Levitation Control Scheme for the Hybrid Maglev System without Acceleration Sensor

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Acceleration sensorless, expert system, hybrid levitation, linear synchronous motor, PID

ABSTRACT

The levitation control scheme is the key problem of the maglev system, and the propulsion system has to be designed on the base of stable levitation. To lower the suspension power, permanent magnets are used in the levitation system. In this paper, a model vehicle with four hybrid magnets poles, which is designed in our Lab, is levitated reliably on the base of the expert PID control scheme. Meanwhile, only gap sensor is needed in the proposed system. Compared with the common PID control, system response speed is increased obviously due to the use of expert system. Through simulation experiments of load sudden change and levitation gap length sudden change, both good robustness and high precision of levitation are obtained by the proposed strategy.

1 INTRODUTCTION

The maglev vehicle is one of the most promising transportation tools in the 21th century, which has the advantages of high speed, low noise, high security and so on. Shanghai Maglev Demonstration and Operation Line (TRANSRAPID) has been operated for almost two years, which can reach the high speed of 430km per hour and attracts more and more scholars to join in the research of maglev train [1]. Typical electromagnetic suspension (EMS) system generally has the levitation air-gap of only about 10mm, which requires very high tracking precision and causes high cost to the long distance maglev line. The levitation control scheme is the key problem of the maglev system, and the propulsion system has to be designed on the base of stable levitation. To lower the suspension power, permanent magnets are used in the levitation system. Hybrid magnet consisting permanent magnet (PM) and controlled coil has been proposed for several years [2]-[3]. Its air gap is enlarged and the energy consumed by the levitation subsystem is significantly reduced due to the use of permanent magnets.

2 SYSTEM CONFIGURATION

The cross section of the proposed hybrid levitation model is shown in Fig.1. Long stator linear synchronous motor structure is designed in the proposed system, and the mover with four symmetrical hybrid magnets is under the long stator. The mover is about 700mm in length, 600mm in width, and 300mm in height. The total payload may be more than 120kg. Hybrid magnets are used to suspend the mover. In this model vehicle, the lateral revertible force between the stator and the mover implements the lateral guidance at low speed, and guidance gap is controlled to be about 10mm. At high speed, we can utilize the active electromagnet force or make use of the passive guidance approach[4].

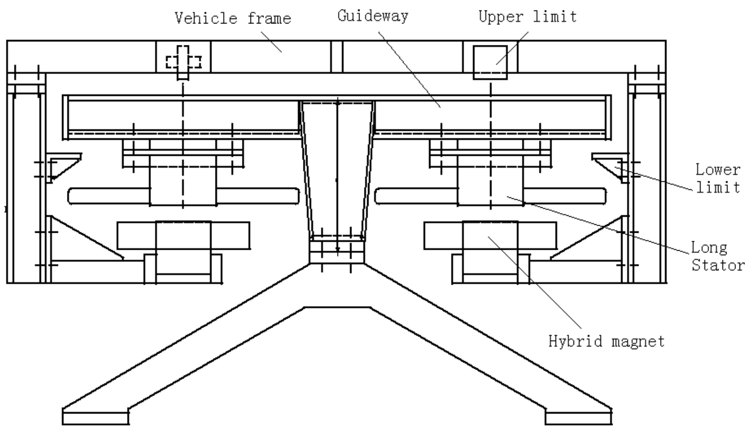


Fig. 1. The cross section of the proposed hybrid levitation system

The structure of the hybrid magnet is shown in Fig. 2, which includes magnetic coil, permanent magnet, and linear generator and so on. The effective length of the air gap is increased by the existence of the slots of the linear generator, which can be modified by Carter's coefficient.

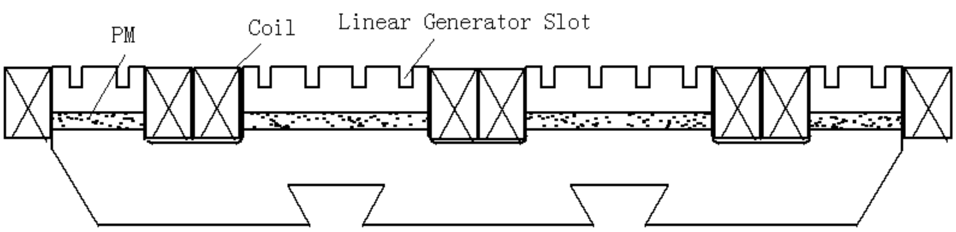


Fig2. The structure of the hybrid magnet

To ensure stable levitation of the mover, the current of the magnetic coil must be adjusted rapidly, so DC chopper is designed to adjust the voltage and the current of the magnetic coil. The topology of the DC chopper is shown in Fig.3. Four poles are made in the proposed model, so four independent choppers are needed, and full-bridge chopper are designed to adjust the currents in two directions.

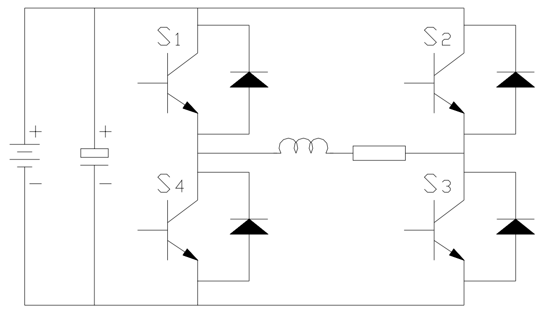


Fig.3. The topology of the DC chopper

3 EXPERT PID CONTROL

Generally, both gap length sensors and acceleration sensors are mounted in the maglev system, but the acceleration sensors increase the total cost and the system complexity. New control scheme called expert PID (proportional-integral-derivative) control is adapted to guarantee the rapid response in the proposed system, so acceleration sensor is removed, and only gap length sensor is used in the proposed system.

3.1 PID CONTROL

PID control is one of the most well known theory and it is most commonly used in all kinds of fields of industry applications. Digital PID control is adapted in our system, whose output increment is

$$\Delta u(kT) = K_p[e(kT) - e(kT - T)] + K_i e(kT) + K_d[e(kT) - 2e(kT - T) + e(kT - 2T)] \quad (1)$$

where $\Delta u(kT)$ is the output increment of the regulator; $e(kT)$ is the error signal for the *k*th sampling period; K_p is the proportional coefficient; K_i is the integral coefficient; K_d is the derivative coefficient. Equation (1) is the increment style of the PID control, which is commonly used nowadays.

3.2 EXPERT SYSTEM

Expert system is on the base of knowledgebase of the controlled objective and control rules, and it makes use of these knowledgebase in the style of artificial intelligence [5]-[6]. A PID controller designed on the base of expert system is called expert PID control.

Error change signal is defined as follows

$$\Delta e(kT) = e(kT) - e(kT - T) \quad (2)$$

According to the error signal and its change, expert PID controller is designed as follows.

1) if $|e(kT)| > M_1$, which shows that error signal is very large, so the output of the controller

should be set to the largest value to adjust the error rapidly despite of what situation error change signal is. Here, system is equal to an open-loop system.

2） if $e(kT)\Delta e(kT)>0$, which shows that the absolute value of the error is changing larger, then

（a） if $|e(kT)|>\mathrm{M}_2$, which shows that the absolute value of the error signal is a little large, strong control value should be set for the controller to lower the absolute value of the error, the output of the controller may be

$$u(kT)=u(kT-T)+K_1\{K_p[e(kT)-e(kT-T)]+K_ie(kT)+K_d[e(kT)-2e(kT-T)+e(kT-2T)]\} \qquad (3)$$

（b） if $|e(kT)|<M_2$, which shows that the absolute value of the error signal is not large, weak control value should be set for the controller, the output of the controller may be

$$u(kT)=u(kT-T)+K_2\{K_p[e(kT)-e(kT-T)]+K_ie(kT)+K_d[e(kT)-2e(kT-T)+e(kT-2T)]\} \qquad (4)$$

3） if $e(kT)\Delta e(kT)<0$ or $e(kT)=0$, which shows that the absolute value is changing smaller or system has reached its steady state, the output of the controller can be set as before.

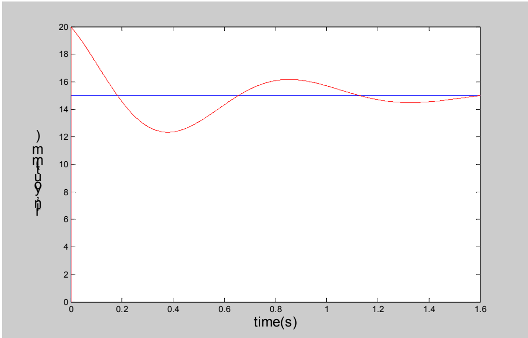
4） if $|e(kT)|\le\varepsilon$, which shows that the absolute value of the error signal is very small, integral terms should be enhanced to lower the stead state error.

where k_1 is a magnifying coefficient, that is to say, $k_1>1$; k_2 is a shrinking coefficient, that is to say, $0<k_2<1$; M_1、M_2 are threshold values set according to the expert experience; ε is a small positive number set by expert experience.

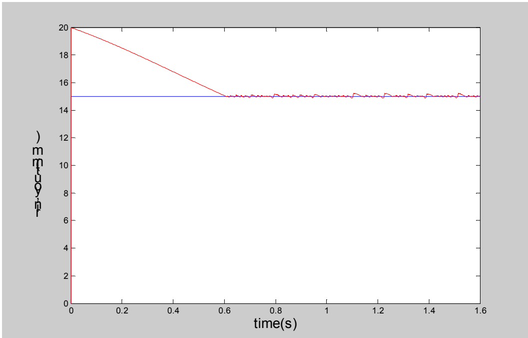
When the control strategies mentioned above are applied, rapid response speed is obtained, and high precision can be achieved at the same time.

4 RESULTS OF SIMULATION

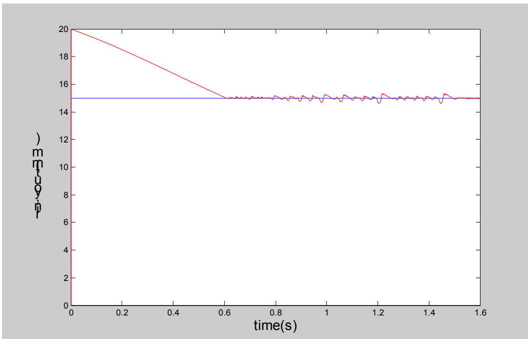
Only gap length sensor is mounted in the proposed system. The simulation result by the common PID control under the load of 80kg is shown in Fig.4(a), which only has a low performance. The simulation result by the expert PID control under the load of 80kg is shown in Fig.4(b), 15mm levitation gap length is set in Fig.4(a) and Fig.4(b); and only load is suddenly added by 40％ after 0.8s from condition of Fig.4(b), the simulation result by expert PID control is shown in Fig.4(c); the simulation result of step response by expert PID control is shown in Fig.4(d), where gap command is changed from 15mm to 12mm. It is shown that there is little difference between Fig.4(b) and Fig.4(c), what is more, when step input is set, system can go to steady state quickly. High precision as well as good robustness are obtained by the proposed strategy. Because the four poles are symmetrical, only simulation results of one pole are shown here.



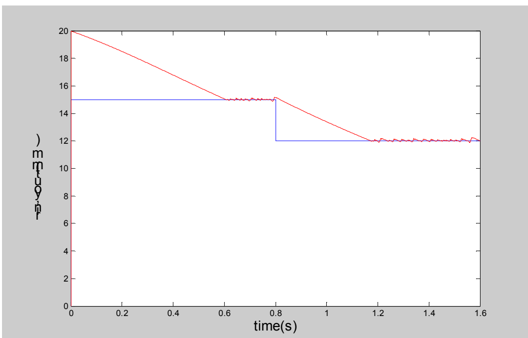
（a）common PID control



（b）normal levitation for expert PID control



（c）sudden load enhancement by 40% at 0.8s for expert PID control



(d) step response from 15mm to 12mm for expert PID control

Fig.4. Simulation results by common PID control and expert PID control

5 CONCLUSION

Compared with the traditional PID control, expert system is added to compose expert PID control in our hybrid levitation system, the response speed of the suspension system is increased obviously. Only gap length is to be monitored, while acceleration sensor is unnecessary in the proposed system. The simulation results show that it is very flexible to control, and good adaptability is achieved. Meanwhile, the high precision is obtained.

Acknowledgement

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