Nonlinear Modeling and Co-Simulation with MATLAB, ADAMS and ANSYS for Active Magnetic Bearings

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Abstract: A new nonlinear model for AMBs is developed and co-simulation is carried out by combining ADAMS, MATLAB and ANSYS. The prototype model of AMBs system is obtained and can be used for co-design. The 1-degree-of-freedom (1-DOF) static levitation of axial magnetic bearing and the 2-degree-of-freedom (2-DOF) static levitation of radial magnetic bearing are respectively realized. The 5-degree-of-freedom (5-DOF) AMBs linear system has also been levitated steady and the system has a good control performance. Simulation results verify the correctness of the AMBs model which is based on the virtual prototype technology.

Keywords: AMBs, MATLAB, ANSYS, ADAMS, Co-Simulation

1 Introduction

Active magnetic bearing system is one of the typical mechatronic systems. Compared with the conventional bearing, AMB has a lot of advantages. However, AMB system is an inherently unstable and nonlinear control system. AMB needs a lot of mechanical components and thus the structure is complex, since it is difficult to guarantee the reliability and safety of AMB. Therefore, to design an effective controller for AMB is the most important work.

ADAMS is one kind of professional software with powerful simulation function in the field of virtual prototype, and can deal with simple control of simple models. However, for complicated models, such as AMBs system, it is difficult to express the operation of the AMBs system exactly only with ADAMS. However, ADAMS/Controls module provides data interface for ADAMS and other kinds of control software such as MATLAB. So it becomes possible to realize co-simulation between the mechanical system and the control system to achieve relatively practical simulation of the complex system by using ADAMS and MATLAB.

Co-simulation by combining simulation tools for mechanical systems with design tools for control systems and calculation tools for electrical systems has many advantages. Problems can be solved from the harmony among the mechanical, control and electrical system. Simulation model of the mechanical system can be obtained directly from its dynamic model in ADAMS, and consequently it has no need for writing complicated equations to express the mechanical system. Therefore, the modeling procedure can be simplified greatly. Paper [1] proposed a co-simulation model of axial magnetic bearing, and paper [2] proposed a co-simulation model of magnetic suspended rotor system, but they all ignored flux nonlinear of magnetic bearing.

In this paper, considers flux nonlinear of magnetic bearing, a new nonlinear model for AMBs is developed and co-simulation is carried out by combining ADAMS, MATLAB and ANSYS. This makes it very feasible to design advanced control algorithms for the AMBs.

Firstly, the mechanical system of a 5-DOF AMBs system is built in ADAMS, and the finite element model of the AMBs is built by using ANSYS, then controller model is set up in MATLAB. The prototype model of the AMBs system is obtained and can be used to co-design. The schematic of the AMBs system are briefly described in section II. System design process is then given in details in Section III. Simulation results in Section IV are given.

2 Magnetic Bearing Systems

Fig.1 shows the structure of a 5-DOF active magnetic bearings system. The AMBs system consists of a rotor, five sensors, one controller and three AMBs.
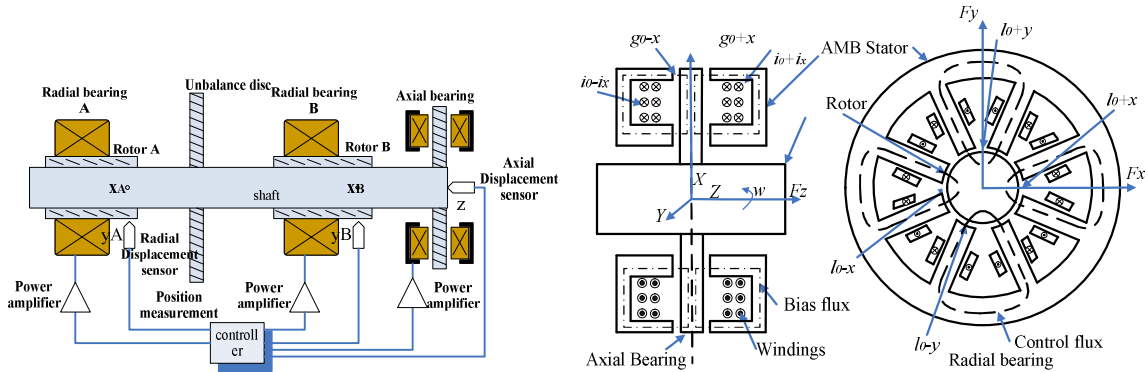

Fig.1 Structure of 5-DOF active magnetic bearing system   Fig.2 Schematic of the AMBs and the force diagrams

Fig.2 illustrates the working principle of the AMBs. The axial bearing consists of two magnetic actuators on each side of a thrust disk. The magnetic actuators in this setup are reluctance type actuators which consist of circular u-shaped cores with tangentially wound coils [3,4]. And an 8-pole magnetic bearing now has four pairs of horseshoe magnetic circuit as shown in Fig.2 [3,5]. The forces of the magnetic bearings depend on current and displacement in a non-linear way. The relation can be defined as follows,

$$F = \frac{\mu_0 A_0 N^2}{4}\left[\left(\frac{i_0 + i_x}{g_0 + x}\right)^2 - \left(\frac{i_0 - i_x}{g_0 - x}\right)^2\right] \quad (1)$$

Where μ_0 is the magnetic permeability of air, g_0 is the air gap, x is the position of the shaft, A_0 is the area of pole pair, i_0 is the bias current, i_x is the control current, N is the number of windings. From Eq. (1), the force can be linearized as,

$$F_z = K_{iz}i_z + K_z z \quad (2)$$

$$K_{iz} = \frac{\mu_0 A_0 N^2 i_0^2}{g_0^3} \quad K_z = \frac{\mu_0 A_0 N^2 i_0}{g_0^2} \quad (3)$$

Where K_{iz} and K_z is the force current stiffness and the force displacement stiffness respectively. K_z is often referred to as the negative stiffness of bearing. Table 1 lists the main dimension of the AMBs system.

Table.1 Specifications of the AMBs system

Main Dimension of the AMB system			
axial bearing properties			
Pole shoe surface	A_a	522.89	$[mm^2]$
Number of windings	N_a	100	-
Air gap length	g_0	0.3	$[mm]$
Bias current	i_a	2	$[A]$
axial bearing properties			
Pole shoe surface	A_r	382.02	$[mm^2]$
Number of windings	N_r	60	-
Air gap length	l_0	0.2	$[mm]$
Bias current	i_r	1.5	$[A]$

3 Modeling and Control of the AMBs
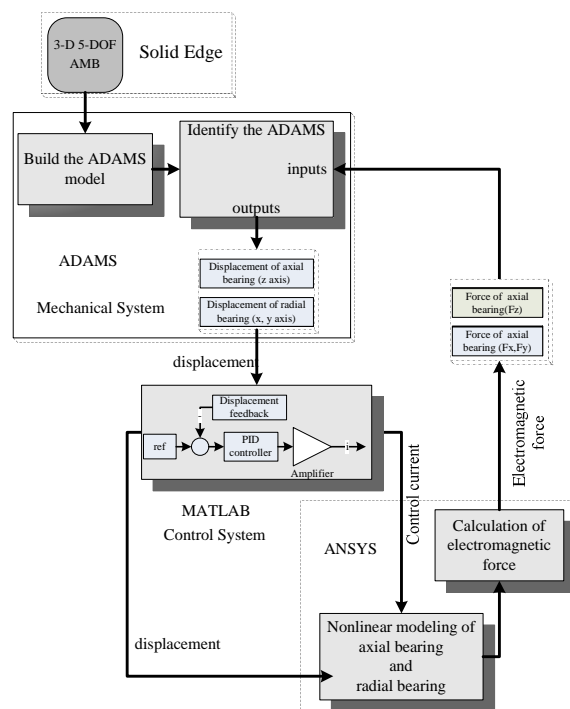
Fig.3 Integrated co-simulation diagram of the AMBs system

A three-dimensional (3-D) model for a 5-DOF AMBs system is built in SolidEdge and imported into ADAMS, and the finite element model of the AMBs is built by using ANSYS, then controller model is built in MATLAB. ADAMS/Controls software is applied to simulate the mechanical system, ANSYS is used to calculate for calculating the electromagnetic forces in the AMBs and MATLAB/Simulink is to simulate the control system. The integrated co-simulation diagram for the AMBs is shown in Fig.3.

3.1 Mechanical system model of the AMBs

The ADAMS model is generated by using SolidEdge software and imported into ADAMS in Parasolid format [6]，as shows in Fig.4. Making use of ADAMS/Control module, all the ADAMS input and output variables of mechanical system module of the AMB system are identified, as shown in Fig.5.
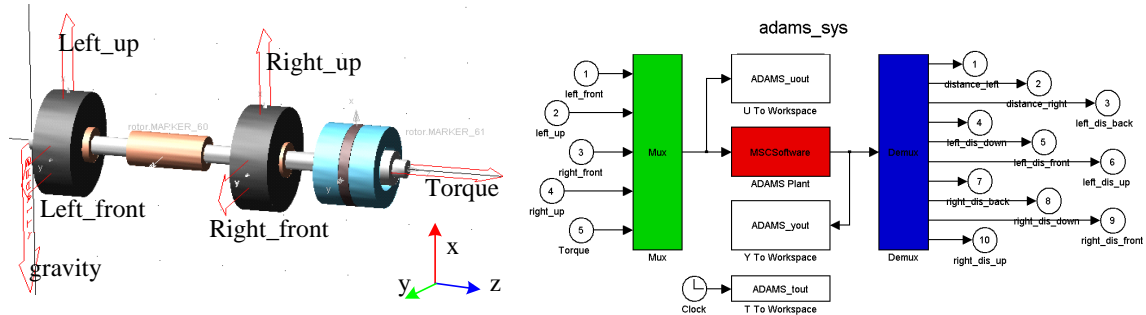

Fig.4. Virtual prototype model of the AMBs   Fig.5 Mechanical system module of the AMBs

3.2 Finite Element Model of the AMBs

Based on 2-D finite element method, using ANSYS APDL macro technology organization and management with the ANSYS finite element analysis of the command [7,8], a nonlinear model of the AMBs is set up in ANSYS .Fig.6 shows the finite element model of the axial bearing. Fig.7 shows the finite element model of the radial bearings.
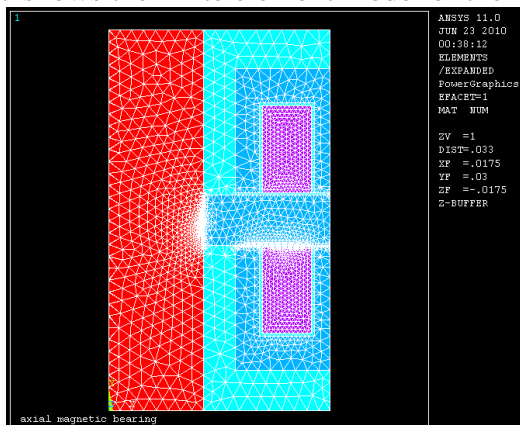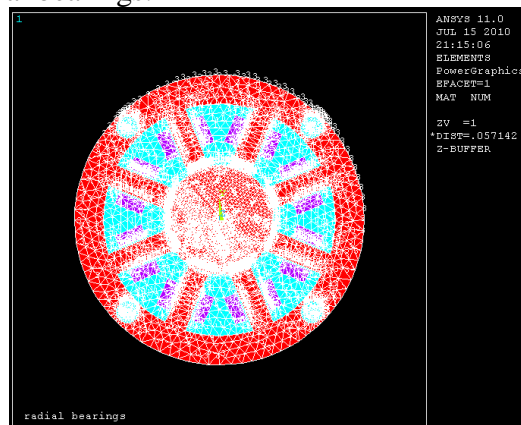

Fig.6 Finite element model of the axial bearing   Fig.7 Finite element model of the radial bearings

3.3 Control system module of the AMBs

Control system module of the AMBs is built in MATLAB/Simulink environment. A PID controller is designed as shown in Fig.8. The axial bearing control system and radial bearing control system are built as shown in Fig.8 and Fig.9. MATLAB calls on ANSYS program through S-function as in Fig.8. The electromagnetic forces of the axial bearing and the radial bearings are calculated respectively by ANSYS. By means of control module in ADAMS platform, Simulink is integrated and the integrated co-simulation model of the AMBs system is developed, as shown in Fig.10.
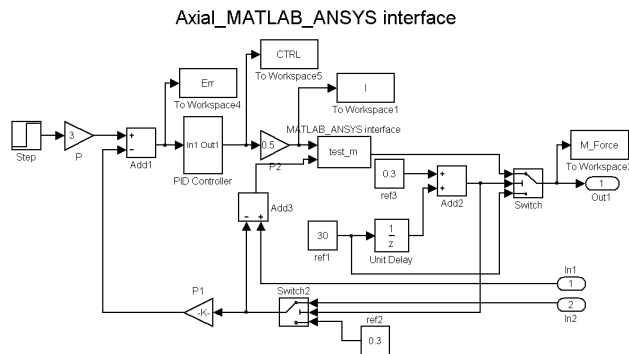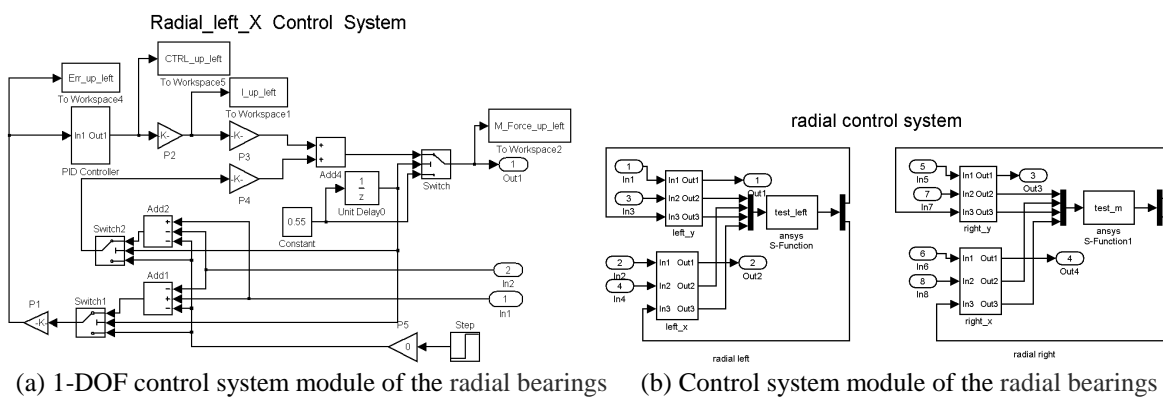
Fig.8 Control system module of the axial bearing

(a) 1-DOF control system module of the radial bearings   (b) Control system module of the radial bearings

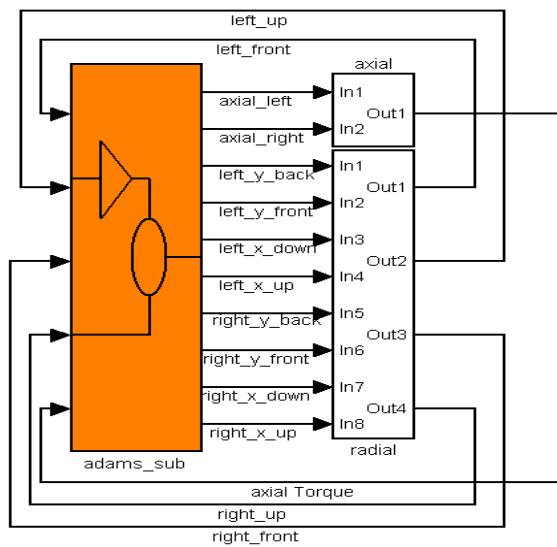Fig.9 Control system module of the radial bearings

Fig.10 The 5-DOF control system module of the AMBs

4 Simulation Results

Based on the co-simulation model of the AMBs system, the system behavior is investigated. The controller parameters of the AMBs system are adjusted and the results are obtained.

Simulation time from 0 to 0.005 s, constant force is imposed on each bearing respectively for a biased displacement as listed in table 2.

Table.2 Initial test condition

Test Conditions		Outer Interference Force(Fn)[N]	Time Disturbance[s]	w[rad/sec]
Axial bearing		30		
Radial bearing				
x	left	1.5	0.005	0
	right	0.55		
y	left	10		
	right	2		

Fig.11 shows the simulation results about step response and dynamic error curves of non-linear force and linear force of the axial magnetic bearing, in which "axial_adams" is the linear force model and "axial_adams_ansys" is the non-linear force model. In contrast, we can see that non-linear force model has a better control performance for 0.0004 s of its rapid response speed, 3% smaller overshoot and strong robustness with the same control parameters.

Fig.12 shows step response and dynamic error curves of the radial magnetic bearings. As can be concluded, response speed, overshoot and settling time of left and right radial magnetic bearings from the left radial magnetic bearing has better control performance than those from the right radial magnetic bearings with the same control parameters.

Compared with article [1, 2], the results show that this system has a better control performance for its rapid response speed and strong robustness.
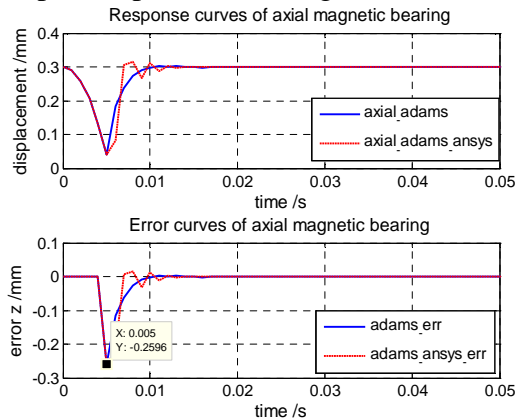

Fig.11 Response curves and error of no-linear and linear model of the axial magnetic bearing

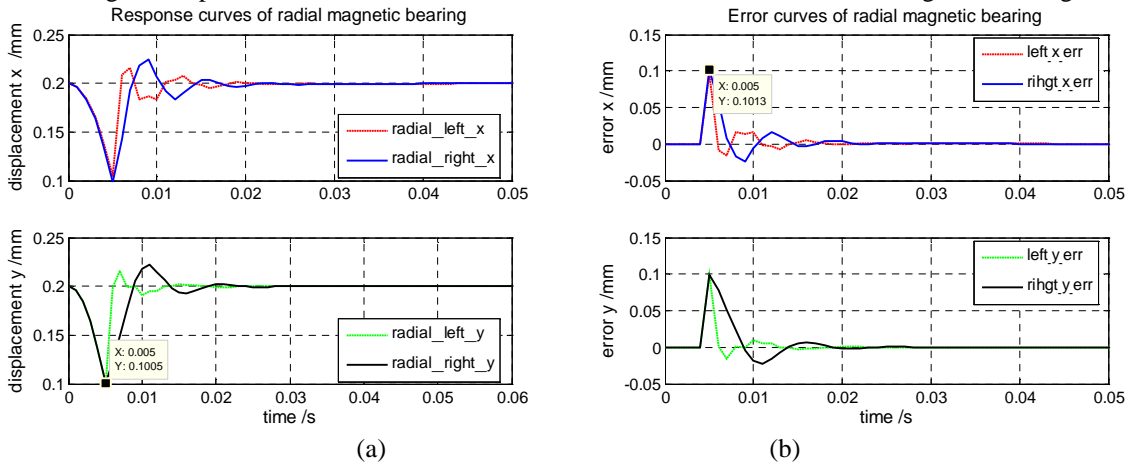(a)   (b)

Fig.12 Response curves (a) and error (b) of the radial magnetic bearings

5 Conclusions

The virtual prototype of a 5-DOF AMBs system is set up by using the software ADAMS, MATLAB and ANSYS. The simulation results verify the feasibility and correctness of the initial structure design for the AMBs system. Simulation experiments also indicate non-linear modeling and co-simulation technique based on ADAMS, MATALB and ANSYS can greatly simplify the design process of an AMBs system. Thereby the design efficiency is improved and the production cost is reduced. It is a very effective design method for modern active magnetic bearings system.

Acknowledgment

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