Advanced Control for Active Magnetic Bearing Systems

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Abstract

Active Magnetic Bearings (AMB) are used in a number of industrial applications namely hard-disk drives, flywheel energy storage systems and milling machines. Rotating spindles are often subject to synchronous vibrations due to the presence of unbalanced mass. The effect of such an unbalanced mass can be modelled as sinusoidal disturbances acting on the spindle. AMBs can be effectively used to control/suppress these disturbances. Feedback controllers based on H_∞ methods have been predominantly used in the AMB literature. Such controllers essentially aid in suppressing disturbances at a fixed operating point / rotational speed. An AMB-spindle operating over a range of rotational speeds exhibits dynamics that depend on the rotational speed. This is modelled by means of a Linear Parameter Varying (LPV) system wherein the system dynamics depend on the rotational speed. It is desirable to design controllers that can also adapt based on the rotational speed measurement. These LPV controllers aid in rejecting disturbances over a range of operating points / rotational speeds.

1 Introduction

The design of controllers for AMB-spindles is challenging as they are multi-variable in nature, exhibit non-linearity and are inherently unstable. Conventionally PD/PID controllers are used with each single-input-single-output (SISO) channel to stabilize the AMB-spindle, [2]. In such a frame-work a notch-filter is used in the control loop to reject disturbances due to the mass imbalances. These controllers essentially stabilize the AMB system and the performance is limited to a particular operating speed. Advanced multi-variable controllers based on H_∞ techniques have been predominantly used in the literature for AMB systems, [3], [4]. In this paper we evaluate the performance of a robust controller and an LPV controller for a multi-variable AMB experimental setup.

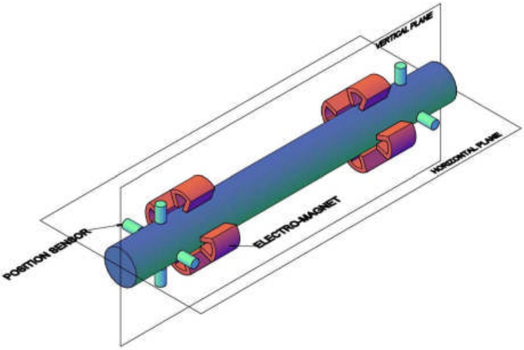


Figure 1: Schematic view of AMB-spindle and sensor assembly

2 System Description

A schematic view of the magnetic-bearing sensor assembly is shown in Figure 1. We assume the system dynamics in the horizontal and vertical planes to be de-coupled that is we neglect gyroscopic effects and any electromagnetic coupling. Hence the entire AMB-spindle assembly is modelled by two 2x2 multi-input-multi-output (MIMO) LTI subsystems. The system dynamics for each plane shows similar behaviour and the frequency response of our model is shown by the dashed-line in Figure 2. The frequency response plot shows two light damped resonances which correspond to the first two flexible modes. For synthesis of stable controllers we neglect the flexible dynamics and use only the rigid body dynamics shown by the solid-line in Figure 2.

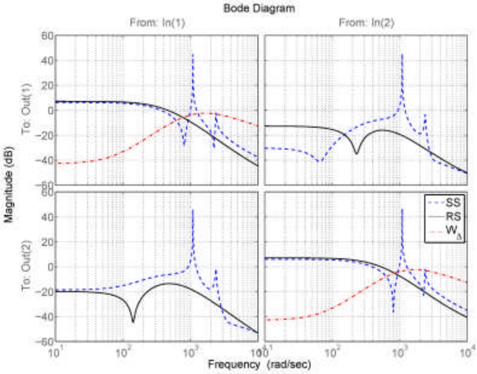


Figure 2: Schematic view of AMB-spindle and sensor assembly

3 Robust and LPV Controller design

We synthesize a robust controller for the dynamics in each of the horizontal and vertical planes using the interconnection shown in Figure 3. The plant G_i represents the rigid body dynamics and the neglected flexible modes are accounted by means of additive uncertainty using the weight W_Δ. The dash-dotted line in Figure 2 shows the frequency response of this uncertainty weight and it encompasses the flexible dynamics. The weighting function W_y determines the desirable disturbance attenuation / sensitivity profile for various frequencies. In general, the desirable frequency response of the sensitivity is shown by the solid line in Figure 5. In order to reject the mass-imbalance disturbances at a particular rotational speed, we incorporate a notch in the closed-loop sensitivity. Our desired profile for sensitivity is shown by the dashed-line in Figure 5.

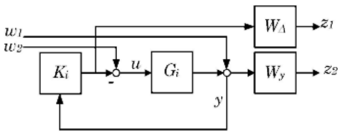


Figure 3: Design of robust controller.

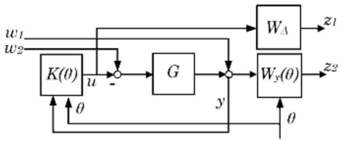


Figure 4: Design of LPV Controller.

In order to reject disturbances for various operating points we use a rotational speed dependent performance weight. The frequency response of the desirable sensitivity function for various values of the rotational speed is shown in Figure 6. We synthesize an LPV controller that depends on the rotational speed measurement using the interconnection in Figure 4. In each of the designs, the controller synthesis is posed as a convex optimization problem to minimize the energy gain between the input-output channels.

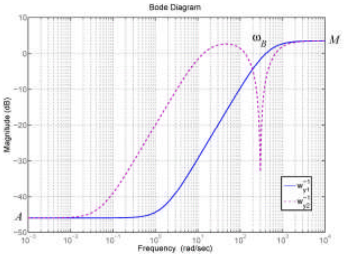


Figure 5: Sensitivity for robust controller.

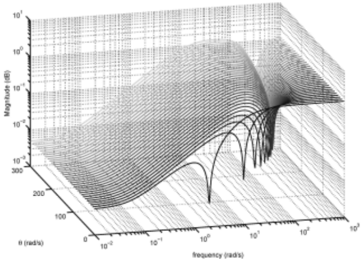
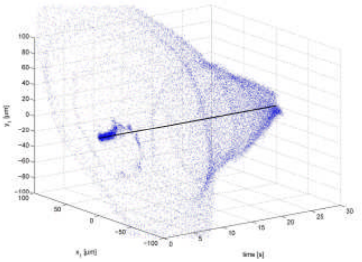


Figure 6: Sensitivity for LPV Controller.

4 Experimental Results and Conclusions

We evaluate the performance of the robust LPV controllers on the experimental active magnetic bearing setup, the MBC 500. The controllers are synthesized using MABTLAB and loaded on to the DSPACE DS1103 processor using a SIMULINK interface. We design and implement a robust controller with a notch corresponding to a rotational speed of 2800 rpm. The LPV controller is synthesized for disturbance rejection over a range of rotational speeds from 0 rpm to 2800 rpm. With each of the controllers, we accelerate the spindle from stand-still up to a rotational speed of 2800 rpm in about 30 seconds. The displacements of one end of the spindle with the robust and LPV controllers are shown in Figures 7 and 8 respectively. Clearly the LPV controller outperforms the robust controller over the entire range of rotational speeds. The measured displacement shown in the figures is in micro-meters.



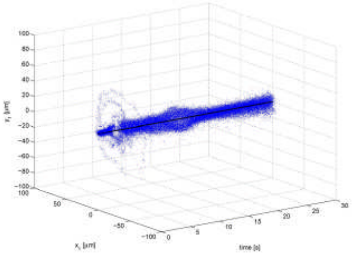


Figure 7: Displacement - robust controller. Figure 6: Displacement - LPV Controller.

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