Mechanism and Machine Theory 108 (2017) 209–216

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Short communication

A simpler method to calculate instability threshold speed of hydrodynamic journal bearings

Yu Huang[a,b], Zhuxin Tian[a,b,*], Runchang Chen[a,b], Haiyin Cao[a,b]

[a] School of Mechanical Science and Engineering, Huazhong University of Science & Technology, Wuhan 430074, PR China
[b] State Key Lab of Digital Manufacturing Equipment & Technology, Huazhong University of Science & Technology, Wuhan 430074, PR China

ARTICLE INFO

Keywords:
Hydrodynamic
Journal bearings
Instability threshold speed

ABSTRACT

In this study, a simpler method is proposed to study the instability threshold speed of journal bearing. State vector is chose as $\mathbf{c} = [\ \varepsilon\ \varphi \dot{\varepsilon} \dot{\varphi}\ ]$, not $[\ X\ Y \dot{X} \dot{Y}\ ]$ in previous discussions, and coordinate transformation (between (ε, φ) and (X, Y)) is avoided. For the short bearing, a simpler expression is obtained without accuracy reducing and the calculation process is simplified. While for the long bearing, the instability threshold speed is expressed analytically by the eccentricity ratio ε_s, the attitude angle φ_s and the Sommerfeld number S_2. The results agree well with the numerical results in previous studies. It is confirmed that, this method is more effective than the methods used in previous studies.

1. Introduction

Journal bearings, as crucial components in rotating machines, attract much attention and are applied widely in manufacturing industry. Better understanding the characteristics of journal bearings could help engineers to improve the performance of the machines. The main characteristics of the bearings are generally divided into two parts, the steady characteristics and dynamic characteristics. Journal bearings working on steady state were studied well by researchers such as Pinkus et al. [1], Williams [2], and Capone et al. [3]. The steady characteristics parameters (for example, friction parameters, load capacity and attitude angle et al.) were presented varying with eccentricity ratio. Based on the traditional hydrodynamic theory, Costa et al. [4] investigated the kinematics of human gait through hip joint formulation, and modeled a planar hip joint under the framework of multibody systems. While for the dynamic characteristics, Danial et al. [5] studied the hydrodynamic bearings in planar mechanical systems considering the cavitation boundaries.

When an external impact force is applied on a journal rotating at the equilibrium position and subsequently breaks the equilibrium state, the journal may return back to previous equilibrium point or lose its stability, hitting on the bearing. To clearly find out which state the journal will reach, a region called stability boundary is introduced. If the journal center is in the stability region, the journal can gradually return back to the equilibrium point.

To calculate the stability boundary, following method is widely used. When a journal is released from a disequilibrium position, the motion trajectory of the journal center is obtained by solving the motion equations [6] using fourth order Runge-Kutta method, then with a trial of iterations, the stability boundary could be ascertained. In this way, Khonsari et al. [7] got the stability boundary of the short hydrodynamic journal bearings lubricated with Newtonian fluid, Lin [8] obtained similar boundary considering the effects of couple stress, and Kushare et al. [9] found the boundary of the finite worn hybrid journal bearing lubricated with cubic shear

* Corresponding author at: School of Mechanical Science and Engineering, Huazhong University of Science & Technology, Wuhan 430074, PR China.
E-mail address: zhuxintian1987@sina.com (Z. Tian).

http://dx.doi.org/10.1016/j.mechmachtheory.2016.11.009
Received 26 October 2016; Received in revised form 8 November 2016; Accepted 9 November 2016

Nomenclature

a, b	components of the vector in Eq. (3).
A, B	integration constants in Eq. (36).
C	radial clearance, mm
D	journal diameter, mm
e	journal eccentricity, mm
f	state equation
f_ε	fluid film reaction component on the eccentric direction for short bearing, N
f_φ	fluid film reaction component perpendicular to the eccentric direction for short bearing, N
F_ε	fluid film reaction component on the eccentric direction for long bearing, N
F_φ	fluid film reaction component perpendicular to the eccentric direction for long bearing, N
g_1, g_2	expressions in Eqs. (4) and (5).
h	film thickness, mm
L	bearing length, mm
m	mass of rotor per each bearing, kg
p	pressure, N mm^{-2}
R	radius of bearing, mm
t	time, s
W	external load, N
X, Y, Z	Cartesian coordinates
x	coordinate of circumferential direction, rad
y	coordinate of the eccentric direction, mm
z	coordinate of axial direction, mm

Greek symbols

φ	attitude angle, rad
μ	dynamic viscosity of lubricant, N•s•m^{-2}
ω	rotation speed of shaft, rad/s
θ	angular coordinate, rad
ε	eccentricity ratio, $=e/c$

Non-dimensional parameters

A_{ij}, B_{ij}, C_{ij}, D_{ij}	parameters in Jacobian matrix, $i, j = \varepsilon, \varphi$
$h^* =$	h/c
$p^* =$	$pC^2/\mu\omega R^2$
$\omega^* =$	$\omega(W/mC)^{1/2}$
$\omega^*_{short} =$	non-dimensional stability threshold speed for short bearing
$\omega^*_{long} =$	non-dimensional stability threshold speed for long bearing
$S_1 =$	$\mu\omega RL^3/2WC^2$
$S_2 =$	$6\mu\omega RL^3/WC^2$
$z^* =$	$2z/L$
$f_\varepsilon{}^* =$	f_ε/S_1W
$f_\varphi{}^* =$	f_φ/S_1W
$F_\varepsilon{}^* =$	F_ε/S_2W
$F_\varphi{}^* =$	F_φ/S_2W

Subscripts and superscripts

s:	stability state
ε:	component on eccentric direction
φ:	component perpendicular to eccentric direction
short:	short bearing
long:	long bearing
*:	non dimensional parameter
.:	first derivative w.r.t time
.:	second derivative w.r.t time

stress law fluid. Wang et al. [10] calculated the journal center trajectory of the axially grooved infinitely long journal bearings. The stability boundary of the long hydrodynamic journal bearings is obtained by Amamou et al. [11] applying the Hopf bifurcation method.

With the rotating speed increasing, self-excited vibration would happen. Different with the critical speed resonance, the self-excited vibration increases with the rising up of the journal speed. When the rotation speed exceeds the whirl threshold, self-vibration comes up and the journal would vibrate with large amplitude, even touch the bearing and destroy it finally. Holmes [12] and Lund [13] completed a linear stability analysis of the journal bearings. In addition, Gardner et al. [14] using multiple scales method and Lin [15] applying the Hopf bifurcation theory accomplished a weekly nonlinear analysis of the journal bearings.

In the previous studies, for the short bearing, the eight dynamic coefficients (four stiffness and four damping coefficients) used to calculate the threshold speed are expressed with Cartesian coordinates, such as the works of Khonsari et al. [7] and Lin [16]. In their

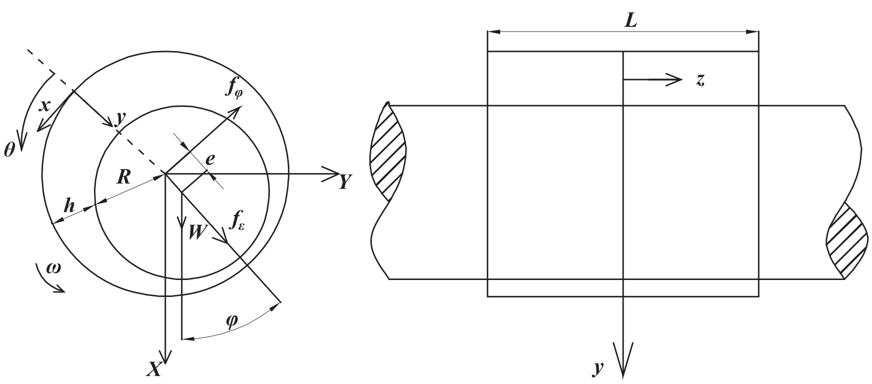

Fig. 1. schematic diagram of the journal bearing.