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Non-linear vibrating systems excited by a nonideal energy source with a large slope characteristic

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ABSTRACT

This paper revisits the problem of an unbalanced motor attached to a fixed frame by means of a nonlinear spring and a linear damper. The excitation provided by the motor is, in general, nonideal, which means it is affected by the vibratory response. Since the system behaviour is highly dependent on the order of magnitude of the motor characteristic slope, the case of large slope is considered herein. Some Perturbation Methods are applied to the system of equations, which allows transforming the original 4D system into a much simpler 2D system. The fixed points of this reduced system and their stability are carefully studied. We find the existence of a Hopf bifurcation which, to the authors' knowledge, has not been addressed before in the literature. These analytical results are supported by numerical simulations. We also compare our approach and results with those published by other authors.

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1. Introduction

The motion of unbalanced rotors constitutes one of the most common vibration sources in mechanical engineering [1,2]. Vibrations due to unbalance may occur in any kind of rotating systems, such as turbines, flywheels, blowers or fans [3]. Actually, in practice, rotors can never be completely balanced because of manufacturing errors such as porosity in casting, nonuniform density of the material, and manufacturing tolerances [4]. Even a subsequent balancing process will never be perfect due to the tolerances of the balancing machines.

Usually, rotor unbalance has a harmful effect on rotating machinery, since vibration may damage critical parts of the machine, such as bearings, seals, gears and couplings [4]. However, there are applications where unbalanced rotors are used to generate a desired vibration. Some examples are the feeding, conveying and screening of bulk materials, or the vibrocompaction of quartz agglomerates, which makes use of unbalanced motors to compact a quartz-resin mixture. Actually, our interest in this vibrocompaction process has been the motivation for the presented study.

A simple model to analyse the dynamic response of a structure to the excitation produced by an unbalanced motor is sketched in Fig. 1. The simplest approach to this problem consists in assuming the rotor speed to be either constant or a prescribed function of time. In the constant speed case, the centrifugal force on the unbalance produces a harmonic excitation on the vibrating system, whose amplitude grows with the square of the rotating speed and whose frequency coincides with the rotating speed [3,5].

Note that, with this approach, it is implicitly being assumed that the rotational motion of the motor is independent of the vibration of the structure. This property is what defines an ideal excitation: it remains unaffected by the vibrating system

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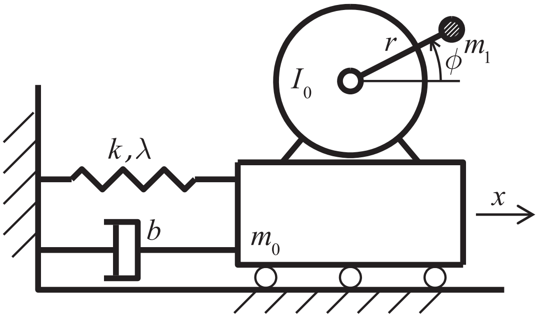

Fig. 1. Model.

response. Thus, the amplitude and frequency of an ideal excitation are known a priori, before solving the vibration problem. Obviously, this notion of ideality is applicable to any kind of excitation, and not only to the one produced by an unbalanced motor.

The ideality assumption is valid, with good approximation, in many real problems. However, there are situations where it is not. In 1904, Sommerfeld [6], whose pioneering work inspired many subsequent investigations, found experimentally kinds of behaviour which could not be explained upon the ideality hypothesis. He mounted an unbalanced electric motor on an elastically supported table and monitored the input power as well as the frequency and amplitude of the response [7]. The experiment consisted in increasing continuously the power input in order to make the rotor speed pass through the resonance frequency of the table, and then conduct the inverse process by decreasing the input power. The results obtained by Sommerfeld are qualitatively depicted in Fig. 2. When the rotor speed was close to resonance, an increment of the input power produced only a very slight increase of the rotor speed, while the oscillation amplitude increased considerably. This means that, in this part of the experiment, the increasing input power was not making the motor rotate faster, but was giving rise to larger oscillations. With further increasing of the input power, the rotor speed jumped abruptly to a frequency above resonance and, at the same time, the vibration amplitude jumped to a much smaller quantity than measured in the resonance region. When the process was reversed, by decreasing the motor input power, a jump phenomenon in the resonance region was also observed (see Fig. 2). However, this jump was found to be different to the one obtained for

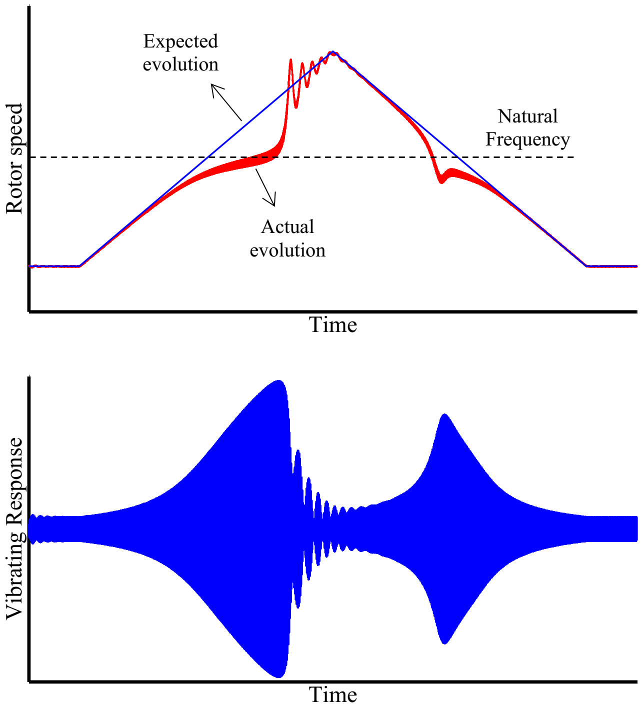

Fig. 2. Sommerfeld effect.

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