Numerical Calculations of Flux-Canceling Maglev with DC & AC excited SCMs

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The paper shows a numerical calculation feature and the levitation characteristics of a flux-canceling Maglev with AC excitation, which has an array of conducting coils on the ground and two arrays of onboard magnets. In numerical calculations, the guideway coils are approximated as ladder coils. First the necessary number of guideway coils to be considered in numerical calculations is indicated. Then the calculated results confirm that AC excitation realize a levitation capacity at zero vehicle velocity, and its dependence on the vertical position of the onboard magnets and the excitation frequency.

Keywords: flux-canceling, Maglev, levitation, ac excitation, multi-coil, ladder coil

1. Introduction

The Maglev vehicle is considered to be a future transport system, since it is going to eliminate the drawbacks of conventional mass transit system, such as limitations on the maximum speed, and harmful environmental effect due to the dependence on friction to suspend the vehicle. In the US, the congress passed the "Transportation Equity Act for the 21st Century", and accordingly a team of MIT, Draper, Bechtel, Hughes Electronics, and General Motors completed a Maglev concept. Thornton et al of MIT then refined the system and developed a flux-canceling Maglev system with fewer losses and the capacity of levitation at standstill ⁽¹⁾⁽²⁾. Recently, in the US two projects were selected as first Maglev systems for practical demonstration by the department of transportation in January of 2001 ⁽³⁾. However, both of those trains employ the same force principle as the Transrapid system. This paper presents the numerical calculations for the flux-canceling Maglev system providing alternative potential advanced Maglev construction.

2. Maglev System and its Numerical Model

Fig.1 shows a schematic diagram for the levitation concept. On the ground, multiple-loop guideway coils are installed, while the vehicle has iron-core magnets with high- T_c superconducting coils to eliminate ohmic losses. The high- T_c SC coils are robust with regard to alternating field. The iron-core is going to enhance the magnetic flux density, but its value is kept comparatively low for the use of SC coils. Table 1 shows the dimensions of the numerical model ⁽¹⁾, which is a 1/5-scale model. In the calculations here, the iron-core is neglected and the multi-loop guideway coils shown in Fig.2 are simplified to the ladder coils shown in Fig.3. From the dimensions indicated in Table 1, the pitch is quite small, forming overlapped coil arrangements. We used a circuit analysis method, where mutual inductance is estimated with Nuemann's formula.

3. Calculated Results

In order to get characteristics by numerical calculations, we first determined an appropriate numerical condition with varying the number of guideway unit coils, which is indicated in Fig.3, while the onboard magnets have the geometry of Fig.2. In Fig.4 we show calculated values for the two cases, i.e., (a) the magnets

Fig.1 Concept of vehicle

Fig.2 On board SCMs and guideway

Fig.3 Guideway coil for analysis

Table 1 Dimension of the model

SC coil	
Length	0.096 (m)
Width	0.06 (m)
Pitch	0.126 (m)
Vertical pitch	0.09 (m)
Number of turn	550
Coil current (DC)	5 (A)
Coil current (AC)	12 (A)
Guideway coil	
Length	0.102 (m)
Width	0.102 (m)
Pitch	0.0085 (m)
Self inductance	280 (nH)
Resistance	0.0007 (Ω)
Gap between SC coil and guideway	0.01 (m)

are passing the guideway coils, (b) the magnets are excited with AC source, being given with the number of coils varied. As the number increases, the magnitude increases and finally reaches a maximum value. In these cases, the values converge when the number of guideway coils becomes around 70. We accordingly set the number for our numerical calculations as 80. In the mean time, the levitation force for AC-excitation changes at double the frequency of the source current, and has the average of 43 N.

Fig.5 shows the levitation force for various magnet positions of 0.4-1cm at standstill, where AC-excitation frequency is 100Hz. As the net flux linkage increases with larger magnet position, the resulting force becomes larger.

Fig.6 shows the dependence of excitation frequency on the levitation force in the case of zero vehicle velocity. It is observed that a larger force is obtained with a larger frequency of the source current, which is equivalent to a high speed in the case of DC-excitation. Because of frequency characteristics of the system and some damping force of both electromagnetic and mechanical elements, the higher frequency of motions may be eliminated.

4. Conclusion

We have made numerical calculations using a circuit analysis method for a superconducting Maglev model with the capacity of levitating at zero velocity. We first determined the number of guideway coils to be considered in the calculations. The levitation force increases as the magnet position or the excitation frequency increases, where the excitation frequency corresponds to the vehicle speed in the case of DC-excitation. We intend to improve the calculations and the vehicle design parameters for high performance.

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References

- (1) M.T.Thompson and R.D.Thornton, Modeling of HTSC-Based Iron Core Flux-Canceling Electrodynamics Suspension for Maglev, Proc. ISMST, pp.81-95, 1998
- (2) R.D.Thornton and M.T.Thompson, Test Results from a Large Scale High Speed EDS Maglev Wheel Test Facility, Proc. ISMST, pp.287-301, 1998
- (3) USDOT, <http://www.fra.dot.gov/o/hsgt/maglev.htm>

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(a) DC-excited coils ($v = 50\text{m/s}$)

(b) AC-excited coils ($f = 100\text{Hz}$, $v = 0\text{m/s}$)

Fig.4 Calculated value vs. number of guideway coils ($\Delta z = 1\text{cm}$)

Fig.5 Levitation force for various magnet positions ($f = 100\text{Hz}$, $v = 0\text{m/s}$)

Fig.6 Levitation force for various excitation frequencies ($\Delta z = 1\text{cm}$, $v = 0\text{m/s}$)