y_i	Vector solution for the transformed potentials
z	Axial bearing coordinate

Greek letters

α	Cavitation angle
β_i	Parameter defined in Eq. (A.2d)
ε	Dimensionless eccentricity
η	Dimensionless axial bearing coordinate
θ	Dimensionless circumferential bearing coordinate
θ_L	Angle that characterizes the lubricant film length
λ	Aspect ratio
μ	Viscosity
μ_i	Eigenvalues defined in Eq. (6a)
ξ	Dimensionless radial bearing coordinate
ϕ	Normalized dimensionless circumferential bearing coordinate
φ	Attitude angle
ψ_i	Eigenfunctions defined in Eq. (6b)
$\tilde{\psi}_i$	Normalized eigenfunctions

Subscripts and superscripts

i	Expansion index
L	Related to angle that characterizes the lubricant film length
max	Maximum value
s	Related to side leakage flow
1, 2	Related to components of the load carrying capacity
–	Integral transformed quantities
$\sim$	Related either to dimensionless quantities or to normalized eigenfunctions

flow leakage factor to improve the solution accuracy of long bearing approximation. In similar fashion, Ritchie [14] introduced the short bearing solution by the Galerkin method to improve the accuracy of short bearing approximation at high eccentricity. A simple and precise solution for the infinitely long and infinitely narrow bearings is presented by Reason and Narang [15]. This technique shows good results when compared to those from the FEM approach. Chandan [16] derived a generalized Reynolds equation to include couple stress effects in the analysis of short journal bearings. Sharma et al. [17] solved the Reynolds equation for a non-Newtonian lubricant for a finite width journal bearing through a finite difference scheme and showed that the lubricant non-Newtonian behavior has an improved beneficial effect for the case of relatively short bearings. An analytical solution for a second order model was developed by Capone et al. [18]; this model reduces infinitely long and infinitely narrow bearing theory in limit cases characterized for a parameter pair (L/D, ε). Hirani et al. [19] have modified the analysis of Reason and Narang [15] to find a rapid method for evaluating the significant design parameters of journal bearings. Mokhiamer et al. [20] have analyzed the performance of finite journal bearings lubricated with a fluid with couple stresses taking into account the elastic deformation of the liner and concluded that the couple stress influence is significant. Recently, Vignolo et al. [21] obtained an approximate analytical solution to the Reynolds equation for finite length journal bearings by using a regular perturbation method.

Regarding the solution methodology, the so-called Generalized Integral Transform Technique (GITT) [22–29] has been successfully employed in the solution related the mathematical modeling of several problems in the field of heat and fluid flow. However, specifically for applications involving moderate and lower Reynolds number flows, one may cite the works of Pérez Guerrero and Cotta [30,31], Pérez Guerrero et al. [32], Castellões et al. [33], Monteiro et al. [34] and Silva et al. [35]. In this context, the present work aims at applying the ideas in the GITT solution methodology to solve a general formulation of the Reynolds equation. Such a hybrid numerical–analytical approach is an eigenfunction expansion methodology for solving linear or nonlinear in multiphysics problems, especially those not a priori transformable by the classical approach. An extensive parametric analysis is done in order to investigate the influence of typical governing parameters for such physical situation. Comparisons with results for typical situations are performed to demonstrate the consistency of the final results and to show the capacity of the GITT approach for handling journal bearing problems.

2. Mathematical formulation

Fig. 1 shows a schematic representation and nomenclature used for the mathematical formulation of a radial journal bearing problem. In it, c represents the radial clearance, which is the