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The coupled vibration in a rotating multi-disk rotor system

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ABSTRACT

The influence on coupling vibrations among shaft-torsion and blade-bending coupling vibrations of a multi-disk rotor system was investigated analytically. The natural frequencies and the mode shapes of the system were solved for one- to three-disk cases as examples. First, numerical results showed how the natural frequencies varied with blades in a disk unit. The diagrams of the coupling mode shapes were drawn. From the results, it was found that the inter-blade (BB) modes were of repeated frequencies of (N_b-1) multiplicity for number blades. At multi-disk unit, the shaft–blade (SB) modes added to N_d modes for number disks. The BB modes were of repeated frequencies of [$N_d \times (N_b$–1)] multiplicity for number disks. Numerical calculations also revealed that the natural frequencies were affected by disk distance. In the rotation effect, the times of instability will due to the number of disk. And, the more disk rotor causes instability earlier than the less disk case.

1. Introduction

The rotor systems composed of shaft, disk, and blades have been extensively implemented in the industry. The demands for higher operational speeds require more precise tuning than usual. The dynamics of rotor systems have been studied for several decades.

Investigations were confined to analyses of individual components, such as blade, Bauer [1] practiced the assumed modes method to investigate the vibrational behavior of a beam rotating with a constant spin about its longitudinal axis. Kammer and Schlack [2,3] utilized the perturbation method to study dynamic characteristics and stability of a rotating Euler beam. In last decades [4–9], many authors have reported new formulations and techniques for the rotating blade. On the other hand, about disks, Shen [10] further employed Rayleigh dissipation function and Lagrange's equation to solve for the forced responses of a rotating disk system. Shen and Ku [11] applied Lagrange's equations and linearized equation of motion to explore the multiple disk system, and found the frequencies of the unbalanced modes were lower than those of disk's one-nodal-diameter modes. Lately, Khorasany and Hutton [12] explored dynamic characteristics and stability of a constraining spinning disk.

Combined systems, like the shaft–disks, Nevzat [13] adopted analytical method to explore the shaft–disk system. He found critical speeds of the 1st and 2nd modes, and verified those with experiments. Wu and Flowers [14] adopted the transfer matrix method to solve for the natural frequency and critical rotational speed of multiple disks.

In the disk–blades unit, Chun and Lee [15] used the assumed modes method to analyze the effects of disk flexibility on the vibrational modes of a flexible disk–blade rotor system. They obtained more efficiency and correct results, compared to finite element method. Omprakash and Ramamurti [16] applied Love and Kichhoff method to study the effects on the natural frequency due to the blade stagger angle and twist angle in a disk–blades system.

Some studies have addressed the dynamic influence onto the coupled vibrations of a shaft–disk–blade unit. Lesaffre et al. [17] used the energetic method to explore the dynamic stability of a flexible bladed rotor in the rotating frame. The authors found and highlighted an unstable phenomenon near the stator critical speed even in case of frictionless sliding. Huang and Ho [18] utilized the concept of structure synthesis for a shaft–disk–blade system. The system was divided into two subsystems, the shaft–disk and blades. The disk was assumed to be rigid and can transmit the motion between a shaft and blades. The results showed that there existed not only the shaft–blade coupled modes but also the inter-blades coupling modes. Yang and Huang [19–21] explored the disk flexibility in a rotating shaft–disk–blade system. They studied the free vibration and classified four types of coupling modes, shaft–blade (SB), shaft–disk–blade (SDB), disk–blade (DB), and blade–blade (BB). Huang et al. [22] used same method to show the damping effect and the vibration analysis of a shaft–disk–blade system with viscoelastic layers on blades. Chiu and Huang [23] used assumed mode method to analyze the shaft-torsion and blade-bending coupling vibrations of a rotor system, in which the blades were grouped with lacing wires. They found the SB modes are unaffected by the lacing wires. That was however for a disk case.

In this paper, the rigid disk was considered and the blade is assumed to be of Euler type with no stagger angle. The emphasis is in the coupling behavior between shaft-torsion and blade-bending. The frequencies and the corresponding mode shapes in the shaft–disk–blade system are derived and discussed. Second, the paper

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