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Q1 Nonlinear vibration analysis of a rotor supported by magnetic bearings using homotopy Q2 perturbation method

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Abstract In this paper, the effects of nonlinear forces due to the electromagnetic field of bearing and the unbalancing force on nonlinear vibration behavior of a rotor is investigated. The rotor is modeled as a rigid body that is supported by two magnetic bearings with eight-polar structures. The governing dynamics equations of the system that are coupled nonlinear second order ordinary differential equations (ODEs) are derived, and for solving these equations, the homotopy perturbation method (HPM) is used. By applying HPM, the possibility of presenting a harmonic semi-analytical solution, is provided. In fact, with equality the coefficient of auxiliary parameter (p), the system of coupled nonlinear second order and non-homogenous differential equations are obtained so that consists of unbalancing effects. By considering some initial condition for displacement and velocity in the horizontal and vertical directions, free vibration analysis is done and next, the forced vibration analysis under the effect of harmonic forces also is investigated. Likewise, various parameters on the vibration behavior of rotor are studied. Changes in amplitude and response phase per excitation frequency are investigated. Results show that by increasing excitation frequency, the motion amplitude is also increases and by passing the critical speed, it decreases. Also it shows that the magnetic bearing system performance is in stable maintenance of rotor. The parameters affecting on vibration behavior, has been studied and by comparison the results with the other

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references, which have a good precision up to 2nd order of embedding parameter, it implies the accuracy of this method in current research.

1. Introduction

Investigation on dynamic behavior of a rotor is a basic component of rotating machines at industry which scientists have studied to understand it. On the other hand, to overcome on friction in rotors which cause energy dissipation, engineers utilize magnetic bearing that are more efficient in this systems [1]. Rankine studied on the centrifugal force of rotating shafts [2]. Nonlinear forces in contact, existing clearance between frames and failure in bearings are three main reasons for producing nonlinear vibration which is main factor for noises [3,4]. Magnetic bearings are new generation which momentum is transmitted by magnetic field. These kinds of bearings create nonlinear vibration in rotors because of three main sources: force stimuli, eddy current and gyroscopic effects [1].

In recent years, scientists researched on nonlinear forces effects on rotors vibration responses. Inayat Hossein [5] has investigated nonlinear dynamic of a flexible rotor in active magnetic bearings numerically which illustrated rotor unbalance effects on its responses. Ji et al. [6], have studied nonlinear response of rigid rotor with considering nonlinear forces effects in active magnetic bearings by multiple scale method. Norbert and Helmut [7], have investigated nonlinear forces effects on active magnetic rotors and its periodic responses by numerical integration method. Ji and Leung [8], studied nonlinear forces effects on active rotors under super harmonic resonance conditions by using of perturbation method. Likewise, they investigated bifurcation behavior of rotors supported by active magnetic bearings by analyzing of control feedback effects. They analyzed the vibrations on horizontal and vertical directions and found that, the vibratory behavior in the vertical direction can be reduced on the center manifold to the Bogdanov-Takens form [9]. Inayat Hossein [10], studied a rigid rotor responses supported by active magnetic bearings. He indicated that oscillations are periodic, semi-periodic and chaotic for disparate parameters. Zhang [11], utilized perturbation method to investigate nonlinear motion and behavior of a rotor supported by active magnetic bearing with considering time-varying stiffness in vertical and horizontal directions. Ji et al. studied the effects of magnetic bearing's nonlinear forces on nonlinear vibration behavior of rotor [12]. Jawaid and Inayat-Hussain researched on a numerical investigation on the bifurcations of a flexible rotor response in active magnetic bearings taking into account the nonlinearity due to the geometric coupling of the magnetic actuators as well as that arising from the actuator forces that are nonlinear function of the coil current and the air gap [13] The collocation method is used to find both stable and unstable periodic solutions for geometric coupling with the rotor weight considered by Chinta, et al. The effects of geometric coupling on the nonlinear response of a magnetically supported rotor were investigated [14,15]. Numerical study that did by Jang and, Chen on the response of a flexible rotor supported by magnetic and auxiliary bearings revealed the occurrence of sub-synchronous vibrations of periods-2, -4 and -8, quasi-periodicity and chaos [16]. The non-linear oscillation caused by gyroscopic effects is analyzed by Mohamed and Emad [17]. Hebbale and Taylor investigated the nonlinearities in magnetic bearings due to the effects of cross-coupling that arose from eddy currents during shaft rotation [18]. Virgin et al. [19] modeled the electromagnetic forces based on flux control. Therefore, in their work in addition to the effect of geometric coupling, the electromagnetic forces also caused the nonlinearities of the system. For a rigid rotor, Radhouane Sghir and Mnaouar Chouchane investigated the stability analysis of a flexible rotor supported by journal bearings using a nonlinear dynamic model and a short bearing approximation.they also studied the effect of rotor flexibility and bearing characteristics on the stability boundaries. They found that the stable operating speed range decreases with rotor flexibility and bearing parameter [20]. Also authors used some references to investigate semi-analytical method [21–32].

2. Equations

Rotor is modeled as a rigid body supported by two active magnetic bearings with eight polar structures. The governing dynamics equations of the system are derived in form of two coupled nonlinear second order ordinary differential Eq. [6]. For solving these, the homotopy perturbation method (HPM) has been used. By applying HPM, the possibility of presenting a harmonic and semi-analytical solution, is provided. In fact, with equality the coefficient of auxiliary parameter (p), the system of coupled nonlinear second order and non-homogenous differential equations are obtained, that consist of unbalancing effects and nonlinear forces due to the electromagnetic field of bearing.

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