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Simulation of Maglev Train Safety Braking Operation

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***Abstract*—In order to enable the maglev train to safely park in the auxiliary parking area set by the line during the emergency braking process, this paper analyzes the safe braking force of the medium-speed maglev train and writes the safety braking running simulation software using C#. By analyzing the various running resistances in the safety braking process, the relationship between the running speed of the maglev train and the compound braking force is obtained. The simulation is conducted with the given line data. The results show that the maglev train can safely be stopped in the auxiliary parking area by adjusting the eddy current braking levels, which have reference values for the real-time operation of maglev trains, the analysis of the braking performance, and the setting of the auxiliary parking area.**

Keywords—maglev train, safety braking, auxiliary parking area

I. Introduction

The maglev train is a ground rail transportation system with the advantages of fast running speed, stable driving process, low noise and environmental friendliness. Maglev train brakes mainly use three kinds of braking methods: electric braking, skid braking and eddy current braking [1]. The maglev train has a fast running speed with no resistance from the wheel-rail relationship. To cope with the situation of emergency braking and restart, an inter-station auxiliary parking area with a power rail installed between stations is provided. In order to make the maglev train safely brake and stop at the auxiliary parking area or station at any speed, this paper analyzes the force of the maglev train safety braking and uses C# to write the maglev train running simulation software for auxiliary research [2].

II. Safety speed protection of the Maglev train

Unlike traditional railway transportation, in maglev transportation, the maglev train can only stop at the auxiliary parking area on or between stations. Therefore, the speed of the maglev train is strictly controlled. The speed range that meets the requirements is called the safety speed protection limit, which is divided into the upper limit of safety speed protection and the lower limit of safety speed protection [3].

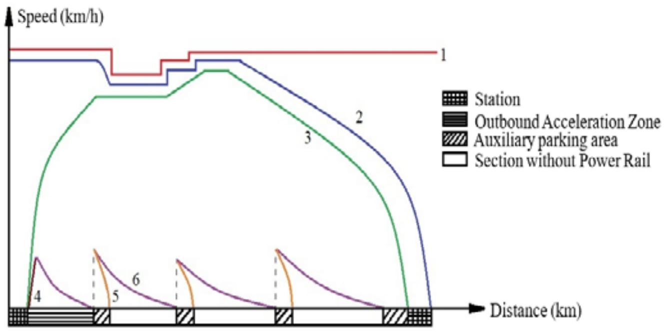
For the medium-speed maglev train, the on-board battery is the power supply system for the train at start-up and low-speed operations. When the vehicle speed is greater than 80km/h, the on-board linear generator supplies power to the on-board system and also charges the on-board battery. In the case of emergency braking, if the power of the traction system is cut off, the train must rely on the energy of the vehicle battery to continue the suspension and braking of the train. After the energy of the vehicle battery is exhausted, the train will not be able to resuspend if it is not recharged. Therefore, in order to ensure that the train has enough energy to suspend under abnormal conditions, in addition to the parking area of the station, the system also sets up a number of auxiliary parking areas installed with power rail. These auxiliary parking area can charge the train , and can also provide safe and fast evacuation channels for passengers and persennel if necesarry[4].

The upper limit of safety speed protection is the distance-speed curve of the train braking process when the power of on-board eddy current brake is set at the maximum value during emergency braking. The safety speed protection upper limit curve is mainly determined by three factors:

- The maximum speed that the maglev train can reach which depends on the technical conditions of the train
- The maximum allowable speed of the line with speed limit section. Train speed will be limited in some specific sections such as residential areas which require reducing noise and vibration pollution.
- Upper limit speed protection curve for safe braking. Before the speed limit section, the initial values of the upper limit speed protection curve for safety braking are the limited speed of the section and the initial position of the the section

The lower limit of safety speed protection is the distance-speed curve when the train loses traction power and, slides forward on its own kinetic energy and potential energy, without eddy current braking force.

The relationship between train operation speed and safety speed protection is shown in Fig. 1.



1-line speed limit, 2 - maximum allowable speed curve, 3 - actual running speed curve, 4 - outbound minimum speed limit curve,5-safety braking speed curve, 6-minimum suspension operation speed curve

Figure 1. Relationship between train operation speed and safety speed protection

Curves 2 and 5 are the upper limit of safety speed protection, indicating that the train can be safely stopped in the auxiliary parking area equipped with a power track when the braking power of on-board eddy current brake is at its maximum value. Curve 6 is the lower limit of safety speed protection, indicating that the train can slide forward after losing traction power when the on- board eddy current brake is closed and be safely stopped in the auxiliary parking area ahead.

The normal operation process of the medium speed maglev train is as follows. When the train leaves the station, the speed shall be increased in the acceleration zone of the station, so that the train can reach the minimum speed of the station at the end of the acceleration zone, to ensure that the train can suspend and slide to the next auxiliary parking zone equipped with power rail with only its kinetic and potential energy. During the operation process between stations, the train shall always maintain a high speed, but meet the requirements of each running section. The operation control system gradually reduces the running speed in the process of entering the station. Finally, the train stops at the drop-off area in the station through the automatic parking steps.

In case of an emergency during the operation of a maglev train, the curve of minimum suspension operation speed and safety braking speed, shall be considered as shown by curves 5 and 6 in Fig. 1. When the train is running in the acceleration zone and the train speed cannot meet the minimum outbound speed limit curve of curve 4 due to abnormal conditions, the on-board operation control system controls the train to complete the emergency stop in the acceleration zone according to curve 5, to prevent failure to suspend to the nearest auxiliary parking zone when the train loses traction power running between stations. When the train needs to stop in an emergency when running between stations, curve 5 provides the basis for braking so as to ensure the train can be stopped in the auxiliary parking area. Its minimum running speed must meet the requirements of curve 6, so that, when the train loses traction power, it still ensures that the train can suspend and slide on its current kinetic energy and potential energy, and be stopped safely in the next auxiliary parking area.

The operation speed curve of the maglev train is a necessary means for the on-board operation control system to control the safe operation of the train. The vehicle safety computer in the vehicle operation control system receives the operation plan of the central control system, forwarded by the zone control system through the vehicle's radio communication unit. It then combines the current running speed, position and train equipment state of the train to generate a running speed curve for controlling the train operation, and adjusts the gear position of the eddy current braking force to prevent the overspeed and underspeed of the train, and ensures that the train can safely run to the parking area in front [7].

III. FORCE ANALYSIS OF THE COMPOSITE BRAKING FORCE OF THE MAGLEV TRAIN

During the braking and stopping process, the train will be affected by the braking force of the synchronous linear motor F_P, air resistance F_A, running resistance caused by the linear generator F_M, slide friction F_W, copper friction F_N, eddy current braking force F_E, ramp resistance of the current running line F_G, curve resistance F_R, tunnel resistance F_S, and other random disturbance factors F_C. Then the resultant force of a single train F_T is (each force unit is kN):

$$\sum F_T = F_P + F_A + F_M + F_W + F_N + F_E + F_G + F_R + F_S + F_C \quad (1)$$

A. Braking force of the synchronous linear motor F_P

Consider F_P=0 in safety braking.

B. Air resistance F_A

Using empirical formula:

$$F_A = 6.08v^2 \times 10^{-3} \ (kN) \quad (2)$$

C. Running resistance caused by the linear generator F_M

$$F_M = \begin{cases} 0 & , v < 100\text{k}m/h \\ 3.4 & ,100 < v < 200\text{k}m/h \end{cases} \ (kN) \quad (3)$$

D. Slide friction F_W

$$F_W = \begin{cases} 0 & ,v > 10\text{k}m/h \\ M \times g \times \mu_1 & ,v < 10\text{k}m/h \end{cases} \ (kN) \quad (4)$$

The value of μ1 is calculated by linear interpolation according to table I.

TABLE I. TABLE OF FRICTION COEFFICIENT AS A FUNCTION OF SPEED

Speed(km/h)	0	10
μ_1	0.27	0.24

E. Copperplate friction F_N

$$F_N = \begin{cases} 0 & ,v > 100\text{k}m/h \\ F_y \times \mu_2 & ,v < 100\text{k}m/h \end{cases} \ (kN) \quad (5)$$

F_y is the normal suction. The value of μ2 is related to the running speed, and the corresponding linear interpolation calculation is performed according to Table II.

TABLE II. TABLE OF FRICTION COEFFICIENT AS A FUNCTION OF SPEED

Speed(km/h)	0	10	20	30	50	100	200
μ_2	0.3	0.25	0.22	0.20	0.18	0.14	0.12

F. Eddy current braking force of train F_E

The eddy current braking force of train F_E is calculated by simulation, including tangential braking force and normal suction force.

With reference to the parameters of the medium speed maglev train in the model, the 12 electrode eddy current brake with current of 56A × 360 turns per pole is calculated by simulation and data processing. The values of tangential braking force and normal suction as a function of speed are obtained by considering the change of air gap when the eddy current brake is applied with current of 56A. The curve of tangential braking force and normal suction force as functions of speed is obtained by fitting the data with a cubic spline interpolation method, as shown in Fig. 2 and Fig. 3.

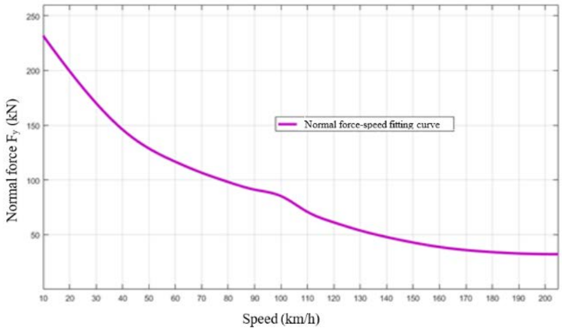


Figure 2. Normal force-speed curve

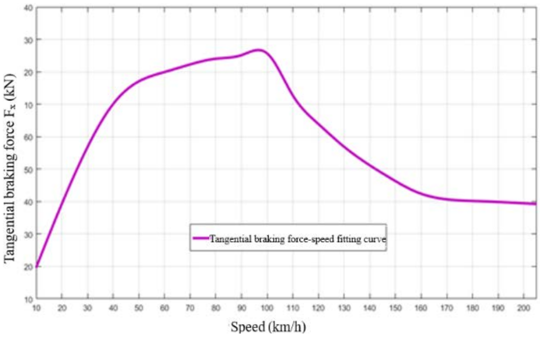


Figure 3. Tangential braking force-speed fitting curve

G. Ramp resistance F_G

The gradient of the line ramp is slight, so it can be taken that sinθ=tanθ. Therefore:

$$F_G = M \times g \times tan\theta \ (kN) \tag{6}$$

H. Curve resistance F_R

When the Maglev train is in normal operation and braking, the on-board linear generator and on-board battery ensure that the maglev train suspension frame will not contact the guide rail directly, so the curve resistance is not considered. Take FR=0.

I. Tunnel resistance F_S

Due to the lack of data on the force analysis of the maglev train passing through a tunnel, the empirical formula in the code for calculation of train traction is used for reference:

$$F_S = \begin{cases} M \times g \times L_s \times v^2 \times 10^{-7} \\ (When\ there\ are\ ramp\ restrictions\ in\ the\ tunnel) \\ 0.00013 \times M \times g \times L_s \\ (When\ there\ are\ not\ ramp\ restrictions\ in\ the\ tunnel) \end{cases} \quad (kN) \tag{7}$$

J. Random disturbance factor F_C

This factor is not considered here, temporarily. Consider $F_C = 0$.

Through the analysis of A - J, the relationship between the compound total braking force and the running speed can be obtained, as shown in Fig. 4.

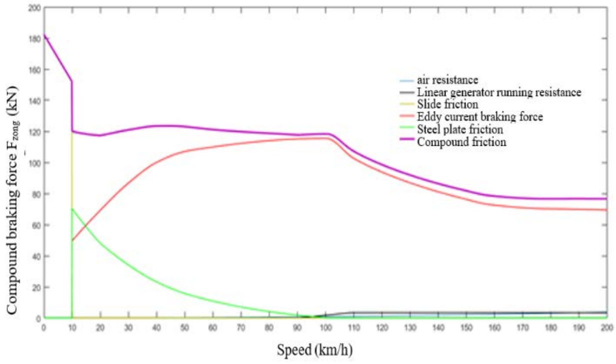


Figure 4. Relationship between compound braking for and speed

IV. EDDY CURRENT BRAKE SIMULATION SOFTWARE FOR THE MEDIUM SPEED MAGLEV TRAIN

In order to study the relationship between eddy current braking force and auxiliary parking area, as there is no maglev line with a speed of 200km/h in China at present, this paper selects a section of Chongqing Guiyang passenger line with a maximum allowable speed limit of 200 km/h as a reference, as shown in Fig. 5.

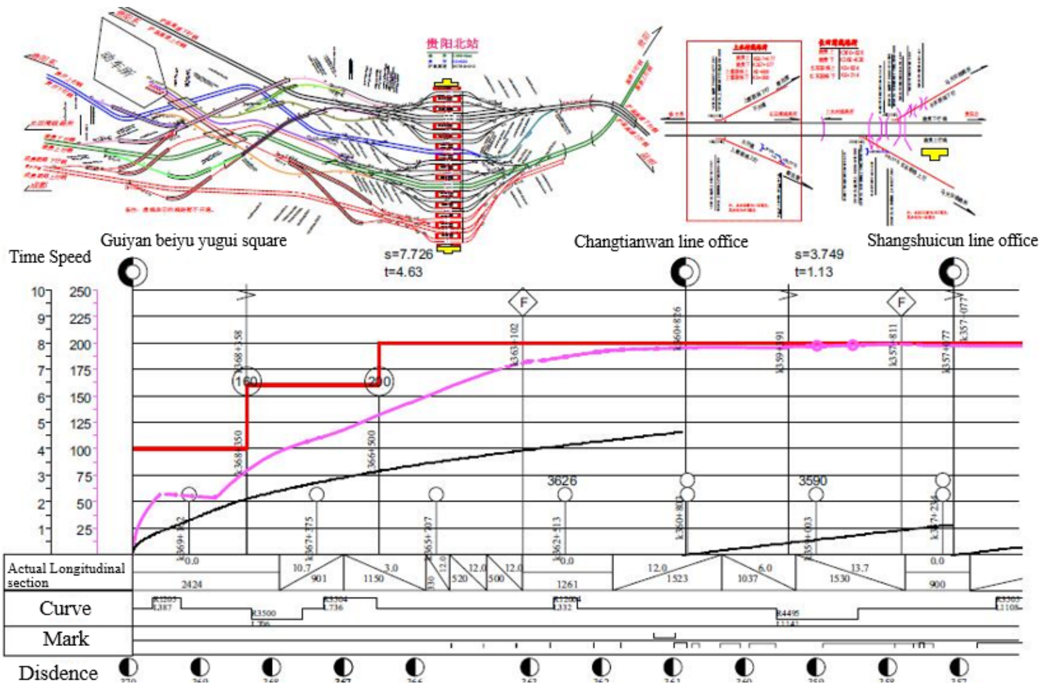


Figure 5. Line diagram of Chongqing Guiyang railway with the maximum allowable speed limit of 200 km/h

The data of line speed limit, slope, and length of ramp is input and saved as an Excel file. C# is used to write the simulation software of eddy current braking of the medium speed maglev train to read the Excel file of line data for research and analysis [8,9]. The software structure is shown in Fig. 6.

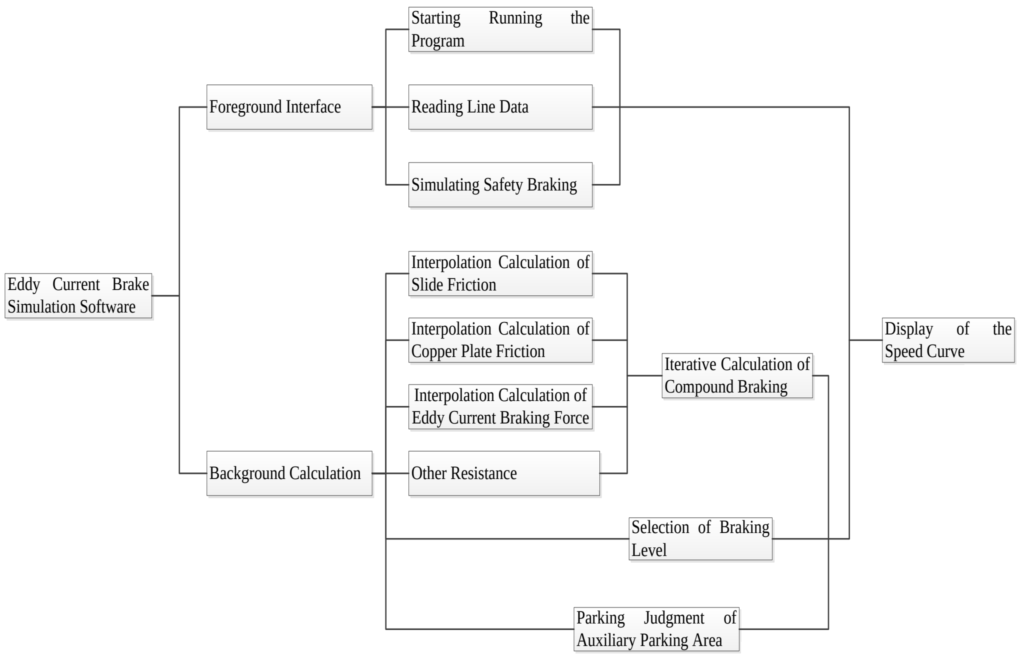


Figure 6. Structure of eddy current brake simulation softwareStarting simulation operation

The software can be divided into three parts according to the function: reading line data, traction curve simulation, and safety braking simulation. The simulation program can be operated by the buttons on the interface.

The main operation buttons are:

A. Reading line

The curve of minimum speed limit, safety braking speed, maximum allowable speed, and line speed limit would be calculated and drawn out after the program reads the line data in the Excel file.

The program iteratively calculates the distance-speed function in the background as the traction curve after clicking the start button in the running simulation software, and displays it in the display area of the running simulation software in real time.

B. Braking, upshift and downshift

The program will calculate and compare the distance when the train stops from the current speed, with the position of the auxiliary parking area in the background, after the brake button is clicked, and will select the appropriate brake gear to brake the train. Alternatively, the maglev train can stop in the auxiliary parking area safely by means of clicking the upshift and downshift buttons to manually control the brake level of the eddy current brake force.

By reading the line data (line speed limit, line ramp data, etc.) in advance, the software can calculate the minimum speed limit curve, safety braking speed curve, maximum allowable speed curve, and line speed limit curve. The traction curve is obtained with reference to the technical parameters of CRH6A EMU with a speed of 200 km/h.

After the start of the simulation, the program will perform interpolation calculation for the slide friction F_W, the copper plate friction F_N and the eddy current braking force F_E in the background. At the same time, the distance-speed function which is iteratively calculated is used as the traction curve, which is displayed in real time.The software interface and operation results are shown in Fig. 7.

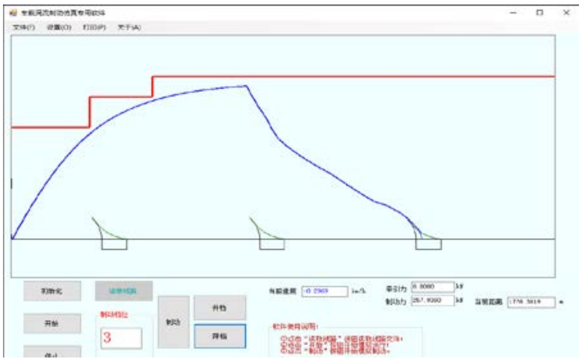


Figure 7. Eddy current brake simulation software

As shown in Fig. 7, the curve in the figure is the result of simulating the actual operation curve (curve 3 in Fig. 1). During the operation of the maglev train, the brake button is clicked to simulate the emergency braking situation. The maglev train is stopped safely in the fourth auxiliary parking area by adjusting the eddy current brake level (gear).

It can be seen that the operation simulation software can simulate the real-time operation and braking of the maglev train through the analysis of the maglev train operation simulation software. The train can be stopped in the auxiliary parking area set on the line safely at any speed after applying safe braking, by automatically adjusting the eddy current braking force.

Running simulation software can verify whether the setting of auxiliary parking area is reasonable when giving the braking force and whether the braking performance meets the requirements when giving the setting position of auxiliary parking area.

V. CONCLUSION

The safety braking operation software is compiled by means of analyzing the braking force of the medium speed maglev train in the process of implementing the safety braking and combining with the line data. The corresponding safety protection curve can be calculated. The maglev train can be safely parked in the auxiliary parking area by adjusting the braking level of the eddy current braking force. The operation analysis can be used as a reference for the real-time operation of the maglev train, brake performance verification and auxiliary parking area setting guidance.

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