Optimal Design of a Hybrid Suspension Magnet for Middle-Low-Speed Maglev Trains

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***Abstract*—A middle-low-speed maglev train is supported by an electromagnetic force between the suspension electromagnet (EM) and the steel rail and is driven by a linear induction motor. The capability of the suspension system has a direct bearing on safety and the technical and economic performance of the train. This paper focuses on the dependence of the electromagnetic force on the variation of the structural configuration of the EM with the purpose of improving performance of a conventional EM. Finally, a novel configuration is proposed of a hybrid suspension magnet, which combines permanent magnets and coils, in order to increase the suspension force while reducing the suspension power loss.**

Keywords—Maglev train, EM, hybrid suspension.

I. Introduction

As a new type of transportation technology, maglev trains have attracted attention due to their many advantages, such as low noise, no pollution, good ability on slopes, small turning radius and others, making them suitable for urban transportation. The electromagnetic suspension (EMS) technology plays a critical role in the development of maglev trains, as they are suspended kept by an attractive magnetic force produced by electromagnets. A hybrid suspension, mixing electromagnets with permanent magnets, has been found to remarkably reduce power loss in the suspension system. Research reported in many countries - especially USA, Japan, Germany, South Korea and China - focused on the development of hybrid maglev trains with permanent-electromagnetic suspension (PEMS) magnets [1]-[4]. But until now this technology has not been commercialized. One of the critical issues to solve is the protection against mechanical contact when using permanent magnets to provide the attraction force. In this paper, an expression for the non-linear magnetic force of a conventional electromagnet is examined and a novel structural configuration of a PEMS magnet is proposed. Finally, the performance of an optimized PEMS magnet is compared with the conventional electromagnetic system.

II. Structure of the Suspension Magnets

Fig. 1 shows a photograph of a middle-low-speed maglev train on the Changsha Airport Express line, designed mainly in the Southwest Jiaotong University, China. Each carriage of the maglev train has five suspension bogies, where four suspension magnets and one linear induction motor are installed on one side of each bogie.

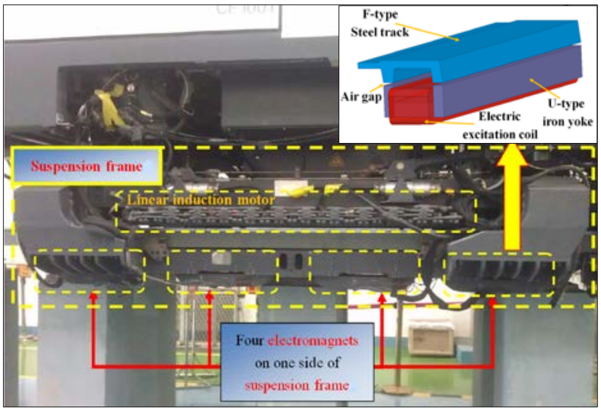


Fig. 1. The electromagnets hanging on the suspension frame.

The structure of the electromagnets, as well as the F-type steel track, is depicted in Fig. 2. The symbols for the main system parameters are described in TABLE I.

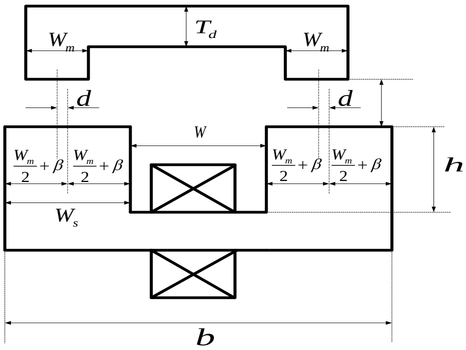


Fig. 2. The diagram of the F-type track and the electromagnets.

TABLE I. System Parameters of an Electromagnet

System parameters	Symbol	Value/*mm*
Magnetic pole width of steel rail	W_r	28
Magnetic pole width of electromagnet	W_s	28
Magnetic yoke height of suspension rail	T_d	21.5
Magnetic yoke height of electromagnet	h	45
Window width of suspension rail	W	112
Air gap of suspension structure	Z	8
Longitudinal length of suspension structure	L	2720

The magnetic field in the air gap can be assumed as uniform if the air gap is relatively small. The suspension force is then

$$F_0 = \frac{B^2 W_S}{\mu_0} L \,, \quad (1)$$

where $$B = \frac{\mu_0 \mu N I}{2Z\mu + \mu_0[2h + (1 + W_S/T_d)b]} \,. \quad (2)$$

A modified and more accurate expression is provided in [4]

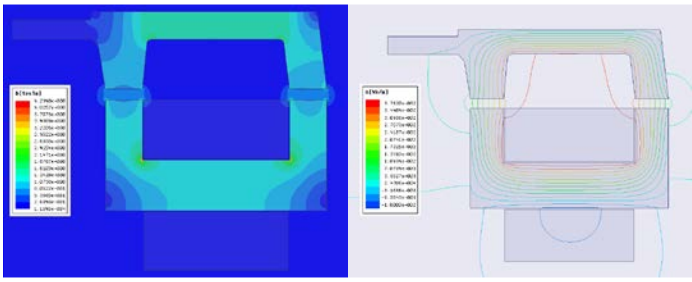
$$F_Z = F_0 \left[1 + \frac{2Z}{\pi W_m} + \frac{\beta - d}{\pi W_m} atan\left(\frac{Z}{\beta - d}\right) + \frac{\beta + d}{\pi W_m} atan\left(\frac{Z}{\beta + d}\right)\right] \quad (3)$$

where d is the value of the pole dislocation and β is given by

$$\beta = \frac{W_S - W_m}{2} \,. \quad (4)$$

III. The Impact of the Coil Current and Suspension Gap on the Electromagnetic Force

Using the 2D Finite Element Method (FEM) simulations, the magnetic flux density and corresponding flux lines for both the U-type iron core and the F-type steel tracks under normal working conditions have been found and are shown in Fig. 3. The principal values used are: suspension gap 8mm; coil current 30A; the number of turns per coil 342 and other parameters as in Table I). The suspension force produced by the EM system is 40.17kN.



(a) (b)

Fig. 3. (a) Flux density distribution in the EM; (b) Corresponding flux lines.

Fig. 4 demonstrates the dependence of the suspension force on the coil current for three different air gaps. The force decreases when the size of the gap increases, with magnetic nonlinearity becoming pronounced for smaller gaps, as expected. Saturation effects are also clearly visible in the relationship of the force versus current, again in accordance with expectations.

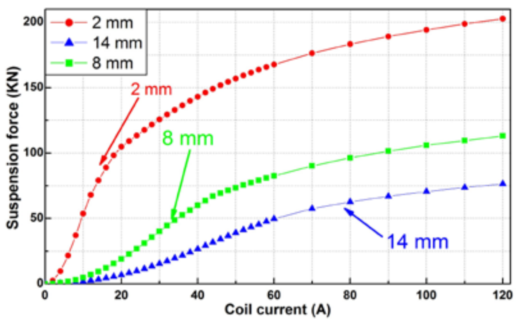


Fig. 4. The relationship between the suspension force and input current for three different air gaps.

IV. Permanent-Electromagnetic Suspension Magnet

A new design has been attempted with the view to reduce the power loss in the suspension system and increase the force by implementing the concept of a hybrid levitation system with both permanent magnets and an electromagnet. The protection against mechanical contact was also considered. Simulation results show that the electromagnet with embedded permanent magnets can increase the available suspension force by 1.07kN to 41.24kN compared to a conventional design. By conducting a series of numerical tests a location of the magnets as shown in Fig. 5 was accomplished.

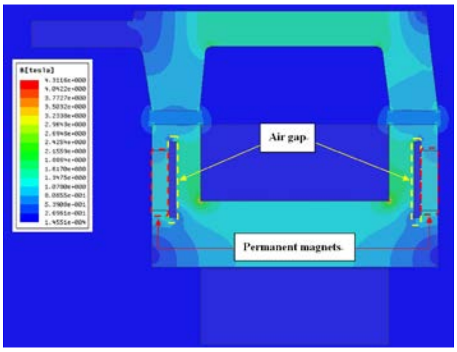


Fig. 5. Flux density distribution in the PEMS system.

V. Optimal Design of Hybrid Suspension Magnet

An optimal design of the structural configuration, including multi parameters and multi objectives, will be realized with the assistance of our previously developed kriging optimizer [5]. Comprehensive comparison of performance between PEMS and EMS will be provided in the extended version.

VI. Conclusions

The performance of a suspension system of maglev trains has been investigated from the point of view of the dependence of the force on the size of the air gap and value of the current. Improvements to the conventional system were accomplished by implementing a concept of a hybrid arrangement of electromagnets and permanent magnets. It is argued that the hybrid system improves the characteristics by increasing the available force while reducing associated losses.

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