Analysis of nonlinear behaviors in active magnetic bearing-rotor system

Zhang Xiaoshen*, Sun Zhe*, Zhao Lei*, Yan Xunshi* , Zhao Jingjing* and Shi Zhengang *

**Institute of Nuclear and New Energy of Tsinghua University, The key laboratory of advanced reactor engineering and safety, Ministry of Education, Beijing, China*

Abstract. Bifurcation behaviors of an active magnetic bearing (AMB)-rotor system with nonlinear bearing force and current saturation were investigated. This paper used the harmonic balance method to obtain approximate solutions containing both static equilibrium term and periodic vibration term. The dynamic characteristics were illustrated based on analytical solutions. It was found the AMB-rotor system exhibited special behaviors on the aspect of suspension rather than vibration. There was supercritical pitchfork bifurcation of static equilibrium which existed due to non-contact support of AMB and was harmful to system. Influences of system parameters were also discussed.

Introduction

In AMB-rotor systems, the rotor suspension position called as static equilibrium is significant as well as vibration amplitude. Due to non-contact support characteristics, the static equilibrium can move in a wide range and may not locate in the reference position[1]. The deviation of static equilibrium makes rotor displacement enlarge significantly, which makes system performance deteriorate and even leads to instability. However in present researches, most reports focused on vibration amplitude[2] and few mentioned static equilibrium. To study effects of static equilibrium on AMB-rotor systems, this paper used the harmonic balance method to obtain approximate solutions and carry out nonlinear dynamic analysis. The research can help to understand dynamic characteristics and propose effective measures to prevent unexpected behaviors.

Results and discussion

Analysis results showed it was static equilibrium that exhibited unexpected behaviors rather than vibration amplitude. As shown in Fig. 1(a), vibration amplitude a increased almost linearly with increase of f. No unexpected behaviors occurred. However, some unexpected behaviors happened in static equilibrium. For small f, there was only one stable static equilibrium, namely trivial equilibrium. As f increased, trivial equilibrium lost its stability and two stable nontrivial equilibriums appeared concurrently. The nontrivial equilibriums can be exhibited due to large mechanical clearance of AMBs. Nontrivial equilibriums would increase if f continued to increase. It was a typical supercritical pitchfork bifurcation. The bifurcation of static equilibrium has negative influences. Fig. 1(c) shows one branch of rotor displacement y. It shows the rotor vibrated at amplitude a in the vicinity of stable static equilibrium. The comparison of time domain response before and after bifurcation is shown in Fig. 1(b). For $f = 0.1$, the rotor vibrated in the vicinity of trivial equilibrium. For $f = 0.2$, the rotor vibrated in the vicinity of a nontrivial equilibrium. The vibration amplitude was larger and the rotor deviated from reference position. It followed that maximum displacement increased significantly. It can be also seen the deviation of static equilibrium made more contribution than vibration amplitude. Both vibration amplitude and static equilibrium affected system performance, and effect of static equilibrium was more predominant after bifurcation. The nonlinearity of bearing force and current saturation were the causes of bifurcation. Influences of system parameters on bifurcation were also discussed. Based on analysis results, controller redesign was conducted to prevent bifurcation and improve system performance.

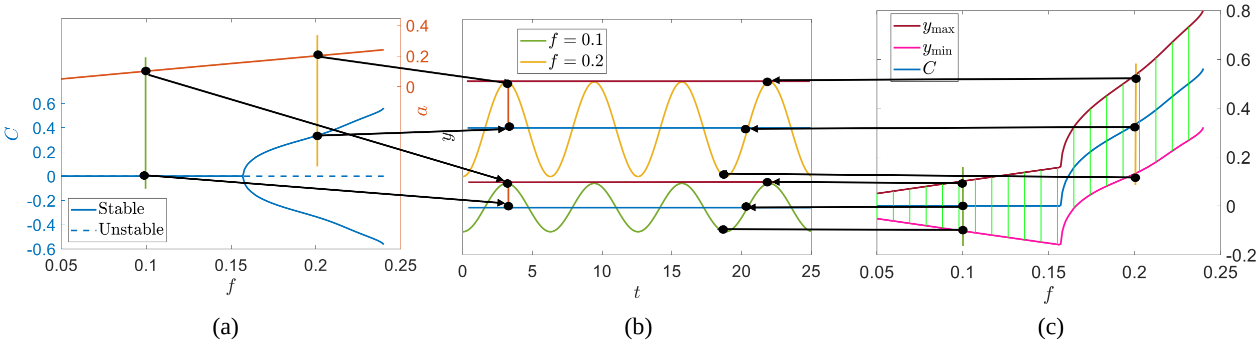

Figure 1: (a) Static equilibrium and vibration amplitude with respect to f; (b)Time domain responses before and after bifurcation; (c) Rotor displacement with respect to f.

References

[1] Z.Sun, X.Zhang, T.Fan, X.Yan, J.Zhao, L.Zhao, Z.Shi (2019) Nonlinear dynamic characteristics analysis of active magnetic bearing system based on cell mapping method with a case study, *Mechanical Systems and Signal Processing* **117**: 116-137.

[2] N.A. Saeed, M.Eissa, W.A. El-Ganini (2013) Nonlinear oscillations of rotor active magnetic bearings system. *Nonlinear Dynamics* **74**: 1-20.