PID Control to Maglev Train System

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Abstract—**The advantage of linear PID control is easy tuning, but its obvious disadvantage is the conflict between the stiffness and the performance when this approach is applied to magnetic suspension system. In order to enhance the stiffness of the system, the usual way of linear PID control is to increase the proportion feedback, but this approach is likely to degrade the performance of the system and even make the system unstable. In order to tackle the problem between the stiffness and the system performance, an approach named nonlinear PID control method is introduced in the paper. This method combines the advantages of robust control and easy tuning. It can provide high stiffness and dose not influence the dynamic performance of the system around the operating point, which reinforces the system ability of resisting outside force impact. The implementation of the nonlinear PID control approach is introduced. The resisting impact capability of the two approaches is compared through experiments and the superiority of nonlinear PID control over linear PID control is demonstrated via experiments also.**

Keywords-maglev train; nonlinear; PID

I. INTRODUCTION

Magnetic suspension systems are widely used in various fields, such as frictionless bearings, high-speed maglev trains, levitation of wind tunnel models, magnetic isolation vibration[1] etc., and it is an important task to control the position of the levitated object since a magnetic levitation system is usually open-loop unstable. The linear PID control method is a easy-tuning way to stabilize magnetic suspension system [2][3]. Here take the maglev train as the research object. As the linear PID algorithm is concerned, the only way to enhance the system stiffness is to increase the proportional feedback coefficient. Usually, this coefficient is designed beforehand to ensure the system dynamic performance. It is proved by experiments that the change of proportional coefficient will degrade the system performance even make the system unstable. In order to get high stiffness the nonlinear PID control [4][5] is adopted in this paper. In reference (4,5), the control input is obtained through a exponential function, and the variables of this function are position and velocity of the research object. The exponents of that function are less than 1. It means that when the system departs from the operating point the feedback coefficients of proportion and velocity will reduce. On the contrary, we choose the exponents more than 1 in this paper. By doing that, the performance of the system will not change obviously. But when the system is apart from operating point, the stiffness of the system will increase rapidly so that it can be endured biggish outside force impact, which guarantee the suspension gap will not change too much and the maglev train will not contact the track.

II. MODELING

The maglev train system includes three subsystems in suspension direction. They are air spring system, track system and electromagnet system. Because the inherent frequency of the air spring is less than close-loop system enormously, so we can ignore the effect of air spring to system dynamic performance. And the research emphasis of the paper is the system stiffness, so we will not consider the flexibility of the track. The effect of track to system dynamic performance is researched in reference (6). By those assumptions, we present the sketch of maglev train system as the follow:

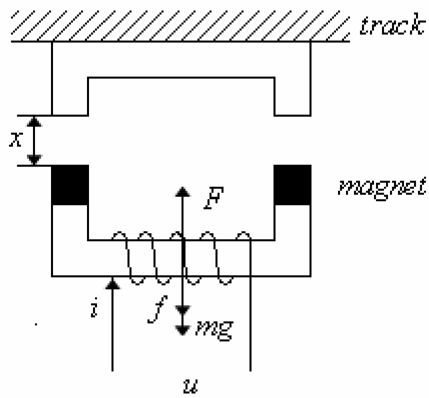

Figure 1. Sketch of maglev train system

And we can get the equations of maglev train system[7]:

$$\begin{cases} \dot{x} = y \\ \dot{y} = f/m + g - ki^2/mx^2 \\ u = Ri + \left(2k/x\right)\dot{i} - \left(2ki/x^2\right)\dot{x} \end{cases} \tag{1}$$

Where x denotes the magnet's position, y is the magnet's velocity, f is disturbance, g is the gravitational constant, k is the magnetic constant, m is the mass of the magnet, u is the applied voltage, R is the resistance of the coil and i is the current in the coil of the magnet.

Here, high-speed current-loop technology is applied to maglev train system. So the current delay of coil can be ignored and the current can be looked as the system input, then we can get the second-order maglev train system [8]:

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$$\begin{cases} \dot{x} = y \\ \dot{y} = f/m + g - ki^2/mx^2 \end{cases} \tag{2}$$

III. CONTROL ARITHMETIC

A. Linear PID Control

For the nonlinear PID control is based on the linear PID control, so we analyze the linear PID control at first. From the second section we know the current delay of coil can be ignored as the high-speed current-loop technology is applied to the system. Now we can look the current as the input and the third-order magnetic system is reduced to a second-order system. In order to imply the linear PID control, we linearize the second-order nonlinear system (2) is around the operating point:

$$\begin{cases} \Delta\dot{x} = \Delta y \\ \Delta\dot{y} = \dfrac{\Delta f}{m} + \dfrac{2ki_0^2}{mx_0^3}\Delta x - \dfrac{2ki_0}{mx_0^2}\Delta i \end{cases} \tag{3}$$

For concision, here we suppose: $\Delta f = 0$, then the linear approximate system(3) is transformed to the following equations:

$$\begin{cases} \Delta\dot{x} = \Delta y \\ \Delta\dot{y} = \dfrac{2ki_0^2}{mx_0^3}\Delta x - \dfrac{2ki_0}{mx_0^2}\Delta i \end{cases} \tag{4}$$

In order to predigest problem, we only analyze an actual magnetic suspension system. The parameters of the magnetic suspension system are as the follows:

$$k = 0.00545$$

$$m = 725kg$$

$$s_0 = 0.012m$$

$$f_0 = 7288.75N$$

$g = 9.8N/kg$ Substitute those parameters into (4), we can get the system state equations:

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 3376 & 0 \end{pmatrix}\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} - \begin{pmatrix} 0 \\ 2 \end{pmatrix} v \tag{5}$$

Here, x_1, x_2 and v is Δx , $\Delta\dot{x}$ and Δi separately. From the equations (5), we know that this second-order system is unstable. So it is necessary to design a controller to stabilize the system. Here, we implement linear PID controller to stabilize the system (5). The control input is in the following form:

$$v = k_p x_1 + k_d x_2 \tag{6}$$

Substituting (6) into (5), through some simple calculating, we can get the characteristic equation:

$$s^2 + 2k_d s + 2k_p - 3376 = 0 \tag{7}$$

So we can adjust the parameters k_p and k_d to stabilize the system. Here, if the anticipant performance of the system is: percentage overshoot is 5%, settling time is $0.1s$. According to this performance, we can figure out the control parameters:

$$k_p = 3367, \qquad k_d = 40 \tag{8}$$

B. Nonlinear PID Control

As mentioned before, the only way to enhance the system stiffness is to increase the proportional feedback coefficient k_p and the method is prone to degrade the system performance. The maglev train system demands the control system have high stiffness and the linear PID control method can not afford satisfactory stiffness, so we choose the nonlinear control. Here we choose the input of nonlinear PID control as the following form:

$$v = k_p x_1^a + k_d x_2^b \tag{9}$$

Now, the keystone is to design the two exponents a and b . The criterion to choose the exponents is: the exponents will not influence the system dynamic performance around the operating point and will enhance the system stiffness rapidly when the system apart from operating point.

Through a lot of experiments, we choose the two exponents as:

$$a = 1.25, \qquad b = 1.45 \tag{10}$$

IV. EXPERIMENT RESULTS

Here, when the system is controlled with linear PID method, we show the air gap variety of one electromagnet when the impact force adding on the magnet is equivalent to 1.5T. The experiment result is shown fig 2

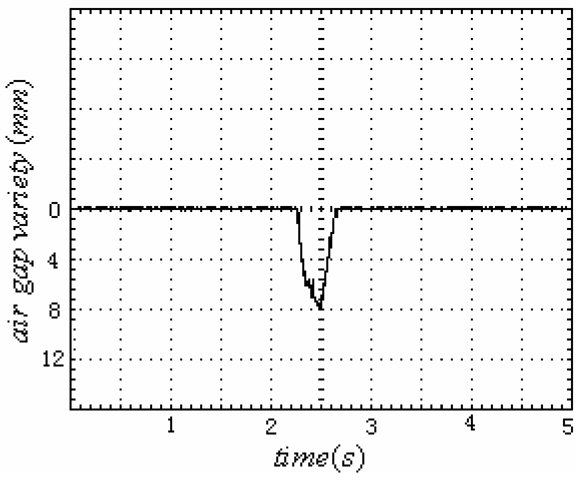

Figure 2. air gap of linear PID control

From fig 2 we know the biggest variety of air gap is 8mm when the linear PID control method is implemented.

Fig 3 is the experiment result when the nonlinear PID control is implemented.

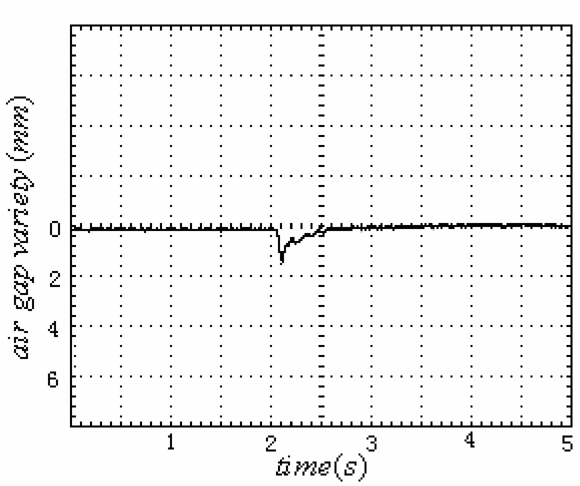

Figure 3. air gap of nonlinear PID control

Fig 3 hows that the biggest variety of air gap is about 1mm when the nonlinear PID control method is implemented.

Because the integral technology is applied in experiment, the variety of air gap is 0 at last.

V. CONCLUSION

From fig 2 and fig 3 we know that the capability of resisting impact of nonlinear PID control is better than linear PID control. Under the impact of 1.5T, the air gap variety of linear PID control is about 8mm while the air gap variety of nonlinear PID control is only 1mm. So the nonlinear PID control can ensure the suspension security when the maglev train runs in high speed.

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