IDENTIFICATION AND CONTROL OF CONTROL DELAY FOR DIGITAL CONTROL MAGNETIC BEARING SYSTEM

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***Abstract* – The delay time of an active magnetic bearing (AMB) digital control system with a decentralized PID controller is measured. Numerical simulation results of time delay effects on the dynamic performance of a 2-axis controlled active magnetic bearing rotor system (AMBRS) are presented. An investigation of reducing time delay effects using a Smith predictor controller is also introduced. Experimental results show that the scale of delay time is from decades to hundreds microseconds. Furthemore, the simulation results indicate that time delay mainly affects journal center orbit, And results in the instability of the first natural mode of AMBRS. The simulation results also prove that Smith predictor is very effective in reducing time delay effects.**

***Index Terms* – Digital Control Active Magnetic Bearing; Time-Delay; Rotor dynamic;**

I. INTRODUCTION

Magnetic bearings have found wide applications in fields such as aerospace, petrochemical and power generation industries due to its advantages over traditional rolling or sliding bearings. Like conventional mechanical bearings, active magnetic bearings are nonlinear in nature. This nonlinear characteristics cause nonlinear motion of rotor supported by them. Various nonlinear studies have been carried out on active magnetic bearing rotor system.

This paper is concerned with the measure and control of time delay of real digital feedback control active magnetic bearing system(shortly: AMBs). In a typical digital feedback control active magnetic bearing system, control time delay is caused by sensors, amplifier, digital operator, and so on. Magnetic bearings are open-loop unstable which means closed-loop control is necessary for stable operation. Usually, such classical feedback control techniques as PD of PID are used. Increasing demands for higher precisions and higher rotor speeds have generated strong interest in the effect of time-delay factor in the AMB system. In the past, we think control time delay is smaller than other time factor in active magnetic bearing systems; it only has tiny influence and can be neglected in system design. In general, it is true. Of curse, more complete control methods should be applied according to practical need[7,8]. Therefore, It is difficult that these complete control methods was implemented by the analogy circuits, so the digital controller have been utilized in a variety of applications[5,6]. However, as active magnetic bearing system have been used in higher rotating speed and higher precision system, the influence of time-delay on the stability and journal center orbit of a active magnetic bearing system has received little attention in the modeling and analysis of the systems[1,2,10].

Specifically, it is possible to collect experimental data on the nominal performance of the mechatronic control systems, and then use a software environment to predict performance changes in these behaviors for different rotor speed, load, time-delay, etc. conditions. In essence, the experimentation is being used to capture the nonlinear factor performance. Simulation is only being used to predict the changes in system performance and is not used to predict the system behavior. So, the paper is organized as follows. In Section II preliminary results are collected for the time-delay of AMBs control systems. The Numeric Simulation results are presented in Section III, and Smith predictor controller are used to reduce time-delay effects in Section IV. Finally, In section V some conclusions are presented.

II. Experimental Measurements

First of all, in order to study the influence of time delay in active magnetic bearing system, we must know how much it is. There are variety sources of time-delay factor in each mechatronic control systems. An even more difficult problem is determining how to accurately time-delay in each sub-system. Normally, it is possible to estimate the scale of time-delay via the experimental measurements. But, now there is a little attention to this work in the AMB systems. Time delay models for sensors, amplifier, and digital operator in active magnetic bearing systems are present and analyzed here. In this section, An AMBs is used in the experiments to show the turnaround time of a task. Then the scales of those time delays are measured in a real active magnetic bearing – rigid rotor system with a decentralized PID controller in dsPACE tools.

dsPACE real-time simulation system is a engineering tools for developing and testing mechatronic control systems, which developed by the German DSPACE company. The system based on a semi-physical development and the software/hardware simulation platform, the fully realized seamless connection with MATLAB/Simulink/RTW. At same time, they also as specifically designed for the implementation of high-speed multivariable digital controllers.

So, a Simulink diagram that based on the PID controller and the low-pass filter are demonstrated in Fig.1 to show the delay time of a task.

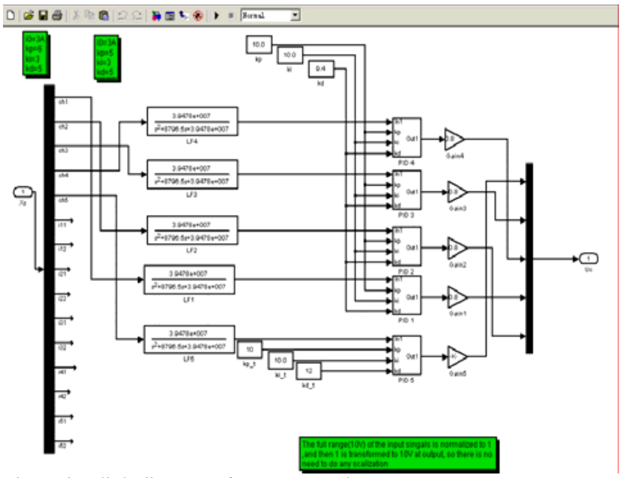

Fig.1 simulink diagram of AMB control system

In our dsPACE experiment system, the control system throughput frequency is 10KHz. And the A/D, and D/A modules throughput frequency are 100KHz. The CPU of system is PowerPC 750 processor. As we know, the calculation time of CPU is high related with the number of control channels. So, the service time with several control channels are shown in Table.1. These experimentation date are captured accurately via the inter function of dsPACE system: turnaroundtime.

Table 1 Service time with several control channels

Number of control channels	**Service time** (uS)
0 (direct connect between input with output)	39.5
2	41.6
4	43.5
5	44.2

It can be seen from Table.1 that when digital controller is used in AMBs, the service time of control system is significant. As an example, the throughput frequency of the A/D and D/A modules usually is 100KHz, which can success in work with normal mechatronic control systems, and their service time are both 10 microsecond. It is also noted that the digital operator calculation time of system with conventional PID controllers and low-pass filters is increased by 100% from two control channels to five control channels. As simple control algorithms, the service time of processors calculation is occupies only a small proportion in the total control time. While the completer control methods, the time-delay will increase remarkably. Specially, the control system of AMBs always includes five control channels, with four axial channels and one thrust channel. It can be seen from Table.1, while the AMBs worked in 60,000rpm, the service time of this dsPACE control system reach about 43μs, which is about 4% of the period of this system. Therefore, all these results present some suggestions for reducing time-delay should be considered for building a better digital controller of active magnetic bearing system to share the time resource.

III. FORMULATIONS OF MODEL

Here a rigid rotor system model with two-degrees-of-freedom(2DOF) [10, 11], as shown in Fig.1 is used for analysis., which can account for the effects of time-delay, is adopted. The State equation can then be written as

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t-\tau) \\ t > 0, x(0) = x_0 \\ y(t) = Cx(t) \end{cases} \qquad (1)$$

Where $x \in R^n$, $y \in R^p$, $u \in R^q$ are state variables,output variables and control variables respectively, $\tau > 0$ is time-delay coefficient.

With

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \qquad B = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 1 \end{bmatrix},$$

$$u(t) = \begin{bmatrix} 0 \\ 0 \\ -\mathrm{F_x/m} + \mathrm{e_x}\omega^2\cos(\theta) + \mathrm{e_y}\omega^2\sin(\theta) \\ (-\mathrm{F_y} + \mathrm{mg})/\mathrm{m} + \mathrm{e_y}\omega^2\cos(\theta) - \mathrm{e_x}\omega^2\sin(\theta) \end{bmatrix}$$

where F_x and F_y are the horizontal and vertical of magnetic forces of active magnetic bearing; e_x and e_y are the horizontal and vertical of mass eccentricity. It can be the angular speed of rotor ω, rotation angle θ, rotor mass m, etc.

IV. Numeric Simulation

One of the main advantages of simulation is that it is easy to manipulate the parameters and then to study the changes in the outputs. Numerical simulation results of time-delay influence on the dynamic performance of a 2-axis controlled active magnetic bearing rotor system (AMBRS) are presented, through shooting method and path-following technique[3,4,9].

The orbit of the center of the rotor is presented in Fig.2 at ω=50000rev/min when time-delay factor is not considered. The corresponding orbit of the center of the rotor at ω=50000rev/min and time-delay τ=40us is depicted in Figure.2, too. It can be seen from Fig.2 that the time-delay has increased the orbit of the center of the rotor. A orbit of the center of the rotor appears at ω=85000rev/min and time-delay τ=40us, which is depicted in Fig.3 . And the Fig.3 indicates the system is instable and the time-delay causes degradation of stability

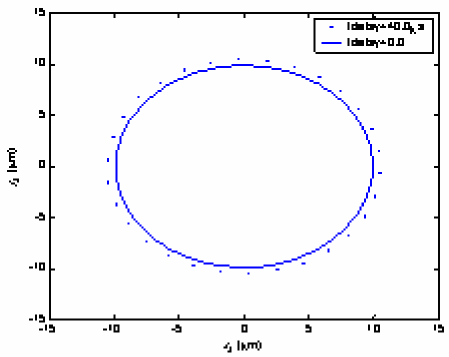

Fig.2 the orbit of the center of the rotor at ω=50000rev/min

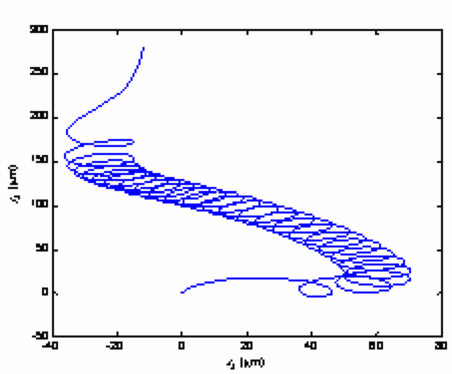

Fig.3 the orbit of the center of the rotor at ω=85000rev/min and τ=40us

All these results indicate that time delay mainly affects journal center orbit, results in the instability of the first natural mode of AMBRS.

V. METHOD OF SOLUTION

Therefore, all these results present the time-delay factors should be compensated for building a better digital controller of active magnetic bearing system to share the time resource. At the same time, an attempt to improve control strategies on compensation for time delay is made. Because of the distinctive characteristics, time delay is even now a difficult and unresolved completely problem in control engineering. Therefore many compensation methods of it have been proposed so far. The most famous one of them all is Smith predictor. It is a kind of prediction method and equivalently eliminates time delay from closed control loop. [11,12,13]

In order to check this method, a state feedback controller with Smith predictor has been proposed for AMBs. And a computer simulation with Matlab/Simulink tools is showed in Fig.4.

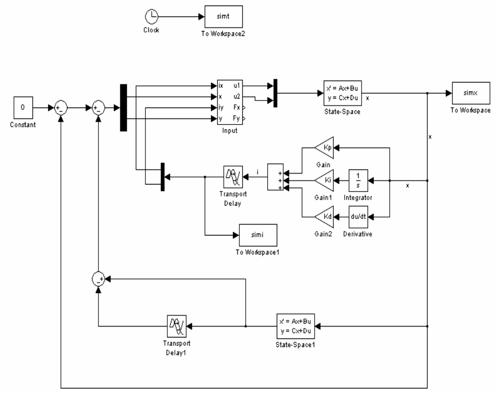

Fig.4 Simulink diagram of AMB control system with Smith predictor

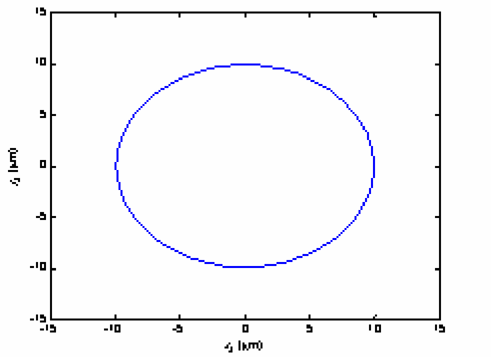

Fig.5 the orbit of the center of the rotor at ω=85000rev/min and τ=40us with Smith predictor

It can be seen from Fig.5 that the orbit of the center of the rotor is stable. The simulation results show that the stability of rotor system is well improved, and Smith predictor is very effective in reducing time delay influence.

VI. CONCLUSIONS

In this paper, the effect of the time-delay on an active magnetic bearing-rigid rotor system has been investigated. Using experiment measure method, the scale of the control system time-delay is presented. The 2-DOE system equations are obtained. Numeric simulation is used to get the influences of the time-delay in the AMBs. The results indicate that the time-delay has great influence on the orbit of the center of the rotor and stability of system, and causes degradation of stability and increasing the orbit of the center of the rotor. Then the Smith predictor used to compensate the effects of time-delay in the control system. And The simulation results show that stability of rotor system is well improved. Therefore sufficient attentions should be paid to the time-delay effects due to the neglect of AMBs in the dynamic analysis and design of rotor systems equipped with digital control in order to ensure system reliability and real-time. At last, the using of Smith predictor in control system is very effective in reducing time delay influence.

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