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Bifurcation analysis of rotor–squeeze film damper system with fluid inertia

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ABSTRACT

This paper focuses on the bifurcation behaviors of a rigid rotor–squeeze film damper system considering the effect of fluid inertia. The equations of motion of the system are formulated considering π oil film model with fluid inertia. Then the averaging method is employed to obtain the bifurcation equation of the system model. By using the C-L method, three different modes of bifurcation behaviors are found from the three regions divided by the transition sets, namely bifurcation set and hysteresis set in system parameter plane. By changing the value of Reynolds number that reflects the fluid inertia of the squeeze film damper, the hysteresis set is moved obviously; it is shown that the fluid inertia plays an important role in determining the bifurcation behaviors of the system. Meanwhile, the bifurcation behaviors of system are affected significantly by the fluid inertia when the bearing coefficient locates within a certain region. Thus in this situation, the fluid inertia must be taken into account for theoretical analysis. Direct numerical simulation is also carried out by using the 4th order Runge–Kutta method to verify the theoretical results. The results obtained in this paper will provide a fundamental theory for designing an effective squeeze film damper.

1. Introduction

Squeeze film dampers (SFDs) are the most commonly used bearing supports to attenuate the vibration of rotor systems [1,2]. However, the response of a rotor system with squeeze film damper may lead to undesirable nonlinear behavior such as jump, bifurcation, quasi-period and chaos due to the highly nonlinearity of the oil film force of the squeeze film damper [3].

The complexity nonlinear response of a rigid rotor with squeeze film damper, has been investigated by Zhao using fourth-order Runge–Kutta integration [4], and the stability and bifurcation of unbalance response of a squeeze film damper-mounted flexible rotor were studied based on the trigonometric series approximation and the Floquet transition matrix method [5], which show that the unpressurized squeeze film dampers may promote undesirable non-synchronous vibrations. Chu and Holmes [6] discussed fast integration method, simple iteration method and harmonic balance method to get the nonlinear dynamic responses of the rotor system with squeeze film damper, which concludes that each of the three methods has its own advantages and disadvantages and a certain method can be chosen according to the practical need. Zhu [7] studied the behavior of the multiple-solution response in a flexible rotor supported by squeeze film damper by synchronous circular centred-orbit motion solution, numerical integration method and slow acceleration method, which shows that there are three basic forms for the multiple-solution response in the system. Bonello

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Nomenclature

$a_{1,2}$	non-dimensional amplitudes in complex coordinates
$\overline{a}_{1,2}$	non-dimensional amplitudes in main vibration directions
B	non-dimensional bearing parameter
c	clearance of squeeze film damper, m
c'	damping of the supports, N s/m
e	radial displacement of journal, m
F_{cx}	oil-film force in x-direction, N
F_{cy}	oil-film force in y-direction, N
F_r	oil-film force in radial direction, N
F_t	oil-film force in tangential direction, N
$\overline{F}_r$	non-dimensional oil-film force in radial direction
$\overline{F}_t$	non-dimensional oil-film force in tangential direction
J_d	equivalent equatorial moment of inertia, kg m^2
J_p	equivalent polar moment of inertia, kg m^2
k	equivalent stiffness coefficient of the supports, N/m
L	length of squeeze film damper, m
l_1	distance from the disc to the left support, m
l_2	distance from the disc to the right support, m
m	equivalent mass of the rotor, kg
$Q_{1,2}$	non-dimensional displacements in complex coordinates
$\overline{Q}_{1,2}$	non-dimensional displacements in main vibration directions
R	radius of the journal, m
Re	Reynolds number
Re_s	relative Reynolds number
r	non-dimensional radial displacement of journal
t	time, s
U_c	non-dimensional couple unbalance value
U_s	non-dimensional static unbalance value
U	non-dimensional integrated unbalance value
U^*	non-dimensional integrated unbalance value
$\alpha_{1,2}$	non-dimensional stiffness parameters
α	unfold parameter
β	unfold parameter
γ	length parameter
Δ	couple unbalance value, kg m^2
δ	static unbalance value, kg m
ζ	non-dimensional damping parameter
η	non-dimensional moment of inertia parameter
μ	kinetic viscosity coefficient of oil, N s/m^2
$\xi_{1,2}$	non-dimensional damping parameters
τ	non-dimensional time
φ_0	angle between static unbalance and couple unbalance, rad
φ	phase angle of integrated unbalance value
φ^*	phase angle of integrated unbalance value
ψ	angular displacement of journal, rad
ω	rotor speed, rad/s
ω_c	natural frequency of rigid rotor on retainer springs, rad/s
Ω	speed parameter

[8] presented an algorithm consisting of receptance harmonic balance method, Floquet theory and time marching method to analyze the rotor system with squeeze film dampers, which concludes that the benefits of using an unsupported SFD in a flexible rotor–rigid bearing housing system are dubious. Qin [9] used the Floquet multiplier and shooting method to analyze non-linear response and bifurcation for elastic support rotor–squeeze film damper system, which shows that saddle-node bifurcation and secondary Hopf bifurcation exist in the system. Hussain [10] used the continuation method and Floquet transfer matrix method to calculate response for non-centering squeeze film damper-rigid rotor system and periodic response stability, which shows that the system would be unstable in specific parameters by period-doubling bifurcation and saddle-node bifurcation. Furthermore, the non-centering squeeze film