The Study on the Virtual Prototype Modeling of MAGLEV Train

Haiyan Qiang^{1,a*}, Shaoping Chen^{1,b}, Chuanzhen Li^{1,c},
Bojing Long^{1,d} and Kaiwei Zhang^{1,e}

¹No.1550, Haigang Avenue, Pudong New District, Shanghai, China

^ahyqiang@shmtu.edu.cn, ^b593169531@qq.com, ^crobinli96@sina.com, ^d1992190925@qq.com,
^e1332850103@qq.com

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Abstract. In view of the strong nonlinearity for suspension system of maglev train and the weak robustness problems of traditional PID controller with external disturbance, firstly, a mathematical model of the magnetic levitation control system has been established. A virtual prototype model of the maglev train has also been established by ADAMS. A self-tuning fuzzy adaptive PID controller which is suitable for the maglev suspension system has been designed by utilizing fuzzy rules to adapt PID parameters on-line. Simulation experiments by virtual prototype verified the anti-interference and strong robustness of the system whose control performances are superior to the traditional PID controllers to overcome interference in practical engineering.

Introduction

In order to overcome the mechanical contact between the wheel and rail and greatly avoid the friction between the wheel and rail, the maglev train came into being. At present, Liming Dai, Bin Qi, Haibo Zhou et al [1] have designed the magnetic levitation controller based on the nonlinear model for the PID control of the magnetic levitation platform. The parameters are adjusted manually on the PID principle, and the adaptive adjustment of the parameters is not involved. Wenrong Song, Yanfeng Wang et al[2] designed a similar PID controller in the magnetic micro feed mechanism of maglev. Yougang Sun[3] et al utilized a genetic PID method to improve the characteristics of controllers in the research and simulation of wave compensation system in offshore floating platform operation. In the control process of traditional PID for the maglev train, parameter adjustment is always adjusted manually by virtue of experience which will lead contingencies in PID parameter adjustment. Due to the inevitable error in manual parameter adjustment, the suspension performance may deteriorate with external disturbances. If the external disturbance is larger, the control performance will be worse, and even the instability which will cause serious accidents.

In addition, it is urgent to increase the research means on maglev train. In order to avoid difficult and time-consuming vehicle tests, virtual prototype technology is introduced in the pre-design stage. The theoretical researches and simulations in the static state of suspended maglev train will provide the reference for the future maglev train.

Establishment of maglev system model

Electromagnetic force model. According to the modeling and preconditions of the suspension frame of maglev train, the reluctance of the magnetic circuit is mainly concentrated on the air gap formed by the pole of the track electromagnet and the suspension frame of the train, as shown in Figure 1. Therefore, the reluctance of the entire magnetic circuit (the effective air gap reluctance) is :

$$R(x) = \frac{2x}{\mu_0 A} \quad (1)$$

where, x denotes the distance between levitation chassis and track electromagnet; A denotes

electromagnetic pole area; μ_0 denotes air permeability, and its value is $4\pi \times 10^{-7} H/m$.

Figure 1. Working principle diagram of levitation chassis

Then, based on the relationship between electromagnetic force and magnetic field energy provided by magnetic levitation system, the electromagnetic attraction force of the levitation chassis can be obtained where μ_0 , A , N are all constant. By defining $k = -\mu_0 K_f AN^2 / 4$, the electromagnetic force formula can be written as :

$$F(i, x) = k \left(\frac{i}{x} \right)^2 \quad (2)$$

The electromagnetic force formula shows electromagnetic force $F(i, x)$ is inversely proportional to the square of the air gap. Therefore, this causes a highly nonlinear magnetic suspension system.

System Dynamics Model. Considering the suspension of the four pressure points as particles, they only have downward gravity and upward electromagnetic force, and neglect external disturbances and perturbation of internal parameter. The dynamic equation in the vertical direction of the levitation chassis can be obtained in this way according to Newton's second law:

$$m \frac{d^2 x(t)}{dt^2} = F(i, x) - mg \quad (3)$$

where, $x(t)$ denotes instantaneous air gap between the lower surface of the levitation chassis and the pole of the electromagnet; m denotes the mass of suspension frame and part of the body mass, $F(i, x)$ denotes electromagnetic attraction; g denotes gravity acceleration.

Nonlinear model of the system. When the train is in a steady state of suspension (levitation chassis stable suspension), its force in the vertical direction is 0. In summary, the nonlinear mathematical model of a maglev train suspension system can be jointly determined by the following equations:

$$\begin{cases} m \frac{d^2 x(t)}{dt^2} = F(i, x) + mg \\ mg + F(i_0, x_0) = 0 \\ F(i_0, x_0) = k \left(\frac{i}{x} \right)^2 \\ U(t) = Ri(t) + \frac{di}{dt} \end{cases} \quad (4)$$

Virtual prototype modeling. ADAMS dynamic analysis software is used as a virtual prototype to simulate the suspension performance and observe the change of suspension gap and the change of suspension force in real time. Considering that the maglev train model is a large assembly composed of a plurality of complex feature parts, and in order to make the virtual prototypes and the actual objects have a high degree of similarity, Solidworks is used to model and assemble the various parts by using the special solid modeling and assembling. Finally, Import the model. As

shown in Figure 2.

Figure 2. Maglev train model in ADAMS

Figure 3. The constraint relationship

In the use of ADAMS simulation, the position of the various parts of the space should be coordinated. Through a variety of constraints, the relative movement between the various components to limit, and by adding force, the different components combined into a complete levitation chassis mechanical model, shown in Figure 3.

Controller design and simulation analysis

Simulink platform was used to design the controller during the research process, and the simulation was carried out with ADAMS dynamics software[12]. The control curve was output and the maglev train was observed in real time.

Controller design. Fuzzy PID controller design, the key lies in finding the proportion of links K_p , integral links K_i and differential links K_d and deviation e and deviation e_c of the rate of change between the fuzzy relationship. The choice of membership function is entirely dependent on the past experience of the controller design and the actual control effect. Considering that the control of the suspension system near the equilibrium point requires more accurate, so in the I / O domain is divided into 7. On the basis of classification, NM, NS, ZO, PS, PM adopt the triangular membership function with higher sensitivity, while NB and PB adopt S membership function.

Simulation analysis. Combined with the nonlinear dynamic model and the designed controller, we can observe the levitation condition of maglev train under suspension force in real time virtual prototype when analyzing the suspension condition. As shown in Figure 4.

Figure 4. Joint Simulink process based on ADAMS and Simulink

When using fuzzy adaptive PID controller to control the gap in real time, we need to get the control experience of the traditional PID controller to get a set or several sets of better control parameters. On this basis, the fuzzy parameters are used to adjust. According to the actual experience, the target gap is set to -9mm. Setting the initial PID parameter is $k_p = 5000$; $k_i = 450$; $k_d = 1050$;

The initial PID parameter is set as the change curve of the 6 clearance as shown in Figure 5~ Figure 7, and the performance comparison between traditional PID and fuzzy adaptive PID control is carried out in the figure. It is obvious that the control performance of fuzzy adaptive PID control is much better than that of traditional PID control.

Figure 5. Airgap variation curves

Figure 6. Airgap under the pulse disturbance

Figure 7. Airgap under the sinusoidal disturbance

Summary

In this paper, the magnetic suspension system is studied by virtual prototyping technology. The conclusions are as follows:

By building the solid model, the virtual prototype nonlinear dynamics test can better verify the simulation results of the fuzzy adaptive PID controller acting on the maglev train's static suspension.

The fuzzy adaptive PID controller can overcome the poor anti-interference ability of the traditional PID controller and so on. It has the ideal anti-interference and good robustness.

It can be used as a reference for solving the instability of the car body caused by the external disturbance in the static suspension state of the maglev train.

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