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Quasimodes instability analysis of uncertain asymmetric rotor system based on 3D solid element model

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ABSTRACT

Uncertainties are considered in the equation of motion of an asymmetric rotor system. Based on Hill's determinant method, quasimodes stability analysis with uncertain parameters is used to get stochastic boundaries of unstable regions. Firstly, A 3D finite element rotor model was built in rotating frame with four parameterized coefficients, which is assumed as random parameters representing the uncertainties existing in the rotor system. Then the influences of uncertain coefficients on the distribution of the unstable region boundaries are analyzed. The results show that uncertain parameters have various influences on the size, boundary and number of unstable regions. At last, the statistic results of the minimum and maximum spin speeds of unstable regions were got by Monte Carlo simulation. The used method is suitable for real engineering rotor system, because arbitrary configuration of rotors can be modeled by 3D finite element.

1. Introduction

A spinning anisotropic or imperfection rotor supported by asymmetric support via multiple bearings is commonly met in engineering rotary machines, such as power generators, wind turbines, aero-engines and cracked rotor systems. If no simplification, the motion of the rotor system is generally governed by ordinary differential equations with periodic coefficients [1,2]. Despite of no closed-form solution of such equation being available, the numerical simulations and experimental studies show that the asymmetric of supports and anisotropic of rotors existing simultaneously causes instability region which may induce serious working condition of the system [1,3,4].

The stable analysis methods of asymmetric and anisotropic rotor systems are mainly based on Hill's infinite determinant [5–7] and discrete state transition matrix (DSTM) [1,8–10]. DSTM, which is in time domain analysis, is suitable for stable analysis of certain spin speed, while Hill's infinite determinant can get quasimode results for different spin speed more conveniently. Recently, AL-Shudeifat etc. serially worked on the stability analysis of open and breathing cracks in rotor system by Floquet's theory and semi-infinite coefficient matrix obtained by applying the harmonic balance solution to the finite element [11–14]. The Hill's infinite determinant method is more suitable for the stable analysis in the whole working range.

Furthermore, uncertainties exist widely in rotor systems and they are the result of a great number of causes, including but not limited to: material variation, geometrical variation (i.e., variation within geometrical tolerances), wear and

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Nomenclature

C	damping matrix
$E(\bullet)$, $SD(\bullet)$	mean value and standard deviation of parameter
$f(\chi)$	distribution function of uncertain parameter
f	reaction force of bearing
F	force vector
I_x, I_y	area moment of the shaft about axis X, Y
I	component vector of quasimode
k	stiffness of bearing
K	stiffness matrix
q	generalized coordinate
T	coordinate transform matrix
V	reduction transform matrix
α	relative angle of principle axis of bearing stiffness
β	asymmetric coefficient of bearing support
χ, $\boldsymbol{\chi}$	uncertain parameter and uncertain vector
γ	asymmetric coefficient of rotor
Λ, $\boldsymbol{\Phi}$	eigenvalue and eigenvector of quasimode
θ	fraction of the support stiffness
Ω	spin speed

thermally-induced geometrical variation. Caused by uncertainties, the variation of support stiffness, rotor stiffness, distribution of unbalance etc., may result in considerable changes of the dynamic properties [15]. Hence, the uncertainties make it more difficult to obtain deep comprehension of instability of asymmetric rotor system. While, the recent research papers are mainly focused on the stochastic dynamic responses of uncertain rotor systems [3,15–18]. All the researches mentioned above did not provide a method for stable analysis of uncertain asymmetric rotor systems.

In addition, the models used in the corresponding research papers are mainly based on transform matrix method [9,19,20], beam element [7,10] and 3D solid element model [5,6,21–23]. Coupling of blade, disk and shaft can be naturally considered and complex configuration of rotors can be accurately modeled by 3D solid element in rotating frame. So the present paper proposed a quasimodes instability analysis method, which is based on Hill's infinite determinant, with uncertain parameters in a 3D solid element rotor model.

2. Equation of the rotor system with uncertainties

A typical asymmetric rotor system used in literature [1] was rebuilt by 3D solid element (Fig. 1). As described in reference [1], a flexible horizontal shaft, a rigid disk and two flexible bearing supports are built. The shaft is of uniform cross-section along its longitudinal axis and has different stiffness along its two principal directions. The difference is that the 3D finite element model in Fig. 1 contains the mass of shaft and the stiffness of disk automatically.

As mentioned in the introduction, uncertainties exist widely in rotor systems, such as in the support stiffness k_{x1}, k_{y1}, k_{x2}, k_{y2} (caused by deviation of bearing size and bearing supports), relative phase angle of the two bearing supports

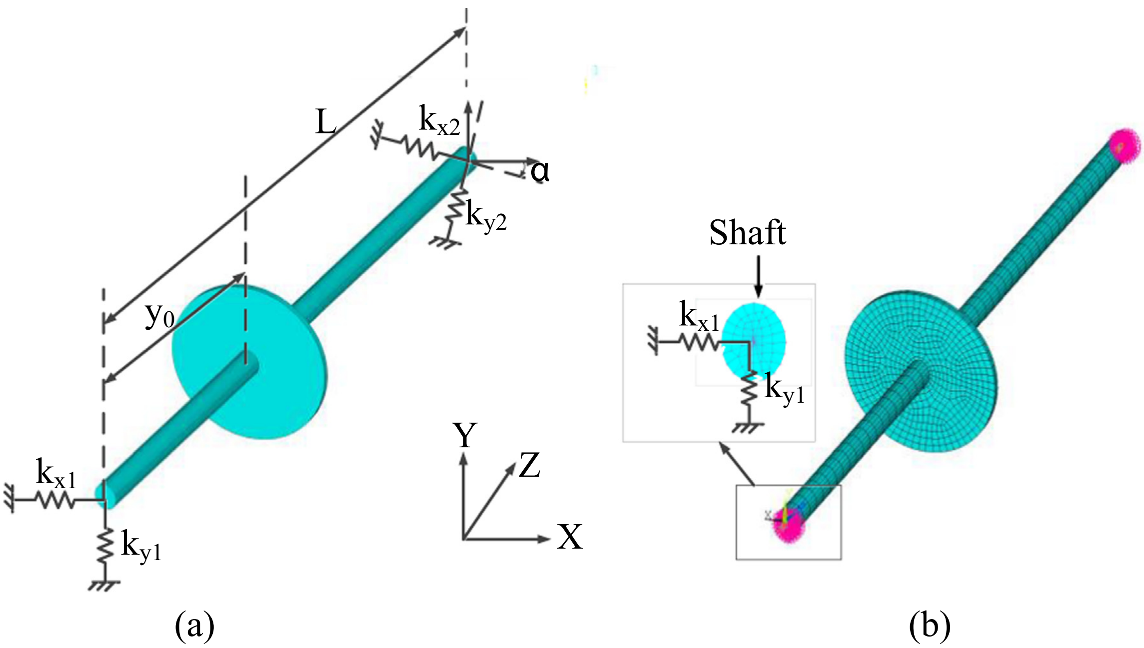

Fig. 1. Asymmetric rotor system: (a) the configuration of the rotor system. (b) 3D solid element model.