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Regulation on radial position deviation for vertical AMB systems

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Abstract

As a source of model uncertainty, gyroscopic effect, depending on rotor speed, is studied for the vertical active magnetic bearing (VAMB) systems which are increasingly used in various industries such as clean rooms, compressors and satellites. This research applies H^∞ controller to regulate the rotor position deviations of the VAMB systems in four degrees of freedom. The performance of H^∞ controller is examined by experimental simulations to inspect its closed-loop stiffness, rise time and capability to suppress the high frequency disturbances. Although the H^∞ is inferior to the LQR in position deviation regulation, the required control current in the electromagnetic bearings is much less than that for LQR or PID and the performance robustness is well retained. In order to ensure the stability robustness of H^∞ controller, two approaches, by Kharitonov polynomials and TITO (two inputs & two outputs) Nyquist Stability Criterion, are employed to synthesize the control feedback loop. A test rig is built to further verify the efficacy of the proposed H^∞ controller experimentally. Two Eddy-current types of gap sensors, perpendicular to each other, are included to the realistic rotor-bearing system. A four-pole magnetic bearing is used as the actuator for generation of control force. The commercial I/O module unit with A/D and D/A converters, dSPACE DS1104, is integrated to the VAMB, gap sensors, power amplifiers and signal processing circuits. The H^∞ is designed on the basis of rotor speed 10 K rpm but in fact it is significantly robust with respect to the rotor speed, varying from 6.5 to 13.5 K rpm.

Keywords: Gyroscopic effect; Active magnetic bearing; H^∞ control

1. Introduction

The theories for robustness have been well studied and developed for decades. In 1981, Zames introduced H^∞ to be applied on control systems by describing the uncertainties boundary in infinity-norm [1]. At the same time, Doyle et al. [2–4] proposed μ-synthesis, to account for structured/unstructured uncertainties in relatively conservative manner. As a matter of fact, for three decades the issues of system uncertainties attract numerous researchers' attention and efforts to solve the model inaccuracy and errors. A great deal of proposals is thus reported from all aspects, such as non-linear modeling and analysis, sliding mode control, adaptive control, fuzzy logic, etc.

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Due to the increasing need of high-speed spindles and maintenance-free requirements for certain industries such as clean rooms, bimolecular centrifugal machines and equipments in aerospace and satellites, active magnetic bearing (AMB) becomes more popular. However, the open loop of the AMB system is inherently unstable, a closed-loop feedback is needed to stabilize the mechatronic system. Nonami et al. [5] ever tried to employ H^{∞} theory for the controller design for AMB-based milling machines and implementation via DSP-chip and electronic technology. Sivrioglu et al. [6] improved the efficiency of energy storage flywheel supported by AMBs, by applying H^{∞} controller and multiple-equilibriums linearization. Chen et al. [7] introduced integral sliding mode controller to stabilize three-axis AMB systems with uncertainties Castano et al. [8] integrated H^{∞}, Quantitative Feedback Theory and Nichols chart to enhance trajectory tracking capability of the closed-loop systems [8].

In order to account for gyroscopic effect of the rotors suspended by AMBs, this paper employs H^{∞} controller design and applies Kharitonov theories [9–11] to explore its stability margin [12]. It is proved that the closed-loop H^{∞} control system is stable as long as a certain set of characteristic polynomials is ensured to have all roots on the left half complex plane. As a matter of fact, the interested AMB open-loop system studied in this paper is a TITO (two inputs & two outputs) plant. Therefore, all individual stable SISO (Single Input & Single Output) transfer functions cannot ensure the stability of the TITO system. To solve TITO stability problem, the generalized Nyquist Stability Criterion would be introduced to examine whether the synthesized control-loop guarantees the closed-loop system stability [13].

There are four major sections in this paper. The VAMB dynamics is established first in the next section. Two approaches to analyze stability of the MIMO closed-loop system, namely Kharitonov Theory and generalized Nyquist Stability Criterion, are introduced. At last H^{∞} controller is synthesized and verified by intensive experimental simulations.

2. Dynamics of vertical active magnetic bearing systems

The studied vertical active magnetic bearing (VAMB) system is shown in Fig. 1. The permanent magnetic bearing located at the bottom is assumed to have constant stiffness and damping coefficient. Hence it is named as passive magnetic bearing (PMB) in this paper, in contrast to the electromagnetic bearings that are called AMB generally. At the top of the VAMB system is the radial electromagnet that exerts magnetic force to regulate the radial deviation of rotors. It is noted that the axial deviation is beyond the scope of this paper

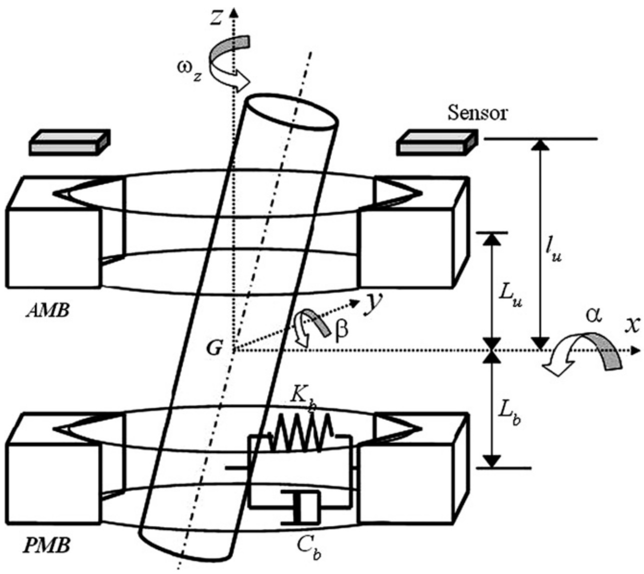

Fig. 1. Vertical AMB systems.