The Performance Analysis of Eddy Current Brake System

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Abstract **– This paper describes the performance analysis of eddy current brake system conside ring a change of rail conductivity and equivalent stack width by 2-dimensional Finite Element Method (2-D FEM). The 2-D analysis model of the eddy current brake can not reflect the leakage flux resulting from the fringing effect and variation of conductivity, these magnetic features are ignored when the analysis of performance. Generally, it is actually difficult to analyze 3-D models in time varying problem. The performance of the eddy current brake has been analyzed by proposed 2-D FEM for an accurate analysis. To prove the analysis method, the analysis result has been compared with the experimental result.**

INTRODUCTION

The increase of speed range in a high speed train accelerates the development of braking systems. The general braking systems rely on the adhesion force between the rails and the wheels. The environment problem such as noise and mechanical wear resulting from friction gives rise to adoption of a way of touch free brake. Therefore, the proportion of the touch free linear eddy current bra ke has been gradually increased and studied. In the design of the eddy current brake to obtain a good performance, it is very important to predict the performance based on accurate analysis method [1].

An eddy current brake used for one of a touch free brake is composed of DC excited magnet poles and reaction rail. The eddy current induced by a related action between the reaction rail with conductivity and magnet poles produces braking force in trains. Thus, the parameters such as rail conductivity, temperature on rail, the dimension of magnet and structure of rail have influence on the braking performance.

We can not accurately analyze the brake system by 2D FEM because the 2D model analysis can not take into account all magnetic phenomena. The 3-D analysis is inevitable for the accurate analysis, however, it is complicated and takes much larger computation time in the time varying field problem. Therefore, it is possible to apply correction factor into 2-D analysis with reasonable technique, and we can reduce the computation time and improve the accuracy of 2-D analysis [2]. This paper presents the efficient 2D analysis method from the correction of conductivity and equivalent stack width.

The transverse edge effect due to the difference of electromagnet stack width and rail width produces that the rail whole conductivity is lower than its actual conductivity [3]. So the performance of the eddy current brake regarding the transverse edge effect has been analyzed by using compensated conductivity. In addition, to improve the accuracy of 2-D analysis, the fringing effects is compensated by the equivalent stack width from solving static magnetic field with the aid of a scalar potential. From this study, the experimental results are compared with both the braking force calculated by actual conductivity and compensated conductivity of the rail.

THE ANALYSIS METHOD

Analysis model

Fig. 1 shows the experimental eddy current brake system used as an analysis model. The specifications are presented in table I. Fig. 2 shows the one pole analysis model of experimental system to analyze braking performance with proposed analysis method.

Field Analysis

The electromagnetic equation for the time varying field problem with vector potential $\boldsymbol{A}$ is as follows:

Fig. 1. Experimental system

Table I. Specifications

Item	Value	Item	Value
MMF per slot	1064 (A)	Magnet stack width	100(mm)
Airgap	8 (mm)	Fly wheel width	240 (mm)

Diameter of fly wheel	44.25 (mm)	Material of fly wheel	S20C

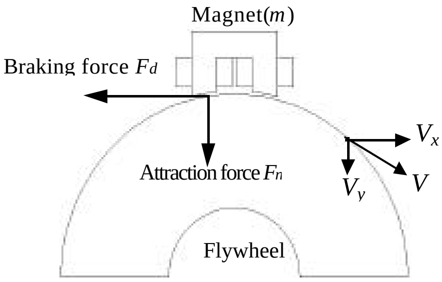


Fig. 2. Analysis model

$$\nabla \times (\frac{1}{m} \nabla \times \boldsymbol{A}) = \boldsymbol{J}_0 + s\,(\boldsymbol{V} \times \boldsymbol{B}) \qquad (1)$$

where $\boldsymbol{J_0}$ is the applied current density, s is the rail conductivity, $\boldsymbol{V}$ is the line velocity in the surface of flywheel and m is the magnetic permeability. The compensated conductivity of rail s is used in equation (1).

The rail is moving along x direction with V_x velocity. The rail is flywheel type in analysis model, hence not only the velocity of x component but also y component should be concerned as shown in Fig. 2. Applying Coulomb gauge condition to equation (1) can be rewritten for 2-D cartesian coordinate, as shown in equation (2).

$$\frac{1}{m}[\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2}] + J_0 - \sigma(V_x \frac{\partial A}{\partial x} + V_y \frac{\partial A}{\partial y}) = 0 \qquad (2)$$

The equation (2) is the characteristic equation to analyze 2-D FEM for the eddy current brake with flywheel.

Equivalent Stack Width Calculation

In order to calculate the equivalent stack width, the governing equation with magnetic scalar potential Ω can be expressed as follows:

$$\nabla \cdot (m \nabla \Omega) = 0 \qquad (3)$$

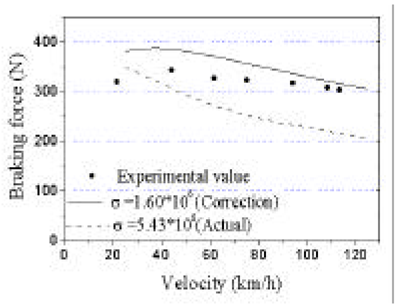
We can obtain air-gap flux per unit width F and stored energy W_m from solving the equation (3).

$$\Phi = S \cdot B = w \cdot 1 \cdot B = w \cdot \mu \cdot H \qquad (4)$$

$$W_m = \int_v [\int_B H \cdot d\boldsymbol{B}] dv \qquad (5)$$

where S is the magnet area, w is the mechanical stack width and v is the whole element of the analysis model.

The magnetic reluctance $\Re$ is expressed by the relation of the flux and stored energy in air-gap.



$$\Re = g/S_{eff}\,\mu_0 = 2W_m/\Phi^2 \qquad (6)$$

where S_{eff} is the effective area of magnet and g is the mechanical air-gap.

Hence, the equivalent stack width can be calculated as equation (7).

$$l_{eff} = (g\Phi^2)/(2W_m \mu_0) \qquad (7)$$

ANALYSIS RESULT AND CONCLUSION

Fig. 3 shows the equipotential distribution, which is not considered the correction of rail conductivity, and the boundary condition for the experimental model at 125(km/h). Fig. 4 and Fig. 5 show the attraction and braking force according to velocity with proposed analysis method. The equivalent stack width of the analysis model is 128.22(mm). From this result, we note that the variation of rail conductivity affects the braking performance and there is a large difference of performance between the actual rail conductivity 5.4×10^6 (℧/m) and compensated rail conductivity 1.6×10^6 (℧/m). Then the result of the analysis considering the rail conductivity is good agreement with the experiment result

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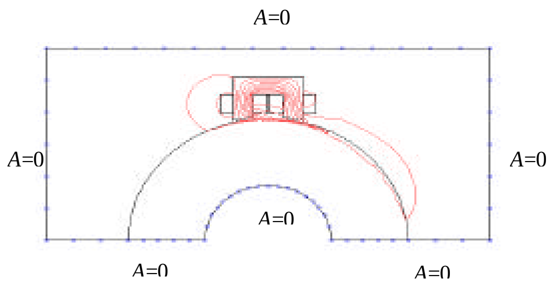


Fig. 3. Equipotential distribution without correction at 125(km/h)

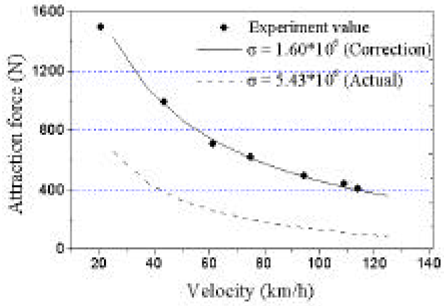


Fig. 4. The variation of attraction forces according to the velocity for the conductivity

Fig. 5. The variation of braking force according to the velocity for the conductivity

The many design variables have influence on the braking performance. Therefore, It is necessary to know exactly on which the parameter has an effect in order to design the optimal eddy current brake. For these reasons, this paper deals with reliable analysis of braking performance according to parameter and the analysis result is compared with experiment value. The magnet dimension, which has the minimized attraction force and maximized barking force, is determined from the analysis result.

The parameter of the number of pole, electric ampere-turns and slot width is selected. Fig. 1 shows the analysis flow to analysis the effect of parameter. In order to obtain reliable analysis result, the equivalent stack width due to difference of rail and magnet width is calculated by field variable with scalar potential, and the correction of rail conductivity according to number of poles is achieved

these magnetic features, so the analysis without these condition is a

These magnetic feature present in 3-D

In 2-D analysis model, These magnetic feature is ignored

The effective 2-demenbtion FEM

the efficient 2 dimensional

is to analyze the performance of eddy current brake system according to variation of design parameter. The allotment of touch free linear eddy brake system increase with high speed of transportation system, so it is necessary to design magnet of eddy current brake with high reliability and performance. Therefore, the effect of design parameter including the number of poles, electric ampere-turns and slot width is investigated by 2 dimensional Finite Element Method (FEM) considering the equivalent stack width.

INTRODUCTION

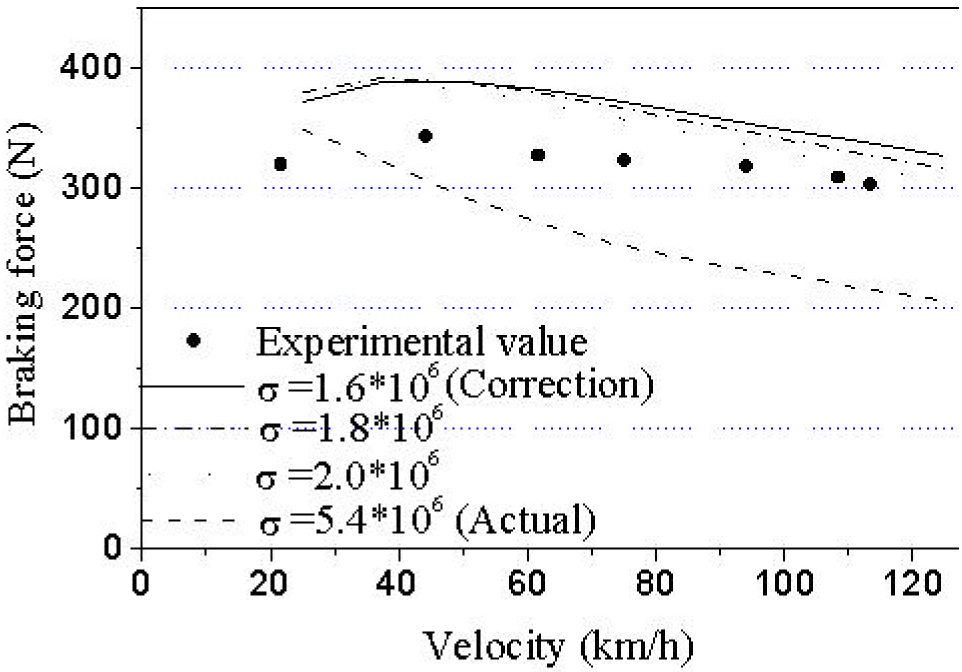
The increase of speed range in high speed train accelerate the development of braking system. The general braking systems relying on the adhesion force between the rails and the wheels. However, the environment problem such as noise and mechanical wear resulting from friction gives rise to adopt a way of touch free, so the proportion of touch free linear eddy current braking has been gradually increased and studied. An eddy current brake used of one of a touch free brake is composed of a DC excited magnet poles and reaction rail. Eddy current induced by a related action between the reaction rail with conductivity and magnet poles produces braking force in train. In the other words, the kinetic energy of the train is converted as electrical energy induced on the reaction rail, which is dissipated as temperature on rail.

The eddy current brake systems have to be equipped with the favorable circumstance of maximum braking force and deceleration to building volume or mass, high braking force at small rate, as small as possible normal forces and stable construction. These contents are reflected in the design of magnet of eddy current brake. In the design of eddy current brake, it is very important to predict the performance based on accurate analysis method. The many design variables have influence on the braking performance. Therefore, It is necessary to know exactly on which the parameter has an effect in order to design the optimal eddy current brake. For these reasons, this paper deals with reliable analysis of braking performance according to parameter and the analysis result is compared with experiment value. The magnet dimension, which has the minimized attraction force and maximized barking force, is determined from the analysis result.

The parameter of the number of pole, electric ampere-turns and slot width is selected. Fig. 1 shows the analysis flow to analysis the effect of parameter. In order to obtain reliable analysis result, the equivalent stack width due to difference of rail and magnet width is calculated by field variable with scalar potential, and the correction of rail conductivity according to number of poles is achieved

Fig. Analysis f low

parameter effectthe propose of process of detail design and analysis of influence on braking force according to variation of the parameters to achieve above-mentioned brake performance in high speed trains. In addition, optimized eddy current brake system is designed by proposed method to maximum braking force and



deceleration.

Fig. 2 Experimental model

the parameters, such as the number of pole, electric ampere-turns and slot width have influence on the braking characteristics. For these reasons, the aim of this paper is the propose of process of detail design and analysis of influence on braking force according to variation of the parameters to achieve above-mentioned brake performance in high speed trains

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This paper presents braking performance and design process of a touch free linear eddy current brake operated electrically for wheel rail high speed transportation systems. The eddy current brake systems have to be equipped with the favorable circumstance of maximum braking force and deceleration to building volume or mass, high braking force at small rate, as small as possible normal forces and stable construction. The parameters, such as the number of pole, electric ampere-turns and slot width have influence on the braking characteristics. For these reasons, the aim of this paper is the propose of process of detail design and analysis of influence on braking force according to variation of the parameters to achieve above-mentioned brake performance in high speed trains. In addition, optimized eddy current brake system is designed by proposed method to maximum braking force and deceleration.

In order to obtain reliable analysis result, the equivalent stack width due to difference of rail and magnet width is calculated by field variable with scalar potential, and the correction of rail conductivity according to number of poles is achieved.