A Levitation Control Method Rejecting Disturbance from the Guide Way Step Error

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ABSTRACT: Due to the installation error or the roadbed sedimentation, the guide way step error between the two neighbored guide ways is hard to be avoided completely. Our experiments show that the train levitation system will vibrate severely and even become unstable if no effective control strategy be adopted when running across a bigger guide way step error in a higher speed[1]. In order to reject the disturbance caused by the guide way step error, based on the two-point levitation model, a new method is provided that is first identifying the guide way step error and then adjusting control strategy correspondingly. With the three-probe gap sensor, by installing one probe to the outside of the magnet end, then the guide way step error can be identified in advance. The simulation result shows that this control method can decrease the levitation gap fluctuation while passing through the guide way step.
Key words: Maglev vehicle; guide way step error; two-point levitation model; gap sensor.

0 INTRODUCTION

A certain gap is often preset between the adjacent guide ways to allow the extension of the beam caused by temperature variance. The guide way gap is usually from 10mm to 30mm. The guide way steps often are caused from installation error of the guide way, the roadbed sedimentation etc.. Obviously, these steps affect the normal running performance of maglev vehicle seriously. For instance, on China Tangshan City test line, the maglev vehicle vibrates violently and even become unstable when it is running across a 2mm step with a speed of 60km/h.

Until now there is no mature technology restraining this kind of vibration completely, except improving the accuracy of the guide way. But improving the accuracy of the guide way is expensive. So a new control method is provided in this paper which is not expensive. Its main idea is replacing measured gap signal with double integral acceleration signal while running across a step. Based on the two-point levitation system model[2,3], this new control method is analyzed and simulated. Some merits of this new method are given.

1 TWO-POINT LEVITATION MODEL

CMS-04 maglev vehicle adopts modular bogies, making every electromagnet module have independent control freedom. The vibration on one side will not influence the other side's control, so it's feasible to consider levitation electromagnet module of one side as research object.

Before building two-point levitation model, supposing as follows: 1.ignore the leakage flux($\phi_L = 0$); 2.ignore the reluctance of core and guide way, electro-magnetic force lies on the levitation gap uniformly; 3.the guide way is rigid enough, and ignore its elasticity; 4.two-point levitation module's mass is uniform, it is divided into two parts equally, and called front point and rear point in this paper. It turns out to be reasonable based on analysis of characteristic mass.

Figure 1 shows the two-point levitation model of one bogie of maglev vehicle. To simplify mathematical model, the rotation on X axis is neglected.

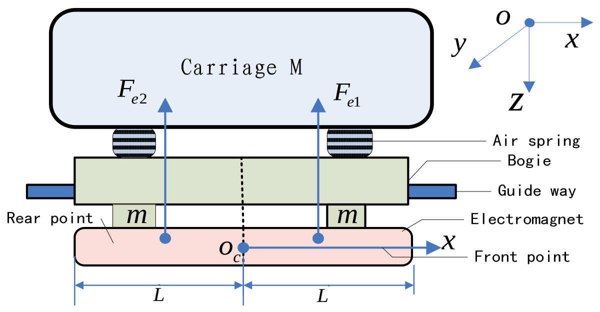

Fig. 1 Two-point levitation model

Where M : carriage mass; m : single point mass under air spring(include bogie and electromagnet); L : single electromagnet length; o_c : center of rigid body mass under air spring; F_{e1} and F_{e2} : electromagnetic force; z_1 and z_2 : levitation gap; i_1 and i_2 : coil current; R_1 and R_2 : resistance; N : the number of turns of the coil; A : pole area; $c=\mu_0 N^2 A/4$ (μ_0 is magnetic permeability). Two-point open-loop levitation model is established as follows, without consideration of secondary suspension dynamic.

$$\begin{cases} m\dfrac{d^2[z_1(t)+z_2(t)]}{dt^2}=(2m+M)g-F_{e1}-F_{e2} \\ \dfrac{8}{3}m\dfrac{d^2([z_1(t)-z_2(t)]}{dt^2}=F_{e1}-F_{e2} \\ u_1=R_1 i_1(t)+\dfrac{2c}{z_1(t)}\dfrac{di_1(t)}{d(t)}-\dfrac{2ci_1}{[z_1(t)]^2}\dfrac{dz_1(t)}{d(t)} \\ u_2=R_2 i_2(t)+\dfrac{2c}{z_2(t)}\dfrac{di_2(t)}{d(t)}-\dfrac{2ci_2}{[z_2(t)]^2}\dfrac{dz_2(t)}{d(t)} \\ F_{e1}=c[\dfrac{i_1(t)}{z_1(t)}]^2 \\ F_{e2}=c[\dfrac{i_2(t)}{z_2(t)}]^2 \end{cases}$$

This open-loop model is unstable without feedback control. State feedback algorithm, using states of current, gap and acceleration is adopted generally. A close-loop control model is established as $x_1(t)=z_1(t)$, $x_2(t)=z_2(t)$, $x_3(t)=\dot{z}_1(t)$, $x_4(t)=\dot{z}_2(t)$, $x_5(t)=i_1(t)$, $x_6(t)=i_2(t)$, $R_1=R_2=R$.

$$\begin{cases} \dot{x}_1=x_3 \\ \dot{x}_2=x_4 \\ \dot{x}_3=\dfrac{2m+M}{2m}g-\dfrac{5c}{4m}(\dfrac{x_5}{x_1})^2+\dfrac{c}{4m}(\dfrac{x_6}{x_2})^2 \\ \dot{x}_4=\dfrac{2m+M}{2m}g-\dfrac{5c}{4m}(\dfrac{x_6}{x_2})^2+\dfrac{c}{4m}(\dfrac{x_5}{x_1})^2 \\ \dot{x}_5=\dfrac{x_1}{2c}(u_{ec1}+k_{i1}i_1+k_{a1}\ddot{z}_1+k_{p1}z_1+k_{rv1}\dot{z}_1)-\dfrac{x_1x_5}{2c}R+\dfrac{x_3x_5}{x_1} \\ \dot{x}_6=\dfrac{x_2}{2c}(u_{ec2}+k_{i2}i_2+k_{a2}\ddot{z}_2+k_{p2}z_2+k_{rv2}\dot{z}_2)-\dfrac{x_2x_6}{2c}R+\dfrac{x_4x_6}{x_2} \end{cases}$$

Where k_{i1} and k_{i2} : current feedback coefficient, k_{a1} and k_{a2} : integral acceleration feedback coefficient, k_{p1} and k_{p2} : gap feedback coefficient, k_{rv1} and k_{rv2} : differential gap feedback coefficient, u_{ec1} and u_{ec2} : electromagnet initial voltage.

2 IDENTIFYING STEP BASED ON THREE-PROBE SENSOR

During building and maintenance of the guide way, there exists error between actual and expected guide way, because of construction, measurement or roadbed sedimentation, and the step appears. Sometimes the step affects the vehicle levitation seriously. So it's necessary and important to identify the step and take effectual control strategy, making maglev vehicle run across the step smoothly.

A gap sensor consists of three probes, which correspond to three gap inspection passages. A certain algorithm is adopted for probe's signal processing. Every passage provides a signal at the same time, the processed gap signal will provide the exact gap of electromagnet and could be used for levitation control. Even one of them breaks down, the other two probes could work normally. Besides, according to the signals of three probes, the system can identify the step's height when the vehicle runs across the step. Figure 2 shows the course of gap sensor crossing the step.

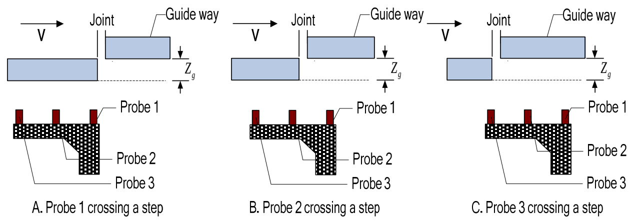

Fig.2 Three-probe gap sensor crossing a step

Assuming that, under normal conditions, the signal processing algorithm takes average value of three measured gap. As Fig.2 stage A, probe 1 detects the gap increasing abruptly first, the measured gap of probe 1 can't distinguish whether the step appears as the joint exists. So the signal of probe 1 is trustless, the algorithm takes average value of the other two probes. When stage B, probe 2 detects the gap increasing. At the same time, probe 1 has crossed the step completely and probe 3 is on the normal guide way. The gap of probe 1 minus that of probe 3 equals to the step height, and the levitation system uses the gap of probe 3. When stage C, probe 1 and probe 2 has run across the step completely and the signal of probe 3 is trustless, the algorithm takes average value of probe 1 and probe 2.

The method mentioned could identify the appearance time and the height of the step, which provide useful signal to controller. However, gap sensor is installed at the end of electromagnet, as a step identified, the electromagnet has crossed the step partly. So the installation method of gap sensor improves to get timely step information, as Fig. 3 shows. One probe of gap sensor(probe 1 in Fig. 2) extends outwards, so that the outward guide way's information can be detected in advance. And this signal is just used to identify the step form, not for levitation control.

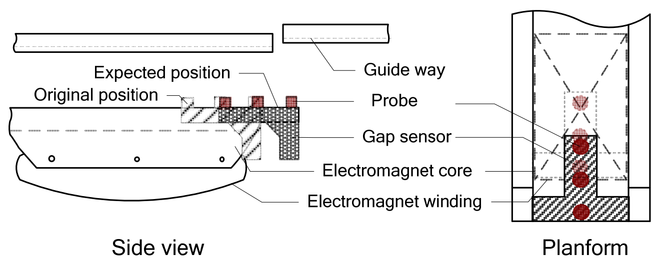

Fig.3 Installation method of gap sensor

3 GETTING LEVITATION GAP

The sensor of levitation system, which is installed on the top of electromagnet, lies on the bottom concave of F steel. It consists of gap sensor and accelerometer, detecting the levitation gap and vertical acceleration to give real-time feedback information. There are two ways to get the levitation gap as follows:

1. By gap sensor measurement. It's the popular way to get the levitation gap. At present, low-speed maglev vehicle selects eddy current sensor. Eddy current sensor detects the vortex effect to measure the gap with non-contact between coil surface and conductor, so the measured value is a relative distance to the guide way. But this measured gap can't reflect the true state of electromagnet, because of guide way's elasticity and irregularity. For instance, as the vehicle running across a step, the signal of gap sensor would detect a skip, but the motion of electromagnet can't reflect the guide way step accurately.

2. By double integral acceleration. Accelerometer, which is installed in gap sensor, can measure vertical acceleration of the electromagnet. When the train levitates stably, the acceleration is 0. According to the acceleration principle, the displacement can be gotten by double integral acceleration. So if the initial position of the electromagnet is known, the absolute displacement and absolute levitation gap would be calculated. This is different from relative gap measured by gap sensor, especially when the train runs across a step and curved guide way or when the guide way vibrates.

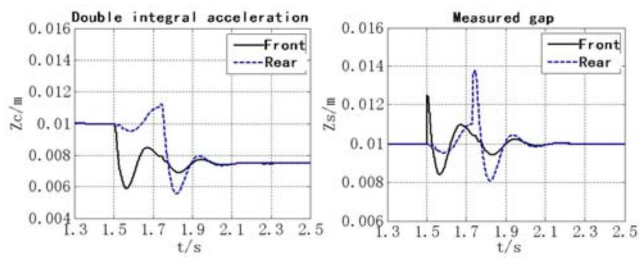

Fig. 4 Curves of measured gap and double integral acceleration when the train crossing a step

For instance, CMS-04 maglev vehicle applies the measured signal of gap sensor to levitation controller, when the vehicle runs across an upward step with the height of 2.5mm, double integral acceleration and measured gap vary as Fig.4 shows.

It can be seen from Fig.4,if levitation system selects gap sensor's value as feedback signal, when the vehicle runs across the step, the front gap sensor detects the step first, and the measured gap increases 2.5mm, then the gap error becomes bigger, which makes control amount increase and electromagnet go up. Double integral acceleration, however, doesn't reflect the step information..

4 COMPARISON OF CONTROL METHODS AND SIMULATION

As the above analysis, there are differences between measured gap and double integral acceleration. As an upward step detected, levitation system will track the step and the electromagnet will go up, in case of selecting measured gap as feedback signal. The absolute displacement, however, has decreased, which disobeys the control goal. So the measured gap is a spurious signal for controller, which would influence the stability of levitation system. Double integral acceleration can reflect motion state and displacement of the electromagnet, if the absolute coordinates fixed. But when the vehicle runs across the vertical curve, the absolute coordinates change, double integral acceleration maybe can't be used for levitation control. So when a step appears, double integral acceleration is selected for levitation controller instead of measured gap, and the algorithm is shown in Fig.5.

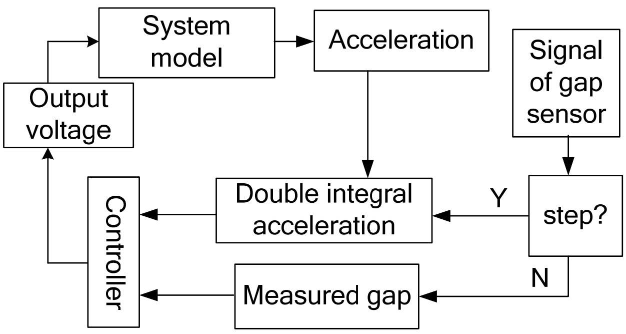

Fig. 5 Control algorithm

According to the identifying method based on three-probe gap sensor, the system can identify the step in advance, and if the step appears, double integral acceleration is selected for levitation controller, otherwise the measured gap would be chosen.

Supposing that the train runs across a step at a certain time as Fig. 6 shows, Choosing the step length $l_g = 10m$, the height $z_g = 2.5mm$, the vehicle velocity as 40km/h, the simulation is shown in Fig 7 and Fig.8, by comparing new algorithm with the primary one.

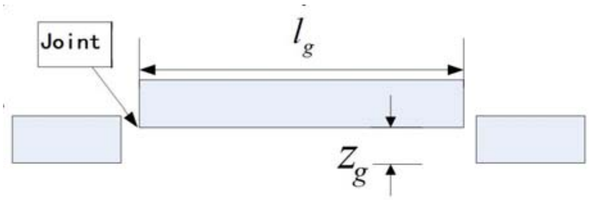

Fig. 6 Guideway step

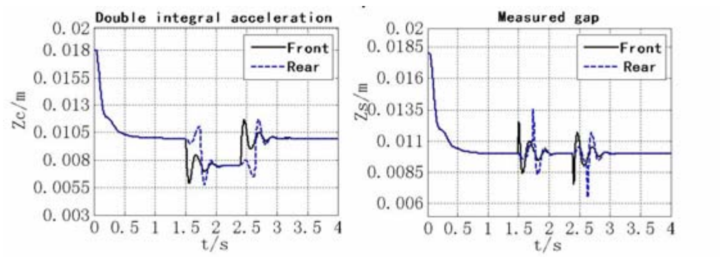

Fig. 7 Simulation of measured gap feedback

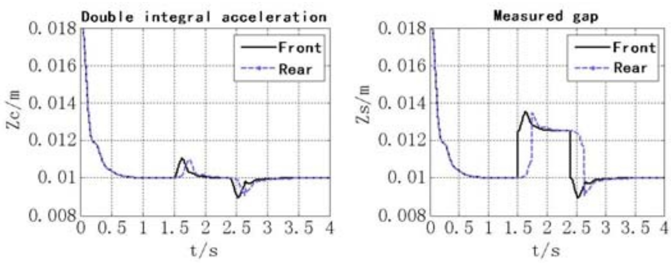

Fig. 8 Simulation of new algorithm

It can be concluded from above results:

1、Under the primary algorithm, applying measured gap to levitation controller, the absolute displacement varies from 5.8mm to 11.6mm, and the measured gap varies from 6.5mm to 13.5mm.

2、Using the new method, replacing measured gap with double integral acceleration when a step appears, the absolute displacement varies from 9mm to 11mm, and the measured gap varies from 9mm to 13.5mm.

The simulation result shows: the new algorithm, replacing measured gap with double integral acceleration when the train runs across a step, can reduce the gap fluctuation and restrain the step disturbance effectively, making the vehicle run across the step smoothly.

5 CONCLUSIONS

Based on the idea of the Acceleration Inertia Navigation, this paper presents a new algorithm that replace the gap sensor signal with double integral acceleration of the electromagnet for feedback control when a guide way step appears , which can eliminate the spurious signal of gap sensor. Simulation results prove the validity of this algorithm. In the next we will test the algorithm by experiment.

6 REFERENCES

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