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Dynamic characteristics analysis of a rotor system with two types of limiters

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ABSTRACT

On the basis of Ref. Ma et al. (2013, *Mechanical System and Signal Processing*, 38, 137–153), the paper adopts a finite element (FE) method to investigate the complicated dynamic characteristics of a rotor system with two types of limiters under multilateral contact and friction conditions when the rubbing occurs between the rotor and limiters. The current study focuses on the effects of different stator/limiter forms on the vibration responses of the rotor–stator coupling system. First, FE models of the rotor with two types of limiters (four pin shaped stators and three pin shaped stators) are established. Then four and three point–point contact elements are used to simulate the rubbing between rotor and the two types of limiters. These contact elements describe the coupling of the rotor and the stators by the augmented Lagrangian method. Complicated vibration responses of the rotor system with two types of limiters under different rotating speeds are analyzed by spectrum cascades, rotor orbits, normal rubbing forces, amplitude spectrum, time-domain waveform and stator acceleration. The results show that the vibration responses of the rotor under the first type of limiter are more stable than those under the second type of limiter by observing the intensity and times of the rubbing, the magnitude of normal rubbing force and the regularity of frequency components caused by rubbing.

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1. Introduction

Rotor–stator rubbing is a serious malfunction in rotating machinery, which may cause catastrophic failures under super-critical operation with large unbalance loads. In order to prevent the damages of vital rotor or stator parts, one way is to use some kind of passive mechanical deflection limiting device [1–8], the function of which is to have a voluntary and controlled rotor–stator contact that will decrease the risk of involuntary rotor–stator contact. The rubbing mechanisms between rotor and limiting device have been studied in the past. Isaksson and Frid [2] studied the dynamical behavior of a rotor contacting with a non-annular stator and analyzed the influences of different stop configurations on the system vibration responses. Shaw [3,4] analyzed the complicated vibration responses of a single degree-of-freedom system with rigid stops and showed evidences of complex dynamics, such as subharmonic and chaotic motions. Dai et al. [5] described the contact between the rotating rotor and the stationary stop by using a simple Coulomb friction model and piecewise linear spring model. Han et al. [6] analyzed periodic motions of the rotor system with two discs where rub-impact occurs at fixed limiter for a test rig with dual discs. In order to reduce the full annular backward motion caused by rubbing, Lahriri et al. [7,8] developed a new unconventional backup bearing design, which utilizes four pin connections to force the rotor to the center and mitigate the lateral motion. In this way, the full annular rubbing can be changed into four-point rubbing.

In recent years, the rotor–stator rubbing simulated by combining the FE method with nonlinear contact theory has become widely researched. Chen et al. [9] investigated the nonlinear transient response due to rotor–stator contact using the FE method and a local contact element. Roques et al. [10] presented a rotor–stator model of a turbogenerator and investigated rotor-to-stator rubbing caused by an accidental blade-off imbalance. Thereinto, the rotor system is modeled by using the finite element method, and rotor-to-stator rubbing is simulated by using node-to-line contact and the highly nonlinear equations due to contact conditions are solved through an explicit prediction–correction time-marching procedure combined with the Lagrange multiplier approach. Based on finite element theory with unilateral contact and friction conditions, Behzad et al. [11] developed an algorithm to investigate the rotor-to-stator rubbing and carried out a case study of the point rubbing between rotor and an elastic rod by using this algorithm. Chavez et al. [12] adapted a rigid contact model to simulate the impact between the rotor and auxiliary bearing. A unilateral contact is applied to simulate the rubbing

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process and Poisson's impact law to simulate the change of the velocity in the normal direction. Ginzinger and Ulbrich [13] developed a simulation environment for rotor dynamical problems. In addition, he simulated the contact between rotor and auxiliary bearing by using unilateral and bilateral constraints, and used Coulomb's friction law to simulate tangential frictional contact. Sahinkaya et al. [14] utilized constrained Lagrangian equations of motion to develop a computationally efficient method to model contact dynamics. This method does not require a direct physical modeling of contact forces. It can be applied to multi-contact cases and is also capable of detecting and simulating the destructive backward whirl rolling motion.

Based on the above analysis, we found that some researchers adopted non-annular stator [2] (passive mechanical deflection limiting device) or four pin connections [7,8] to prevent vital rotor or stator parts from coming into contact or make possible full annular rubbing translate local fixed-point rubbing to protect the bearing. At present, there are few investigations about the suppression or control of rotor vibration by changing stator structures, which may change the dynamic characteristics of the system. Based on the present literatures, this paper will focus on the effects of two types of limiters: four pin shape stators and three pin shape stators on dynamic characteristics of rotor and stator based on contact theory. It is expected that the simulation method and results can provide some thoughts to simulate rotor vibration caused by rubbing.

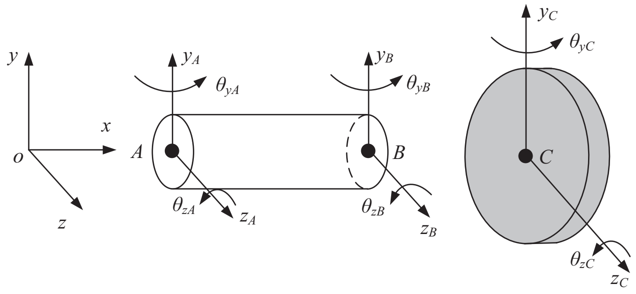


Fig. 1. FE model of a shaft element and a rigid disk.

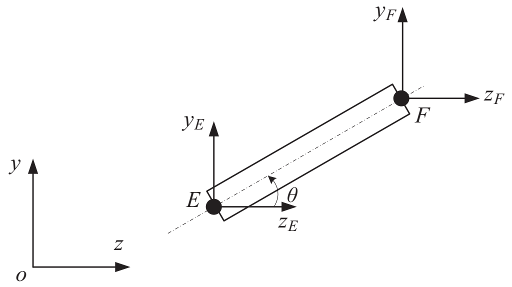


Fig. 2. FE model of a pin shape stator element.

2. Finite element modeling

A flexible rotor-bearing system, attached with two disks (geometric dimensions can be found in Ref. [1]), is used as the research object in order to study the complicated dynamic characteristics of the rotor-bearing system efficiently, the FE model of the rotor-bearing system is simplified according to the following assumptions:

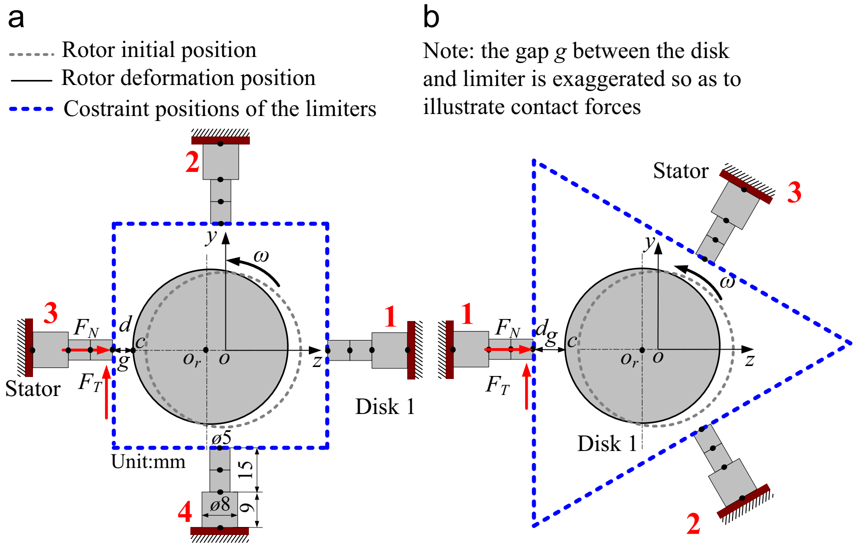
(a) The shaft is divided into 24 Timoshenko beam elements and 25 nodes; every node has four degrees of freedom as is shown in Fig. 1. In the figure, z_A, y_A and θ_{zA}, θ_{yA} denote displacements in translation directions and angular displacements in rotation directions, and subscripts A and B denote nodes A and B in shaft respectively.

(b) The rigid disks are simulated by lumped mass elements and superimposed upon the corresponding nodes, which are specified by the mass m_d, the diametral and polar mass moments of inertia (I_d and I_p), meanwhile the gyroscopic effects of the disks are also considered. In Fig. 1, subscript C denotes node C in rigid disk. In this paper, two disks are identical with m_d=0.5674 kg, I_d= 2.5×10^{-4} kg m^2 and I_p=4.7×10^{-4} kg m^2.

(c) The pin shape stator is simulated by cantilever Timoshenko beam considering axial and transversal flexibility. A plane element in *yoz* plane is used to simulate the pin shape structure, as is shown in Fig. 2.

(d) The left and right bearings are simulated ideally by identical linear stiffness and damping in y and z directions and the cross terms are neglected.

Neglecting axial displacement and corresponding torsional deformation, the general displacement vector of a beam element



Note: the gap g between the disk and limiter is exaggerated so as to illustrate contact forces

Fig. 3. Rubbing schematic between rotor and two types of limiters: (a) four pin shape stators, (b) three pin shape stators. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

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