Research of Sorption Problem in Hybrid Maglev System

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Abstract: Compared with traditional EMS maglev, The hybrid maglev system has many advantages, for example, it can realize zero-power levitation control, so the suspension power loss and released heat is decreased evidently, also can increase the levitation airgap properly, which makes the system require lower precision of guideway and reduces the cost of guideway greatly. But the probability of sorption problem which could lead to fatal accident prevents it from engineering application. In this paper, a new structure of magnet is put forward, and its magnetism is calculated, also the corresponding controller system and power supply system are studied, which all together make the whole system redundancy. when half of the system breaks down, the other goes on, which can ensure sorption will never happen. The theory analysis and simulation prove the rationality and availability of the new system.

Keywords-component; hybrid maglev system; zero-power control; sorption problem; EMS; redundancy;

I. INTRODUCTION

Compared with traditional EMS maglev, the hybrid maglev system has so many advantages. For example, because of zero-power levitation control, which means the vehicle is levitated by only permanent magnets, the power consumption of system and the capacity of the batteries are decreased greatly. At the same time, the levitation airgap can increased properly, which makes the system only require lower making and fixing precision of the track and the cost to the long distance maglev line is reduced, also the propulsion motor is more efficient. But the sorption problem in hybrid maglev system has never been resolved totally. While the system levitates at a small air gap, if the power is cut off suddenly, the mass of the system is not enough to overcoming the attraction force between permanent magnet and guideway, then sorption happens, which would damage the train, even lead to fatal traffic accident. Presently there are few references about this problem, some scholars put forward some control methods, detecting the sorption trend and preventing, which are based upon countercurrent to counteract the attraction force, all these methods need the precondition that the whole hybrid maglev system keeps in gear. If the power supply system, or the electric coil in magnet or the controller system fails, fatal accidents will come along. In this paper, some innovations to the old system are put forward, including innovations to magnet, power supply system and controller. All of these make the hybrid maglev system redundancy, and bring down the probability of sorption close to zero.

II. THE STRUCTURE OF HYBRID MAGLEV SYSTEM

In order to keep the compatibility with old system, first the old structure of magnet is analyzed, the characteristic of magnetism is calculated using Ansoft Maxwell, and corresponding experiments is carried out. After that, innovation to the old structure is put up. the magnetism of the new structure is calculated, the result shows the rationality. Compared with the old structure, new structure keeps the same characteristic of magnetism with the old one, but has a redundancy which the old structure has not.

Figure 1 shows the schematic of the old magnet structure in hybrid maglev system, where $\delta(t)$ is the levitation airgap, δ_p is the thickness of permanent magnet, S_δ is the area of the surface of magnetic pole, $u(t)$ is voltage between the terminals of the coil, $i(t)$ is current in coil.

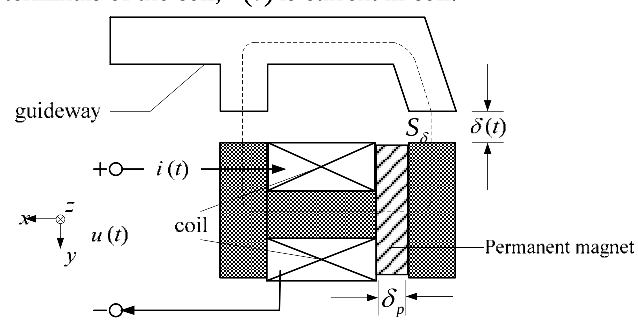

Figure 1. Schematic of old structure of magnet in hybrid maglev system.

Figure 2 shows the magnetic flux distribution in old hybrid maglev system, it shows that the magnetic flux distribution is symmetrical in the guideway, the magnet, the airgap between guideway and magnet, at last form a close loop, there is little magnetic flux leakage in this system, which means the system is efficient and there is little radiation.

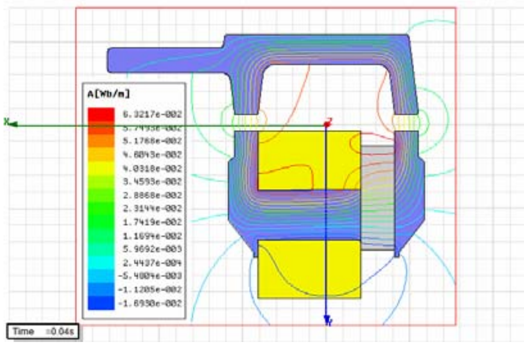

Figure 2. Schematic of magnetic flux distribution in old system.

Figure 3 shows the experiment result of old system, including waveforms of displacement and current in coil. The initial airgap is 20mm, while the mass is 4700kg, in order to levitate the magnet from initial position to the balance point, the maximum current needed is 66A, because of the zero-power levitation control, around the balance point, the levitation force is mainly generated by permanent magnet, the current is used to generate adjustment force, so it is close to zero usually. It is calculated in Ansoft Maxwell that when the airgap is 20mm and the excited current is 65A, the attraction force will be 46976N, while the balance airgap is around 9mm, it is accorded with the result of experiment.

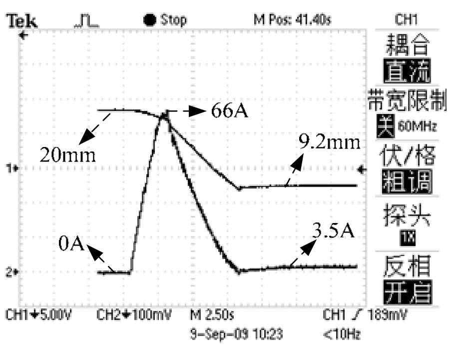

Figure 3. Expriment result of old system.

In order to achieve the redundancy, the coil in magnet is separated to two parts, as shown in figure 4, they are controlled by two controllers respectively, and there are two sets of power supply systems, $u1(t)$ and $u2(t)$ come from different power supply systems. Even if one controller, or one power supply system, or one part of the coil fails, the other one can keep system from sorption. Figure 5 shows the schematic of magnetic flux distribution in new system, it is almost similar to the old one.

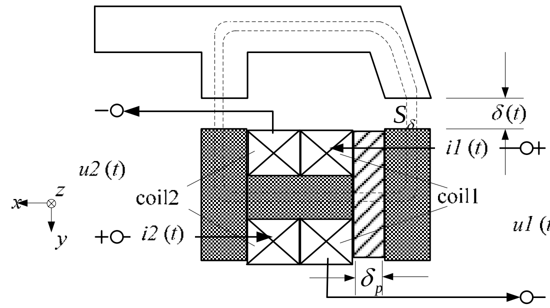

Figure 4. Schematic of new structure of magnet in hybrid maglev system.

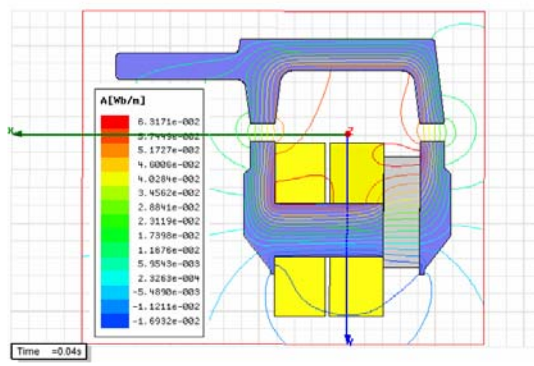

Figure 5. Schematic of magnetic flux distribution in new system.

It is calculated in Ansoft Maxwell that, to levitate the same mass, the maximum current is 65.3A, which is almost equal to the old one, when the system is in zero-power suspension, the balance airgap is 9.1mm, which is similar to the old system again. It shows that the new system not only has as good performance as the old one, but also owns redundancy.

III. The Controller of the New System

As shown in figure 4, the single-pivot magnetic suspension system is controlled by two controllers, the primary single input single output (SISO) system becomes a MISO system, it's more complicated than the old system. First the controllability is analyzed, neglect the leakage, the magnetic force between hybrid magnet and guideway is:

$$F = \mu_0 S_\delta \left(\frac{N(i_1 + i_2)}{2\delta + P} + \frac{H_c \delta_p}{2\delta + Q} \right)^2 \qquad (1)$$

The voltage and current equation of coil is:

$$u_1 = Ri_1 + \frac{C_1(\dot{i}_1 + \dot{i}_2)}{(2\delta + P)} + \left(\frac{2C_2}{(2\delta + Q)^2} - \frac{2C_1(i_1 + i_2)}{(2\delta + P)^2} \right)\dot{\delta} \qquad (2)$$

$$u_2 = Ri_2 + \frac{C_1(\dot{i}_1 + \dot{i}_2)}{(2\delta + P)} + \left(\frac{2C_2}{(2\delta + Q)^2} - \frac{2C_1(i_1 + i_2)}{(2\delta + P)^2} \right)\dot{\delta} \qquad (3)$$

Where C_1、C_2、P、Q satisfy :

$$C_1 = \mu_0 N^2 S_\delta = 0.0009267$$
$$C_2 = -\mu_0 N S_\delta H_c \delta_p = -0.1697$$
$$P = \delta_p S_\delta \big/ \left(1.11 \mu_r S_p\right) = 0.03304$$
$$Q = \delta_p S_\delta \big/ \left(\mu_r S_p\right) = 0.03683 .$$

Where μ_0 is permeability of vacuum, μ_r is relative permeability of permanent magnet, S_p is area of permanent magnetic pole, N is number of turn of coil, H_c is coercive force of permanent.

Choose $\boldsymbol{x} = \begin{bmatrix} x_1 & x_2 & x_3 \end{bmatrix}^T = \begin{bmatrix} \delta & \dot{\delta} & i_1 + i_2 \end{bmatrix}^{\mathrm{T}}$ as the states of system., $u = \begin{bmatrix} u_1 & u_2 \end{bmatrix}^T$ as the inputs. because of zero-power levitation control method, the balance point is $x_0 = \begin{bmatrix} -\dfrac{C_2}{2\sqrt{C_1 M g}} - \dfrac{Q}{2} & 0 & 0 \end{bmatrix}^T$, then the linearized model of the system around the balance point is

$$\begin{cases} \dot{x} = \boldsymbol{A}x + \boldsymbol{B}u \\ y = \boldsymbol{C}x \end{cases} \tag{4}$$

Where

$$\boldsymbol{A} = \begin{bmatrix} 0 & 1 & 0 \\ -\dfrac{4gL}{C_2} & 0 & \dfrac{2C_1 g}{T} \\ 0 & \dfrac{2TL}{C_1 C_2} & \dfrac{RT}{2C_1 L} \end{bmatrix}$$

$$\boldsymbol{B} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ -\dfrac{T}{2LC_1} & -\dfrac{T}{2LC_1} \end{bmatrix}$$

$$\boldsymbol{C} = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}$$

Where

$$T = C_2 + \left(Q - P\right)\sqrt{C_1 M g} < 0$$
$$L = \sqrt{C_1 M g}$$

The controllability judgement matrix is:

$$P_c = \begin{bmatrix} B & AB & A^2 B \end{bmatrix} \tag{5}$$

It's easy to prove that: $rank(P_c) \geq 3$,which means the system is controllable. There are roughly two kinds of control strategy for the new hybrid maglev system: one is fixed gap levitation control; the other is fixed current control, which can realize zero-power levitation control. In order to simulate the condition that the levitation gap is small, and levitation current is negative, and suddenly one part of the system fails, the first strategy is considered in this paper.

In detail, states feedback control method is adopted, in order to eliminate the static error, the gap integral is added, and the integral of error between currents in different coils is used to eliminate itself. The control law is described as equation (6) and equation (7):

$$\begin{aligned} u_1 = {} & k_p(\delta - \delta_0) + k_d \dot{\delta} - k_c i_1 \\ & + k_{i1} \int (\delta - \delta_0) dt + k_{i2} \int (i_2 - i_1) dt \end{aligned} \tag{6}$$

$$\begin{aligned} u_2 = {} & k_p(\delta - \delta_0) + k_d \dot{\delta} - k_c i_2 \\ & + k_{i1} \int (\delta - \delta_0) dt + k_{i2} \int (i_1 - i_2) dt \end{aligned} \tag{7}$$

Where k_p, k_d, k_c, k_{i1}, k_{i2} are control parameters, u_1, u_2 are control voltage, δ_0 is stable operating airgap.

IV. RESULTS AND CONCLUSION

Using the control law as above, the simulation results are shown as figure 6, figure 7 and figure 8. When the levitation gap is 7.6mm, the currents in two coils are both negative 15A, suddenly current in coil 1 becomes zero, the other one turns to negative 25A, and there is little change to airgap, which means the system still runs in gear and sorption will never happen.

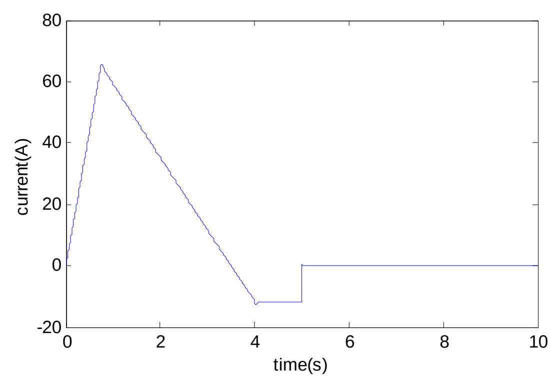

Figure 6. Waveform of current in coil 1.

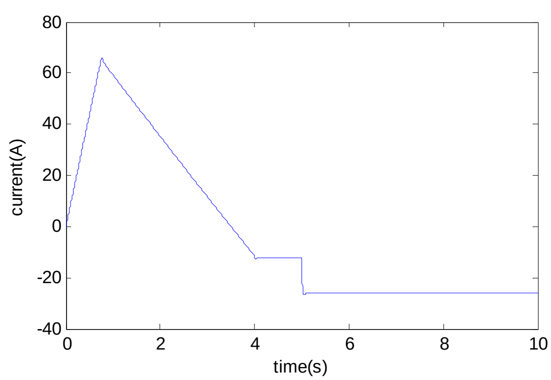

Figure 7. Waveform of current in coil 2.

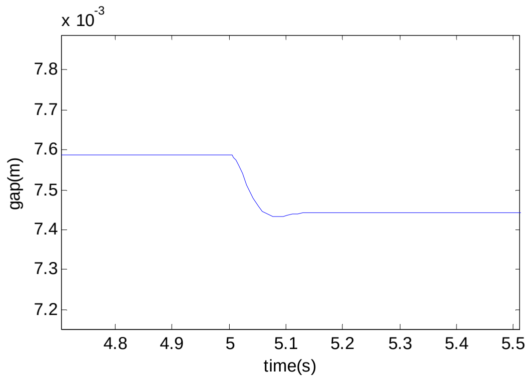

Figure 8. Waveform of airgap.

In this paper, redundancy is achieved by some innovations to the magnet structure, controller and power supply system, the probability of sorption is brought down close to zero, through theory analysis and simulation, it's proved that the new system is available and realizable. The corresponding control method is studied .

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