Influence of the Permanent Magnet Structure on Magnetic Forces in Maglev System with Hybrid Magnets

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ABSTRACT: Permanent magnet and electromagnet are combined to form hybrid magnet, the lift force could be increased effectively with the same air-gap length, and decrease the vehicle weight and electrical exciting power loss. At the same time, the electrical exciting winding can produce adjustable lift force to stabilize the levitation system. Therefore it has great developing potentialities. In this paper, we research the effect on magnetic forces for permanent magnets of different structures such as the type of "V" and flat, and present the analysis results calculated with FEM about the effect of the permanent magnet structure on a hybrid maglev model vehicle system in our Lab.

1 INTRODUCTION

A long-stator linear synchronous motor (LSM) with iron cores is used to drive the high-speed maglev vehicle in Transrapid (TR) system. At the same time, the electromagnet poles of the LSM provide lift and guidance forces to control the vehicle. Since the exciting winding turns of electromagnet and current are limited by the size, weight of the pole, the lift force is limited, and the air-gap length is only 10mm.So that the construction cost is high and it limits the EMS Maglev development.

Compared with an electromagnet, a permanent magnet has higher energy density. At present, high energy level of NdFeB can meet the need of most motor performances. If permanent magnets and electromagnets are combined to form hybrid magnets, the lift force could increase effectively with the same air-gap length, and the vehicle weight could be decreased. In a maglev system with hybrid magnets, permanent magnets may provide the base lift force required for levitation while electromagnets produce adjustable lift force to stabilize the levitation system.

In a hybrid Maglev system, in order to make full use of permanent magnet and decrease the magnet weight, it is required to research the location, size and structure of permanent magnet, to seek for more suitable structure and location, etc., to obtain high ratio of magnet force and weight.

Figure 1. Hybrid levitation model vehicle in IEE, CAS.

In this paper, based on the hybrid levitation model vehicle with permanent magnets and electromagnets combined in our Lab (Figure 1), we approach the flat and V type permanent magnets, use the finite element method (FEM) to calculate the magnetic field, then use the principle of virtual work to calculate the forces along the X (traction force), Y (lateral resilience force) and Z (lift force) axis. The calculation results of the force of two type of permanent magnet are obtained. These results can give us some guidance in the hybrid maglev vehicle design.

2 HYBRID LEVITATION MODEL VEHICLE

Figure 2 shows the cross section of the hybrid levitation model vehicle and Figure 3 shows the LSM schematic drawing of the model vehicle with permanent magnets (PM) and electromagnets combined in our Lab. The vehicle is driven by two LSM located in two tracks. The long-stator core and windings are arranged along the tracks, the hybrid magnets are located at the vehicle [2].
Since there are slots for linear generator coils on the surface of magnet iron core, it is impossible to locate the permanent magnet on the surface, thus the core is divided into two parts, and the flat blocks of permanent magnets are sandwiched between the upside and underside of the core. The concentrated windings are set in the slots.

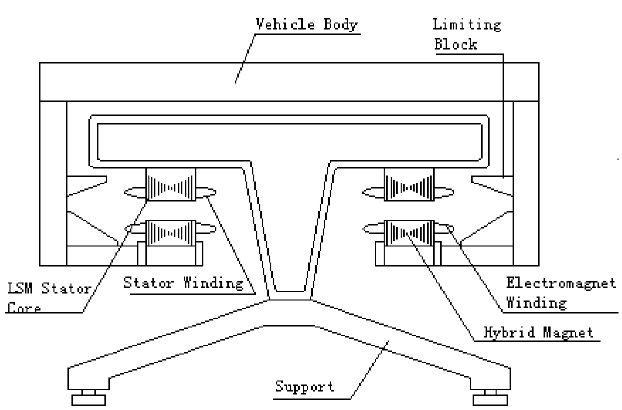

Figure 2. Cross section of the model vehicle

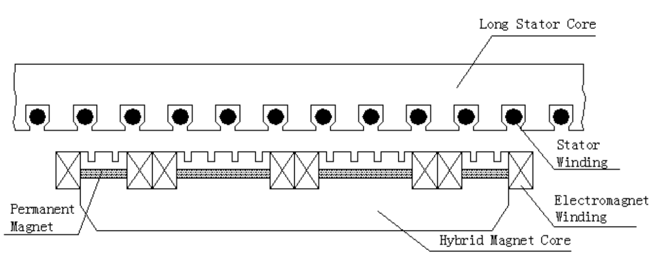

Figure 3. Structure of the LSM with flat PM (One unit of hybrid magnet)

The model vehicle has four units of hybrid magnets placed along double-side tracks, each unit is composed of two full and two half magnets shown as Figure 3. The distance of two units is two pole pitches along the length direction. The rated air gap is 10mm, rated lift weight is 120kg, and the thickness of the permanent magnet is 5mm.
For a hybrid magnet with V type permanent magnet posed in reference [1], we adopt the same structure and size as our model vehicle, shown as Figure 4, for comparison.

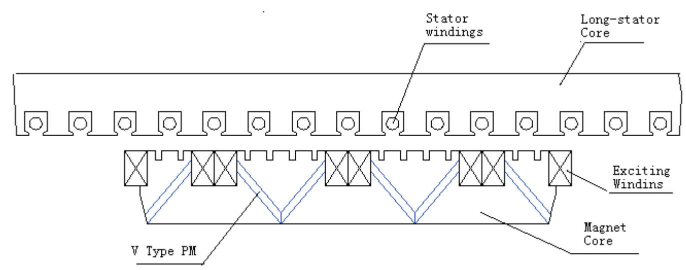

Figure 4. Structure of the LSM with V type PM (One unit of hybrid magnet)

3 CALCULATION MODEL OF MAGNETIC FORCE

Compared to a general rotation synchronous motor with air gap about 3mm, the LSM of our model has bigger air gap due to mechanical structure requirements, which can lead to bigger flux leakage. Therefore 3D finite element method is used to calculate the lift force and lateral resilience force to avoid a bigger calculation error. After analysis, we know that the transverse leakage flux has less effect on the traction force, thus 2D FEM is used.
Figure 5 shows the region used in 2D FEM calculation. Since the units and nodes for 3D FEM calculation will increase greatly, and need too much computer time, one pole region is adopted with the consideration of field symmetry. The long-stator windings are no load when calculating lift force and lateral resilience force, while they have rated phase current 13A for calculating traction force.

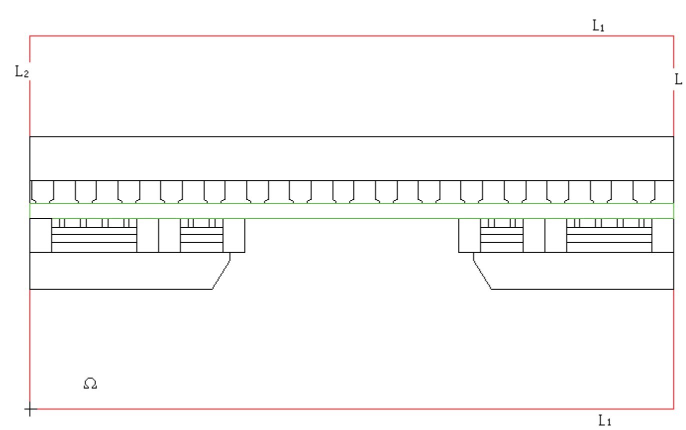

Figure 5. 2D FEM calculation domain.

For the field of the LSM with nonlinear ferromagnetic material mentioned above, vector potential **A** is used as the field function, the question can be described as (1):

$$\begin{cases} \Omega : \nabla \times (\frac{1}{\mu} \nabla \times \mathbf{A}) = \mathbf{J}_c \\ L : \frac{1}{\mu_1} (\nabla \times \mathbf{A}_1)_t \big|_{L^-} - \frac{1}{\mu_2} (\nabla \times \mathbf{A}_2)_t \big|_{L^+} = \mathbf{J}_{sm} \\ L_1 : \mathbf{A}\big|_{L_1} = 0 \\ L_2, L_3 : \mathbf{A}\big|_{L_2} = -\mathbf{A}\big|_{L_3} \end{cases} \qquad (1)$$

Here, **A** is vector potential, μ is material permeability, $\mathbf{J}_c$ is armature current density in a stator slot, $\mathbf{J}_{sm}$ is equivalent current density of a permanent magnet, and satisfy $\mathbf{J}_{sm}=\mathbf{M}\times\mathbf{n}$, **M** is the magnetization of permanent magnetic material used. Ω is the domain of solution. L is the interface of permanent magnetic material and other material. L_1 is the outer boundary away a distance from the long stator and hybrid magnets, L_2 and L_3 are the boundaries satisfied half periodic relationship.
The magnetic field can be obtained with FEM by solving the field equation (1), the magnetic forces can be solved using the principle of virtual work.

4 RESULTS

Figure 6 to Figure 11 show respectively the variation of lift, maximum traction force and lateral resilience forces produced by the hybrid maglev vehicle with flat PM and V type PM when air gap and exciting ampere-turns are varying. For the convenience of comparing, Figure 12 to Figure 14 respectively show the three forces produced by the two types of PM only in a same drawing.

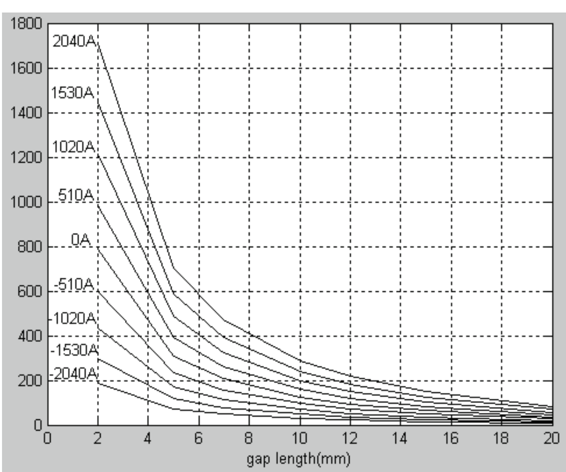

Figure 6. Lift force (Flat PM)

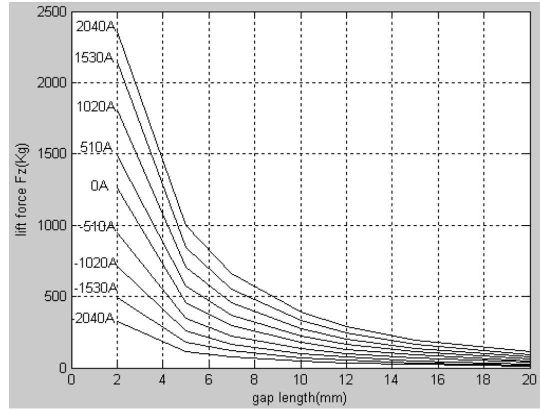

Figure 7. Lift force (V type PM)

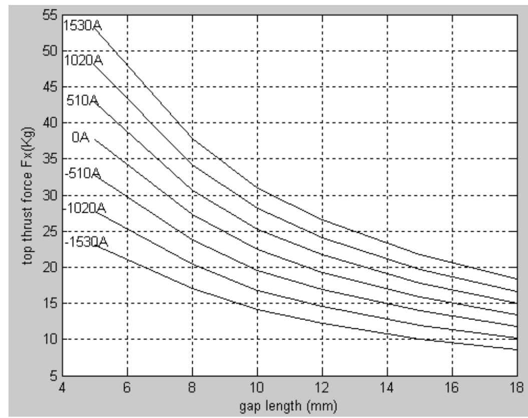

Figure 8. Maximum traction force (Flat PM)

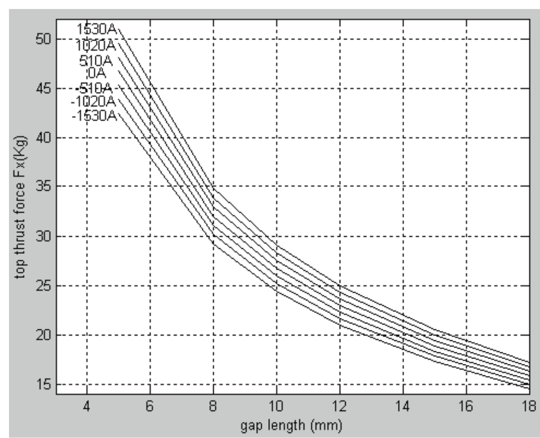

Figure 9. Maximum traction force (V type PM)

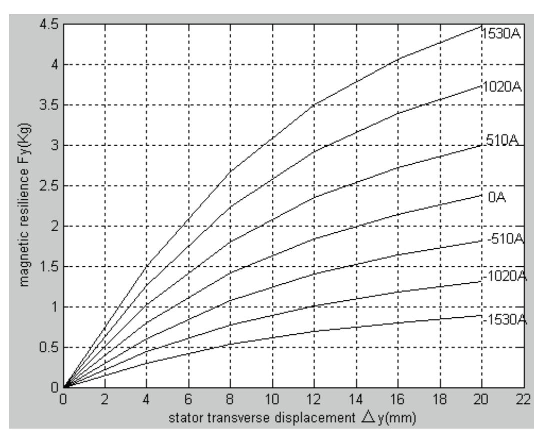

Figure 10. Lateral resilience force (Flat PM)

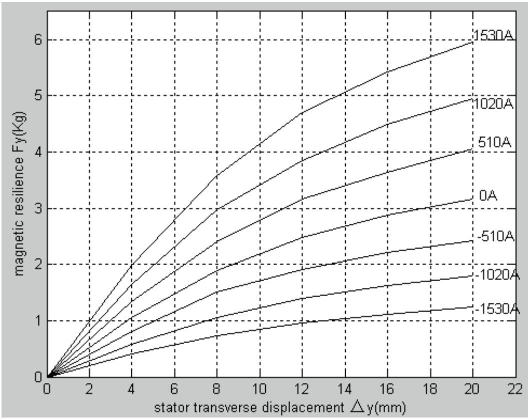

Figure 11. Lateral resilience force (V type PM)

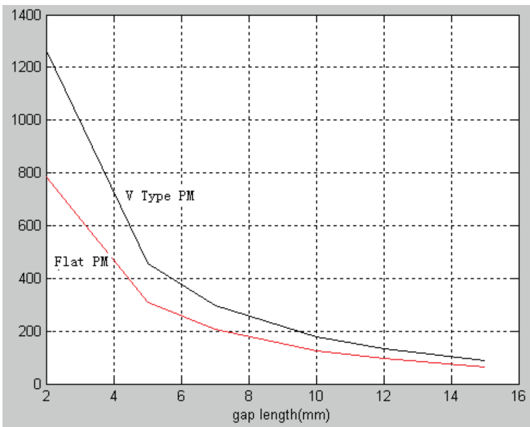

Figure 12. Lift force comparison

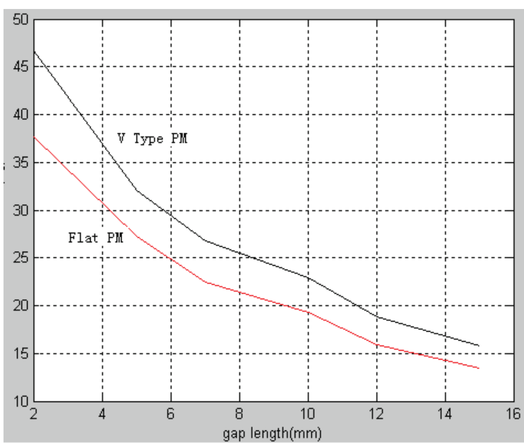

Figure 13. Maximum traction force comparison

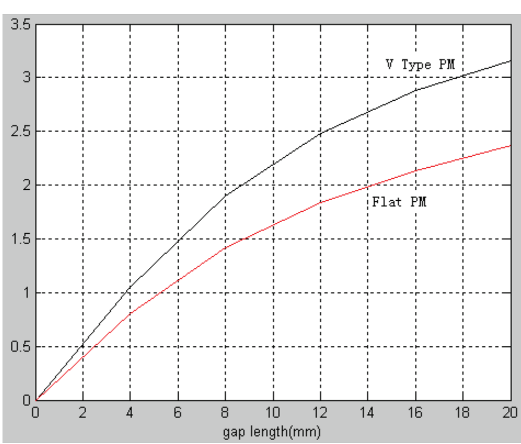

Figure 14. Lateral resilience force comparison

Some results can be gained from Figure 6 to Figure 12: 1) The three forces produced by the two types of hybrid maglev vehicle have respectively the same variation tendency with air gap length varying under different exciting ampere-turns. 2) The three forces produced by the vehicle with V type PM are all larger than that produced by the vehicle with flat PM at the same conditions. The comparison for typical point in Figure 12 to Figure 14 are listed in table 1. 3) From Figure 8 and Figure 9, we can deduce that the traction force produced by the vehicle with V type PM has less fluctuation than that with flat PM when electrical exiting ampere-turns change.

Table 1 Comparison for typical point in Figure 12 to Figure 14

	V type PM	Flat PM	Force increasing
Lift force(kg)	176.8	125.8	40.5%
Maximum traction force (kg)	26.7	22.5	18.7%
Lateral resilience force(kg）	3.16	2.37	33.3%

5 CONCLUSIONS

In a hybrid maglev vehicle design, it is necessary to optimize the type of permanent magnet in order to fully use permanent magnetic material, lessen flux leakage, reduce the vehicle weight and obtain bigger magnetic forces. In this paper, the three forces produced by the hybrid maglev vehicle with two types of PM are approached and compared. Some benefit conclusions are provided. It will give guidance in the future design for the hybrid maglev vehicle

6 REFERENCES

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