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A novel methodology for the angular position identification of the unbalance force on asymmetric rotors by response polar plot analysis

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ABSTRACT

It is well known that some mechanical systems, as a two pole generator, exhibit two different stiffness on the main inertial axis of its transverse section, which leads to complex vibration modes and complicates the determination of the angular position of the unbalance force and, consequently, the balancing process by conventional methods. Therefore, a methodology for the angular position identification of the unbalance force, based on a two-degrees-of-freedom mathematical simplified model of a rotor with unequal principal moments of inertia of the shaft transverse section, is proposed in this work. The methodology requires the analysis of the response polar plots of the rotor, as well as the information of the vibration response of at least four points from the response polar plot: vibration amplitude, phase angle and the angular velocity of the rotor. The identification of the unbalance force angular position was numerically and experimentally validated using the response polar plots experimentally acquired from a Jeffcott type rotor, which exhibits unequal principal moments of inertia of shaft transverse section and two inertial disks, which were analyzed for several unbalance force angular positions. The results showed slight differences between the identified and the experimental angular positions.

1. Introduction

Rotors can be classified as symmetric or asymmetric according to the stiffness parameters of their transverse section. The symmetric rotors exhibit equal inertial moments on its transverse section; in contrast, the asymmetric rotors exhibit unequal principal moments of inertia of the shaft transverse section, which produces a parametric excitation and, consequently, instability and perturbations on the vibration behavior of the rotor. A two blade propeller, a fan or pump impeller, a teetered wind turbine and a cam shaft are examples of mechanical systems which exhibit unequal rotary inertia around two principal axes of the rotating disk. The determination of the operation conditions of the parametric instability is crucial for the design process and the asymmetric rotors operation [1].

The investigations on this phenomenon have been addressed to the understanding of the mechanisms that cause the instability of the system. Ota and Mizutani [2] described the conditions under which unstable vibration occurs; in their

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Nomenclature

c	damping coefficient
c_c	critical damping coefficient
EON	fixed global coordinate system
XOY	rotating local coordinate system
k_η	rotor stiffness along axis ON
k_ξ	rotor stiffness along axis OE
m	rotor mass
f_d	unbalance force
r	vibration amplitude
$c\,\omega\, r$	damping force
$k_\xi \xi$	elastic force along axis OE
$k_\eta \eta$	elastic force along axis ON
$m\,\omega^2 r$	inertial force
ξ	rotor displacement along axis OE
η	rotor displacement along axis ON
θ	phase angle of r measured from axis OE
θ_d	angular position of f_d measured from axis OE
ω	angular velocity of shaft
t	time
ζ	modal damping
ω_ξ	natural frequency of the rotor, corresponding to k_ξ
ω_η	natural frequency of the rotor, corresponding to k_η
ωt	angular displacement
ω^*	average natural frequency, $\omega^* = \sqrt{\frac{1}{2}\left(\omega_\eta^2 + \omega_\xi^2\right)}$
μ	asymmetry ratio

study, a Jeffcott type rotor with asymmetrical shaft supported by asymmetrically flexible pedestals was considered. In an independent work, Yamamoto et al. [3] analyzed the vibration behavior of a shaft carrying an unsymmetrical rotor by considering forced vibration. In addition, Parszewski et al. [4] determined the instability region by combining the information obtained from the harmonic response of the rotating shaft and the harmonic response of the supporting structure. More recently, Qinkai Han et al. [1,5] reported the results of a study dealing with the parametric instability of a rotor involving both a fracture in the shaft and asymmetric disks, and found that, under specific conditions, the existence of transverse crack has an attenuation effect upon the instability regions. However, the two-pole generators also exhibit unequal principal moments of inertia of shaft transverse section, therefore it is necessary to predict the instability regions and the unbalance vibration response, as stated by Taylor [6], Bishop and Parkinson [7] and Matsukura et al. [8], who have reported that this type of rotors exhibit two remarkable features: (a) the first feature is related to the vibration response, where both the vibration amplitude and phase angle change for different angular positions of the unbalance force, and (b) a double frequency vibration that occurs at a half of the main critical speeds caused by the effect of the gravity, besides a polar plot of unbalance response vector draws an ellipse as the rotor is run through a critical speed, the ratio of major to minor axis is related to the rotor asymmetry. The effect of the asymmetric transverse section on the vibration features of the rotors are of great interest for the development of balancing methodologies, since there is a lack of efficient methods for this type of rotors due to the complexity for accurately determining the angular position of the unbalance force. In the last few decades, several researchers as Matsukura et al. [9], Songbo et al. [10], Parkinson [11], Inagaki et al. [12] have proposed different balancing methods for asymmetric rotors; however, the majority are iterative methods, which implies that it is necessary to perform several running test before reach the balanced condition, principally because the difficulty for locating the angular position of the unbalance force and the variation of the rotor influence coefficients. According to the mentioned above, it has been showed that the estimation of the rotating dynamic systems parameters allows the development and enhancement of methods and devices addressed to the control of vibration caused by unbalance forces. There is a vast of methods for identification and estimation of the rotor dynamic parameters, as those proposed by Yuan-Pin and An-Chen [13], who developed a method based on the transfer matrix for the estimation of the unbalance distribution in flexible axis with inertial disks, or De Queiroz [14], who reported an identification active method for the determination of the unbalance parameters of a Jeffcott-type rotor based on a robust dynamic control technique and, finally, Sudhakar and Sekhar [15], who theoretical and experimentally determined the unbalance parameters using an approximation method for the failure identification. Currently, there is a method known as algebraic identification, based on differential algebra and operational calculus, for the development of the estimators from the mathematical model of the system. The estimation of the unbalance parameters is performed both on-line and continuous or discrete time. Authors as Beltrán-Carbajal et al. [16], Beltrán-Carbajal et al. [17], Beltrán-Carbajal et al. [18], Colín Ocampo et al. [19], Mendoza Larios et al. [20], Arias et al. [21], Blanco Ortega et al. [22] used the algebraic