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Chaos and bifurcation of a flexible rub-impact rotor supported by oil film bearings with nonlinear suspension

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Abstract

The dynamic analysis of the rotor-bearing system is studied in this paper and is supported by oil film journal bearings. An observation of a nonlinearly supported model and the rub-impact between rotor and stator is needed for more precise analysis of rotor-bearing systems. Inclusive of the analysis methods of the dynamic trajectory, the power spectra, the Poincaré maps, the bifurcation diagrams and the Lyapunov exponent are used to analyze the behavior of the rotor centre and bearing centre in the horizontal and vertical directions under different operating conditions. The periodic, quasi-periodic, sub-harmonic and chaotic motion are demonstrated in this study. A special phenomenon is occurring at $s = 2.27$, the motions of the bearing centre and the rotor centre in the horizontal direction are still at chaotic motions but the motions of the bearing centre and the rotor centre in the vertical direction are at 3T-periodic motions. It is concluded that the trajectory of rotor centre and bearing centre have undesirable vibrations. With the analysis of the dynamic behavior of these operating conditions, the theoretical and practical idea for controlling rotor-bearing systems with rub-impact condition can be more precise.

Keywords: Rotor-bearing system; Rub-impact; Chaos; Bifurcation; Long bearing

1. Introduction

In a fluid film rotor-bearing system, the hydrodynamic pressure is generated entirely by the motion of the journal and depends on the viscosity of the lubricating fluid. Because the hydrodynamic pressure around the bearing is nonlinear, the fluid film rotor-bearing system in mechanical engineering has a strong nonlinearity and the analysis of this system may become complicated. There are a lot of researches in analyzing the nonlinear dynamic of rotor-bearing system. Ehrich [1] studied about the bifurcation of a bearing-rotor system identifying a sub-harmonic vibration phenomenon in a rotor dynamic system. It may be the first time that such a phenomenon was identified in a mechanical system. In 1978, Holmes et al. [2] published

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Nomenclature

c_1	damping coefficient of the supported structure
c_2	viscous damping of the rotor disk
e	$\sqrt{X^2+Y^2}$
F	fluid film force
f	friction coefficient between rotor and stator
f_e, f_φ	components of the fluid film force in radial and tangential directions
F_x, F_y	components of the fluid film force in X and Y directions
g	acceleration of gravity
k_1, k_2	stiffnesses of the springs which support the bearing housings
k_c	radial stiffness of the stator
k_p	stiffness of the shaft
L	bearing length
m, m_1	masses lumped at the rotor mid-point and bearing housing mid-point
O_m	center of rotor gravity
O_1, O_2, O_3	geometric center of the bearing, rotor and journal
$p(\theta)$	pressure distribution in the fluid film
R	inner radius of the bearing housing
r	radius of the journal
v	$\sqrt{\dot{X}^2+\dot{Y}^2}$
X, Y, Z	horizontal, vertical and axial coordinates
x_1, y_1, x_2, y_2	X_1/c, Y_1/c, X_2/c, Y_2/c
ρ	mass eccentricity of the rotor
ϕ	rotational angle ($\phi=\omega t$)
ω	rotational speed of the shaft
φ	attitude angle
c	radial clearance $= R-r$
θ	the angular position
μ	oil dynamic viscosity
η	δ/r
v	response frequency/ω
ε	e/c
s^2	$\frac{\omega^2}{\omega_n^2}$
ω_n^2	k_s/m
β	ρ/c
f	$\frac{mg}{ck_s}$
b	$\frac{\Lambda}{\sqrt{f}}\frac{1}{s}$
Λ	$\frac{mgc^2}{24\pi\mu LR^3\omega_0}$
ω_0	$\sqrt{\frac{g}{c}}$
ξ_2	$\frac{c_2}{2\sqrt{K_s m}}$
C_{om}	$\frac{m_1}{m}$
c_p	$\frac{k_s}{k_1}$
s_1^2	$c_{om}c_p s^2$
ξ_1	$\frac{c_1}{2\sqrt{k_1 m_1}}$
α	$\frac{k_2 c^2}{k_s C_{om}}$