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Active control of coupled flexural-torsional vibration in a flexible rotor–bearing system using electromagnetic actuator

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ABSTRACT

Rotor–shaft systems are subject to non-uniform spin speed during start-up, coast-down or any non-stationary situation changing the spin speed suddenly, e.g., load fluctuation or sudden mass-loss like loss of a blade or a part thereof. For a flexurally and torsionally compliant rotor-shaft, the dynamics under non-uniform spin-speed shows inertial coupling among transverse and torsional coordinates through mass-unbalance and gyroscopic effect. This results into coupled transverse-torsional vibration, where torsional response consists of significant harmonic components at bisynchronous spin frequency, torsional natural frequency of the shaft, and at combination frequencies corresponding to sum and difference of spin and transverse natural frequencies and twice the transverse natural frequency of the rotor-shaft. As a result of the coupling, transverse rotor motion also influences the torsional motion. The Method of Multiple Scales (MMS) is used in this work to carry out an analysis of a simplified system to get an idea about the dominant frequencies of excitation. Results of numerical simulation are presented next to show the effectiveness and influence of actively controlling the transverse rotor motion on its torsional motion, at the dominant frequencies, with the help of non-contact electromagnetic force from an actuator. Transverse vibration control is also observed to control the torsional oscillations due to coupled nature of the problem. The Stability Limit Speed (SLS) of the system is also increased as a result of application of the active control action. Constant axial torque is observed to diminish the influence of coupling, and protect the system against torsional instability, but control action is a must to stabilize the transverse vibration of the system above SLS.

1. Introduction

Vibration in the rotor–shaft–bearing systems is a major concern in industries, as it creates operational difficulties, inaccuracies, power loss, fatigue and even failure of the system. Generally, rotor–shaft systems undergo transverse vibration due to bending and torsional vibration due to twisting simultaneously during unsteady operating conditions. Though extensive studies exist on transverse as well as torsional modes of vibration, when they are considered uncoupled, analysis and study of coupled transverse and torsional vibrations in rotors is much less reported comparatively. This is primarily due to the fact, that under steady operating speeds, rotor vibrations are principally due to transverse vibration, and secondarily, under coupled transverse and torsional motion, the equations of motion become non-linear causing difficulty in solution. Nevertheless, study and control of combined transverse and torsional vibration in rotor-shafts are important to avoid fatigue, the prime cause for developing rotor crack.

Spin speed of a rotor-shaft varies with time, when it undergoes (a) any change of speed (e.g. during speeding up or coasting down), (b) torsional oscillation (e.g. due to load fluctuation), or (c) a tangential impact or sudden loss of mass (e.g. due to breaking of a blade or a part thereof) at a rotor section. Under such situations, the resulting equations of motion for transverse and torsional oscillations get coupled and non-linear, where the unbalance in the rotor as well as the gyroscopic action introduce the coupling and non-linearity. Effect of this coupling has been reported in Refs. [1–4]. For an example, a problem may be envisioned where a rotor with a non-central disc undergoes a sudden change in linear and angular velocities for conserving momenta, after a sudden loss of mass in the form of a blade or a portion thereof. In this process the rotor section, where the impact or mass loss takes place, experiences a sudden, but finite change in the spin speed, while the sections away from it tend to maintain the original

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