The Levitation Control Simulation of Maglev Bogie Based on Virtual Prototyping Platform and Matlab

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Abstract

Maglev train is a complex coupling system. In the past, differential equations are applied to describe the system model. It is difficult to simulate the system with this conventional method. The advanced virtual prototyping technology is applied to set up a 3D model and to simulate the levitation controlling system, which avoids the difficulty of describing differential equations. The simulation results are given at the end of the paper, which accord with the results of experiments. The results prove the correction of the virtual prototyping model. This paper effectively combines the virtual prototyping technology with the maglev system studying.

1 Introduction

The virtual prototyping technology, is involved with multi-body kinematics and dynamics, is based on the integrative application of the advanced modeling, multi-field simulation, information control, interactive interface and virtual reality technology. And it is playing an important role in the auto-control industry because its simulation system is convenient to modeling, and offers reliable results, and helps to rapidly explore products[1-3].

Maglev train is a new kind of vehicle which is lifted by magnetic force and driven by linear motor[4]. The maglev system is one of ideal vehicles because it will offer the advantages of lower noise and emissions and better ride quality, as well as potential energy savings and economic benefits[5]. As a controlling object, maglev train is a complex coupling and unstable system. There needs many hypotheses to describe and simulate the system with differential equations. References [6-10] regarded the levitation controllers as spring and damping; references [11,12] regarded controllers as uncoupled ones and designed controllers for one point. These hypotheses may neglect some important factors of the system and make the result less creditability and persuasion. In this paper, virtual prototyping technology is applied. The digital model of maglev bogie is built in ADAMS software. The model simulates the real system in vision, in function, in machine performance, in force and in motion. It replaces conventional real prototyping with digital analysis to simulate levitation control system and analyze the system performance, which may provide reliable reference for levitation controller design.

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2 The virtual prototype model

It needs two steps to set up the virtual prototype model. The first is to build the 3D model of components. The second is to assemble all components together by real connection and force into the object model.

2.1 The 3D components in SolidWorks

The virtual prototype software-ADAMS is applied here. Because ADAMS is weak in 3D modeling, SolidWorks is applied to build the components. The test system of maglev bogie mainly includes: magnet, pole, roll-beam, and box girder, which are shown in figure 1.

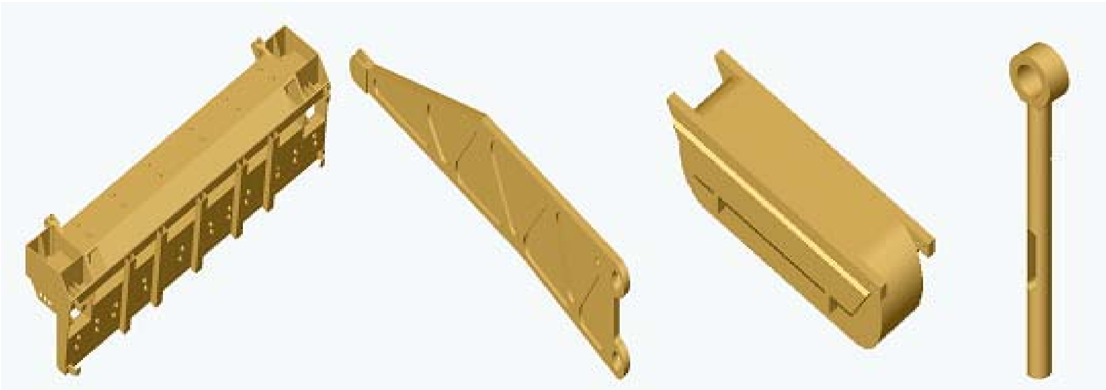


Fig.1 The main components of maglev bogie

2.2 The virtual prototype model in ADAMS

The components built in SolidWorks are imported into ADAMS and assembled into the virtual prototyping model according to the real connection and force. Detail connects and forces are listed in references [13, 14], and the main connections and forces are introduced here:

1) Airsprings connect the floor of bogie and box girder. The character of each airspring is shown in table 1.
2) The electromagnetic force: There are eight magnets in a bogie. They are divided into four groups. Four resultant forces are applied at the middle of each group to simulate the electromagnetic force. The force expression is:

$$F=\frac{dW_m}{dz}=\frac{d}{dz}\int I(t)d\psi=N\frac{d}{dz}\int I(t)d\phi_m=\frac{\mu_0 N^2 A}{4}\left[\frac{I(t)}{z(t)}\right]^2 \quad (1)$$

3) The components mass should be set in ADAMS, or the simulation will fail.

At last the maglev bogie model is shown in figure 2.

Tabel.1 The character of airspring

Design length(*cm*)	Load(*kg*)	Pressure(*kg/cm²*)	Stiffness(*kg/cm*)	Frequency(*Hz*)
26.67	680	1.85	65	1.54
	1360	4.3	120	1.37
	2000	5.5	147	1.34
	2500	6.8	175	1.32

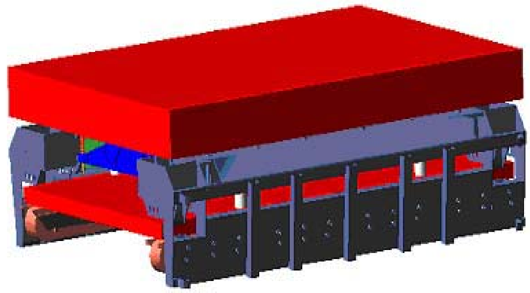


Fig.2 The maglev bogie model

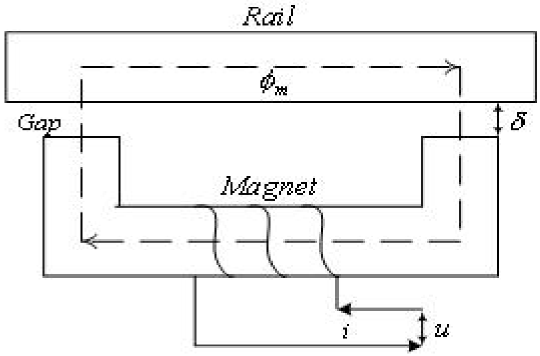


Fig.3 The magnet shape and magnetic field

3 The simulation of maglev levitation control

3.1 The voltage-balance formulation

The CMS-3 maglev train in National University of Defense Technology belongs to EMS. The magnet shape and magnetic field are shown in figure3.

Suppose the inductance is constant near the equilibrium point because the gap between the magnet and rail keeps fixed. So the voltage balance equation is:

$$u = R \cdot I + \frac{\mu_0 A N^2}{2\delta_0} \cdot \dot{I} \qquad (2)$$

where μ_0 is the free-space permeability, A is valid area of magnet, N is the circles of coil, R is the resistance of the coil, δ_0 is the given gap, and I is the current.

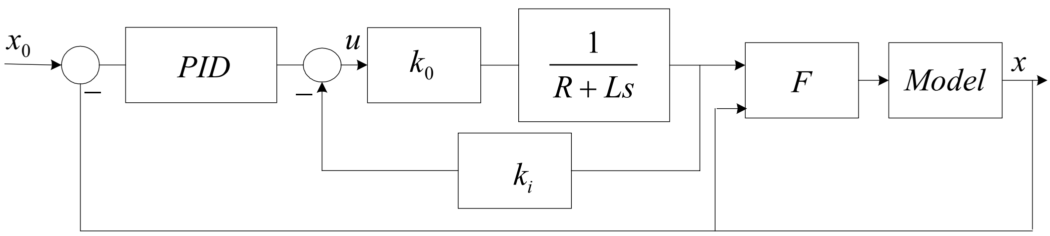


Fig.4 System transfer function diagram

3.2 The levitation control system design

The series module control design is mature. The control system is composed of preceding controller and current loop[15]. Current loop means current feedback and preceding controller applies PID method. The system transfer function diagram is shown in figure4.

In the system the parameters are set: $N = 324$, $A = 0.021m^2$, $m = 750kg$, $R = 0.5\Omega$, $L = 0.05H$, $\delta_0 = 8mm$. And the controller design refers [16].

3.3 Matlab controller

Because ADAMS has interface with Matlab, the controller is designed in Matlab[17], which has perfect control function. And figure 5 clearly exhibits the input and output of the system. Designer must make sure of these before controller design.

1) Set up the input and output in ADAMS. There are two output signals: one is the gap between magnet and rail; the other is the differentiation of the gap. There is an input signal: current, which is consistent to I in equation (1). The virtual prototype model is exported into Matlab in virtue of the interface between ADAMS and Matlab.

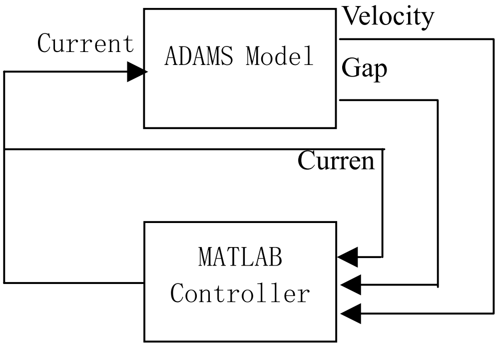


Fig.5 Input-output relation

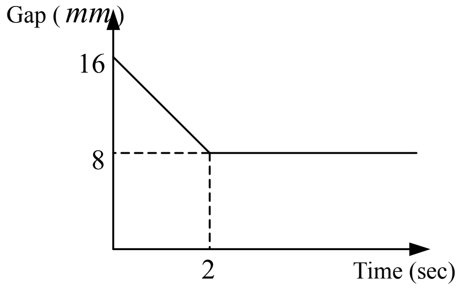


Fig.6 The reference signal of rising

2) Import the information of virtual prototype model in Matlab workspace and finish the controller design in simulink. The information includes the input and output of model and module that represents the model in simulink. There needs four controllers in a bogie.

3.4 The system simulation

Two simulations have been finished here to compare with the experiments. One is the process of rising; the other is the test under square wave excitation.

3.4.1 The simulation of the process of rising

The initial gap is 16mm and the expected gap is 8mm. In view of comfortability, special method is designed to lift the bogie slowly. During the process of rising, the expected gap follows the signal, which is shown in figure6.

The result is shown in figure7. The system follows strictly the signal shown in figure6 and the overshot is little. This realizes the smooth levitation.

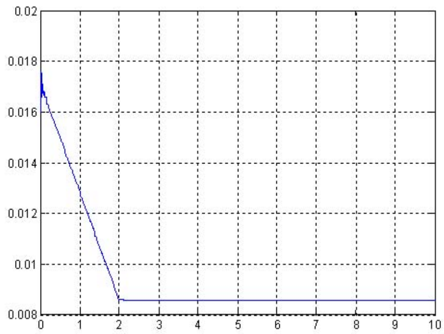


Fig.7 The result of rising

3.4.2 The test under square wave excitation

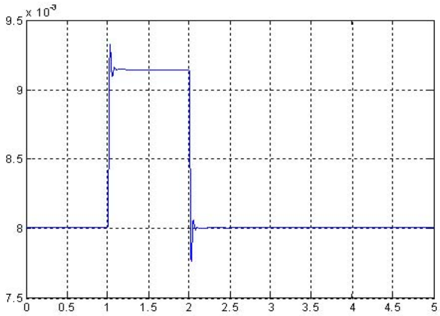


Fig.8 Response of excitation point

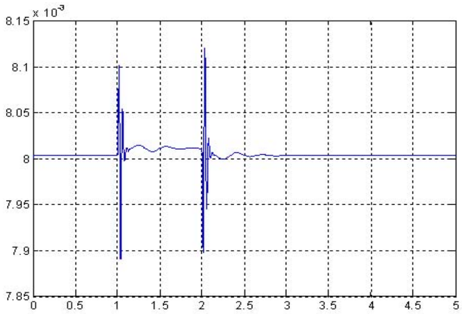
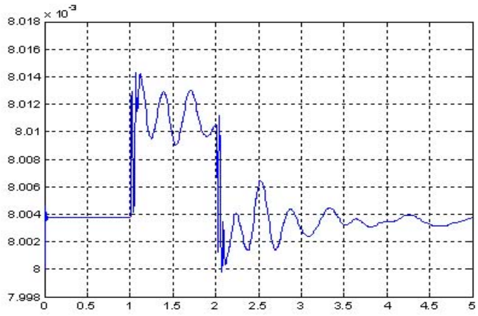


Fig.9 Response of homolateral point

After the system getting balance, a square wave excitation is used to test the system dynamic performance, which includes system damp and coupling of four controllers. The results are shown in figure 8-11. The overshot of system is about 10%, which is calculated from figure8. The disturbance amplitude in figure 9 is greater than that in figure 10 or figure 11. This means the coupling degree of homolateral points is greater than antarafacial points.



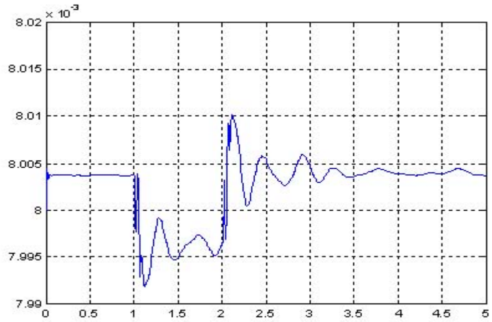


Fig.10 Response of one antarafacial point **Fig.11 Response of the other antarafacial point**

4 Conclusion and prospect

In conclusion, this paper sets up the virtual prototyping model of maglev bogie and simulates the system. The simulation results demonstrate the correction of model and the reliability of the results. Maglev train and virtual prototyping technology can be combined to set up a 3D dummy computer simulation platform, which includes dynamic modeling, control and visional simulation. This platform can provide such functions that optimizing structural and dynamic parameters and validating control algorithm. This will be a new research region of maglev technology.

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