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Research on Temperature Rise of Inductive Board on Eddy Current Brake for Maglev Train

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Abstract

In this paper , aiming at the temperature rise of the inductive board of eddy current braking of high-speed maglev train, a method for calculating the temperature field of the inductive board is proposed. Through the eddy current loss as the connection between the electromagnetic field and the thermal field, a finite element analysis model based on the coupling of electromagnetic field and thermal field is established, and the temperature results of the inductive board are obtained. Compared with the analytical method, the accuracy of the calculation results is verified. At the same time, this method has the advantages of intuitive temperature distribution and convenient subsequent structural optimization design, which is conducive to the further optimization of eddy current brake and improve the efficiency in the future.

Keywords: eddy current brake, temperature rise of inductive board, electromagnetic-thermal coupling, simulation calculation.

1 Introduction

The emergency braking of high-speed maglev train mostly adopts eddy current braking, and the actuator is eddy current brake fixed between two suspension frames of each vehicle [1]. The principle of eddy current braking is to cross arrange the magnets according to the N and S poles and maintain a certain gap with the inductive board. At this time, the magnetic flux generated by the magnet enters the air gap and passes through the secondary inductive board to finally form a complete circuit. According to Faraday's law of electromagnetic induction, when the magnet moves relative to the inductive board, the corresponding eddy current will be induced in the inductive board. The induced magnetic field of the eddy current interacts with the original magnetic field, distorting the original magnetic field, resulting in the eddy current braking force that hinders the relative movement trend. The structure of eddy current brake of maglev train is shown in Figure 1 below.

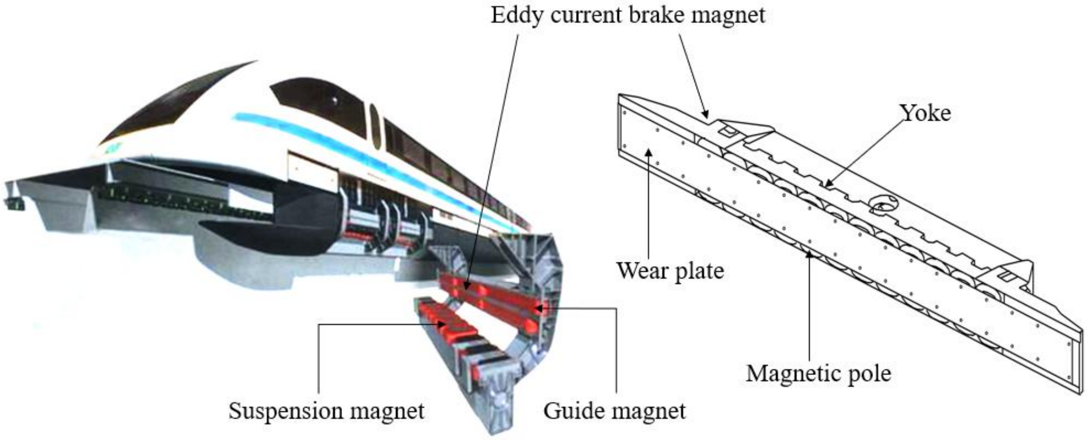

Figure 1: The structure of eddy current brake of maglev train.

At present, scholars at home and abroad have deeply studied the braking force characteristics of eddy current brake of high-speed maglev train, but there are relatively few studies on the heating and temperature rise of inductive board during braking. The inductive board is on the outside of the rail, as shown in Figure 2. From the perspective of energy transformation, in the process of eddy current braking, the kinetic energy of maglev train gradually decreases by converting eddy current into heat energy on the inductive board. At this time, the eddy current on the guide rail inductive board releases a large amount of heat energy, and the thermal effect of eddy current braking is generated. When these heat cannot be dissipated rapidly, various physical parameters of the inductive board will change, which limits the possibility of further speed increase of high-speed maglev train.

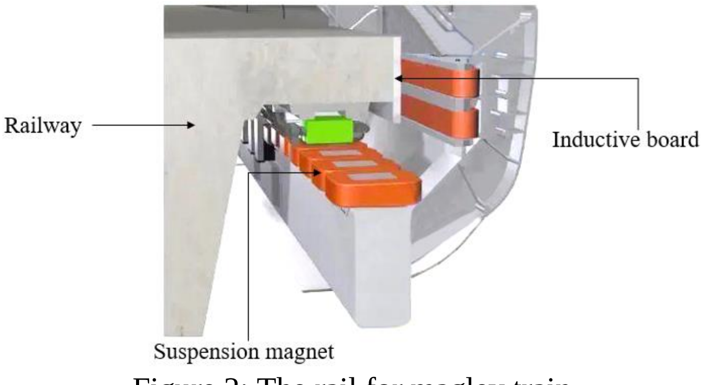

Figure 2: The rail for maglev train.

Based on the above background, the electromagnetic thermal coupling model is established by finite element method, and a simulation calculation method is proposed to study the relationship between train speed and inductive board temperature rise when high-speed maglev train uses eddy current braking.

2 Methods

Eddy current braking system for high-speed maglev train mainly includes magnetic pole, yoke, coil, inductive board, etc. Because the materials of magnetic pole and inductive board of eddy current brake are nonlinear magnetic conductive materials, it is very difficult to obtain accurate calculation results through theoretical and numerical calculation. Therefore, the relatively accurate method is to carry out simulation calculation with the help of finite element software at present. Based on the magnetic circuit analysis method [2], the eddy current braking system can be equivalent to the two-dimensional model shown in Figure 3.

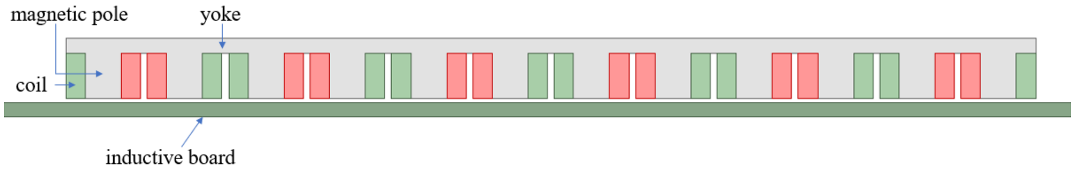

Figure 3: Simulation model of eddy current brake for high speed maglev train.

In the process of eddy current braking, the temperature rise of inductive board caused by eddy current includes two processes: the first is the formation of eddy current loss; The second is the temperature rise of the inductive board caused by eddy current loss. Through the ANSYS finite element analysis software, we can carry out the coupling analysis from eddy current loss calculation to thermal simulation.

Firstly, the eddy current analysis is completed under ANSYS Maxwell, and the eddy current loss of the inductive board is mapped to transient thermal in the form of volume power density heat source for thermal simulation calculation. And the temperature and temperature rise distribution of the inductive board caused by eddy current loss are obtained, so as to realize the coupling analysis of electromagnetic field and temperature field, as shown in Figure 4 below.

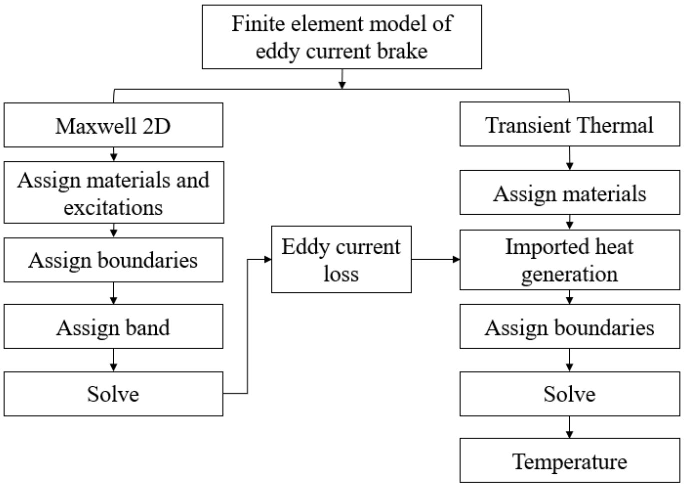

Figure 4: Simulation analysis process.

According to the established coupling model, the relationship between the temperature field distribution of the inductive board and the train speed can be obtained by setting the corresponding simulation parameters, such as materials, excitations, boundaries and motion conditions.

3 Results

Based on the above model, taking a single eddy current brake as the research object, input the actual parameters of the electromagnetic components of the eddy current braking test-bed [3] developed according to the eddy current braking device parameters of TR08 high-speed maglev train, and the density of the inductive board is 7.8×10^3kg/m^3, the specific heat capacity is 0.462×10^3J/(kg·℃), the conductivity is $0.97\times10^{-7}\Omega\cdot$m, the magnetic conductivity is 1.0×10^{-3}H/m; And let the air gap l_0 be fixed, l_0 = 18mm; The excitation current I_0 = 50A. Firstly, taking the initial braking speed of 300km/h as an example, through the electromagnetic field simulation calculation by ANSYS Maxwell, the eddy current loss distribution of the inductive board when the eddy current brake moves to the 10th millisecond can be obtained, as shown in Figure 5 below.

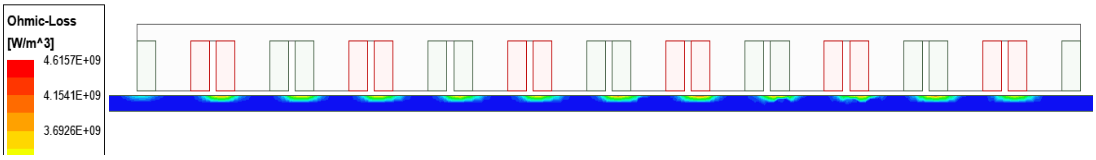

Figure 5: Eddy current loss distribution at 300 km/h.

Through the electromagnetic-thermal coupling, the calculated eddy current loss is input into the thermal simulation module, and the initial temperature of the inductive board is set to 20°C. The temperature field distribution shown in Figure 6 below is calculated.

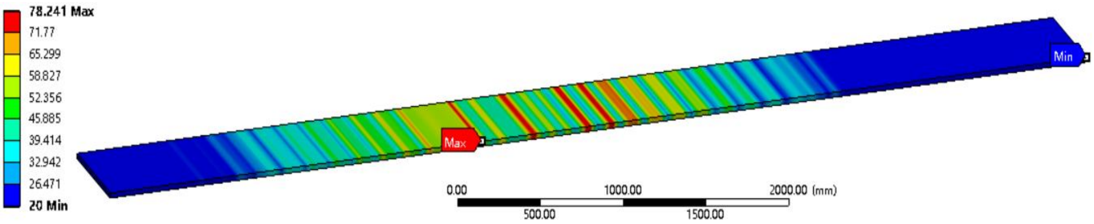

Figure 6: Temperature distribution of inductive board at 300km/h.

Starting from the speed of 0km/h, the value is taken every 50km/h until 400km/h. The following results are obtained and compared with the results calculated and verified by the analytical method in literature [4].

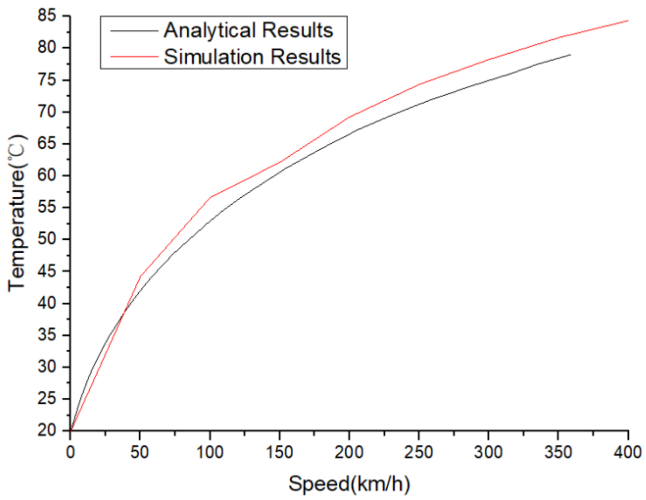

Figure 7: Relation curve between temperature and speed of inductive board.

As can be seen from Figure 7 above, compared with the verified analytical calculation results, the maximum temperature of the simulation results is slightly higher, which is caused by the eddy current Skin Effect. On the whole, it is in good agreement, which verifies the effectiveness and accuracy of the simulation model. The simulation results show that for the complex structure of eddy current brake, the analysis method based on electromagnetic-thermal coupling described in this paper can not only obtain the relationship curve of inductive board temperature, but also accurately and intuitively obtain the temperature distribution. Therefore, we can analyse the temperature rise of inductive board caused by eddy current braking better, and it is more convenient to optimize the design of eddy current brake through the established finite element model.

4 Conclusions and Contributions

High speed maglev train is one of the major trends in the field of rail transit in the future, and eddy current braking, as a necessary emergency braking mode of high-speed maglev train, is a very important research field. Eddy current brake converts the kinetic energy of the train into the thermal energy of the inductive board, so the temperature rise of the inductive board should be paid attention to people in the rail transit industry.

In this paper, the action principle of eddy current braking is analysed. Considering the temperature rise of inductive board and the complexity of electromagnetic coupling, a method for calculating and analysing the eddy current temperature rise effect of inductive board is proposed, that is, a finite element analysis model based on electromagnetic-thermal coupling is established, and the finite element model is used for calculation. The temperature rise calculation results are accurate and the temperature distribution is intuitive. At the same time, through the electromagnetic-thermal coupling simulation analysis method proposed in this paper, by adjusting the finite element model, we can quickly and effectively analyse the change of the temperature rise of the inductive board when the train speed, the structural design scheme of the eddy current brake and the materials change, so as to improve the efficiency of optimizing the design of the eddy current brake and reduce the risk.

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