Research on Traction Calculation Simulation System of Mid-low Speed Maglev Train

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Abstract. According to the basic principle of train traction calculation, the traction calculation simulation algorithm of maglev train is designed, and the simulation system is developed. The system can realize the traction calculation simulation under different operation modes of single train. At the same time, taking the actual line as an example, the simulation results of train operation are given. The results show that there are some differences in running time, tractive time and energy consumption of trains under different operation modes, among which the running time of Cruise (time saving) mode is shorter, and the comprehensive evaluation effect of Cruise (energy saving) mode is better on total energy consumption, running time and comfort.

Keywords. Maglev train, Operation mode, Train traction calculation, Computer simulation.

1. Introduction

The principle of the maglev rail transit system is to balance the earth’s gravity with electromagnetic force, and use the linear motor for traction, so that the train can be suspended on the track. Compared with the traditional rail transit, the maglev rail transit system has the characteristics of small turning radius, strong climbing ability, good acceleration performance, stable and comfortable ride. The mid-low speed maglev system is suitable for the traffic connection between urban areas, short distance cities and tourist attractions. At present, the maglev projects in operation include Changsha Airport maglev and Beijing S1 line. With its unique advantages, the mid-low speed maglev has broad development space.

The traction calculation of train is very important in the design of rail transit. The running speed is the basic for setting the curve super elevation. The running time data provides the basis for setting the air shaft in the tunnel section. The traction energy consumption data is the basis of traction power supply capacity design. Applying train traction calculation simulation system to project design can improve design efficiency.

Scholars have done some research on related issues. Luo J et al. [1] analyzed and calculated the traction characteristics of maglev train, and determined the rated output power of the traction motor. Rao P et al. [2] established the traction calculation model and developed the traction calculation simulation software. Mo S et al. [3] used the finite volume method to calculate the aerodynamic resistance under the conditions of no crosswind and crosswind at different speeds. Zhu L Y et al. [4] analyzed the traction characteristics of the linear motor and calculated traction characteristics.

Based on the general-purposed train movement simulation system [5-6], this paper designs the traction calculation simulation algorithm of maglev train, and develops the traction calculation
simulation system, which can realize the train traction calculation simulation under different operation modes.

2. Basic Principle of Train Traction Calculation
The external forces that the train receives in the process of operation include tractive force, resistance and braking force. The value of resultant force depends on the traction, resistance and braking force as well as their relationship with line conditions and running speed.

2.1. Ttractive Force of Train
The tractive force of maglev train is produced by linear induction motor, which is different from the traditional train. In practical application, according to the motor traction curve, the traction force \( F \) at corresponding speed is calculated by linear interpolation method.

\[
F = n_1 \cdot n_2 \cdot f \quad \text{(kN)}
\]

where: \( n_1 \) is the number of motor cars; \( n_2 \) is the number of motors of each motor car; \( f \) is the tractive force of single motor, kN.

2.2. Resistance of Train
The resistance mainly includes basic resistance and additional resistance.

The basic resistance is the resistance of the train running along the straight track in the open area. It is caused by the friction and impact between the internal and external contact of the train. It is mainly related to the structure. The basic resistance includes electromagnetic resistance, current collector resistance and air resistance.

The additional resistance is mainly caused by the line. The additional resistance of maglev train includes ramp, curve and tunnel.

1. Additional resistance of ramp: it is the component force of train gravity downward along the ramp, with positive uphill and negative downhill.

2. Additional resistance of curve: maglev train adopts the electromagnetic force guidance mode. Compared with wheel rail train, its curve additional resistance is much smaller and can be ignored.

3. Additional resistance of tunnel: Due to the low running speed of the train, the additional resistance of the tunnel can be ignored; if the tunnel is long, the value can be taken according to the experience of wheel rail train.

Train resistance \( W \) is:

\[
W = G \cdot (w_0 + w_j) \cdot g \times 10^{-3} \quad \text{(kN)}
\]

where, \( G \) is the total weight, \( t \); \( w_0 \) is the unit basic resistance, N/kN; \( w_j \) is the unit additional resistance, N/kN; \( g \) is the acceleration of gravity.

2.3. Braking Force of Train
Calculation of train braking force is an important means of train speed regulation, especially in speed limit, downhill and parking. The common braking methods of mid-low speed maglev train are regenerative braking, reverse braking and mechanical braking. The first two are collectively referred to as electric braking.

The train braking is generally divided into the following stages: when the train speed is high, regenerative braking is adopted. With the decrease of train speed, reverse braking and mechanical braking will be adopted.
2.4. Determination of Train Motion Equation

The equation of train motion is the relation equation of speed, time and distance, which is used to determine the running time of the train in the interstation and the running speed of each position in the interstation.

There are three working conditions during train operation: traction, coasting and braking. \( F, W, B \) and \( C \) are used to represent the tractive force, resistance, braking force and resultant force respectively. The resultant force acting on the train under each working condition can be expressed as: ① traction: \( C = F - W \), ② coasting: \( C = -W \), ③ braking: \( C = -(B + W) \).

If the acceleration at time \( t \) is represented by \( a' \), the unit resultant force, speed, position and energy consumption are represented by \( c' \), \( v' \), \( d' \) and \( H' \) respectively, the rotating mass coefficient is represented by \( \gamma \), and the running state update of the train can be represented as:

\[
a' = \frac{127}{1 + \gamma} c' \quad \text{(km/h}^2\text{)} \tag{3}
\]

Maglev train \( \gamma = 0 \), so \( a' = 127c' \)

\[
v'^{t+1} = v' + a'\Delta t \tag{4}
\]

\[
d'^{t+1} = d' + v'\Delta t + \frac{1}{2} a'\Delta t^2 \tag{5}
\]

\[
H'^{t+1} = H' + UI'\Delta t \tag{6}
\]

3. Realization Method of Train Traction Calculation System

Through operation calculation, the simulation system obtains the data of train speed, time and energy consumption, which provides the basis for the planning, design and transformation of maglev line.

3.1. System Structure Design

The simulation system includes basic data management, train operation calculation, calculation result output and other modules. The system structure is shown in figure 1.

![Figure 1. Simulation system structure.](image)

The basic data management module is responsible for the management of line data and motor car data. The train operation calculation module is responsible for the definition of calculation parameters,
initialization and operation calculation. The output module of calculation results includes screen output and file output.

3.2. *Train Operation Algorithm Analysis*

The calculation process of train operation includes initialization of train operation speed limit, calculation of interstation operation process, determination of parking braking process, etc.

3.2.1. *Main Algorithm Design.* The main algorithm design process is as follows: ① Initialize the train speed limit according to the line and train conditions. ② Obtain the train running speed, position, current time and speed limit at the beginning of step length. ③ Determine the working condition of the train. ④ Calculate train operation data. ⑤ Save the running data. ⑥ Judge whether the train has reached the calculation end point. If it has not reached the calculation end point, advance the simulation clock to calculate again, otherwise, the calculation ends.

3.2.2. *Initialization of Train Operation Speed Limit.* Speed limit mainly includes: ① Line speed limit. ② Maximum running speed of train. ③ Station speed limit, including turnout speed limit and passing station speed limit. ④ Curve speed limit, including horizontal curve and vertical curve speed limit. ⑤ Other speed limits, including temporary speed limit, etc. The final static speed limit is the lowest of the above speed limits. After the static speed limit is generated, the part from high-speed limit to low-speed limit is reversely generated into a continuous curve by braking.

3.2.3. *Calculation of Intersation Operation Process.* When the train is running on flat slope, uphill and small downhill, the speed will be reduced when it is coasting. When the speed reaches the speed limit, the train will use the coasting. When the speed drops to the given value, the train will use traction again. And train use the coasting again when it reaches the speed limit, and then the train will maintain traction-coasting operation.

When the train runs on a large downhill, it is necessary to apply braking. When the speed of the train drops to the given value, the train will use coasting again. And train use braking again after approaching the speed limit, and then the train will maintain brake-coasting operation.

When the train runs from high-speed limit to low-speed limit, braking will be used until the speed is lower than low speed limit, then the train will operate according to the above conditions.

3.2.4. *Calculation of Parking Braking Process.* The parking braking algorithm is designed as follows: ① Set the speed limit of the target point. ② Determine the operation parameters of the train, including time, speed, position and resultant force, etc. ③ Perform brake stop detection. ④ If the stop error is not satisfied, advance the clock and turn ②. ⑤ The train brakes and stops at the current point. When the train speed is 0 at the end of the step, the calculation ends.

4. *Operation Results*

The line takes two stations with the length of 7480 m between stations. The train adopts three operation modes, namely, cruise (time saving), cruise (energy saving) and traction-coasting. Among them, the cruise (time saving) mode means: the maximum tractive force is used to reach the speed limit, and the cruise operation will be used when the train reaches the speed limit. Cruise (energy saving) mode means: the train shall avoid braking as much as possible during operation and adopt coasting operation. When the train reaches the speed limit, cruising operation will be adopted. Traction-coasting mode refers to that the train shall avoid braking as much as possible during operation and adopt coasting operation. When the train reaches the speed limit, traction-coasting operation will be adopted. The operation curves of the three modes are shown in figure 2, figure 3 and figure 4.
Figure 2. Cruise (time saving) mode.

Figure 3. Cruise (energy saving) mode.

Figure 4. Traction-coasting mode.

The operation results of the three modes are shown in Table 1.

| Operating mode            | Running time (s) | Tractive time (s) | Tractive energy consumption (kWh) | Suspension energy consumption (kWh) | Reverse braking energy consumption (kWh) | Regenerative braking energy consumption (kWh) | Total energy consumption (kWh) |
|---------------------------|------------------|-------------------|----------------------------------|-------------------------------------|-----------------------------------------|------------------------------------------|-------------------------------|
| Cruise (time saving)      | 429.74           | 350.59            | 45.75                            | 9.94                                | 0.85                                    | -9.00                                    | 47.54                         |
| Cruise (energy saving)    | 465.03           | 320.00            | 35.64                            | 10.65                               | 0.85                                    | -6.22                                    | 40.91                         |
| Traction-coasting         | 478.77           | 258.00            | 35.30                            | 10.92                               | 0.85                                    | -6.08                                    | 40.99                         |

According to the operation result data in Table 1, in the cruise (time saving) mode, the train operates close to the speed limit, so the running time is shorter (429.74 s) and the tractive time is longer (350.59 s). In the traction-coasting mode, the train operates with traction-coasting after reaching the speed limit, so the running time is longer (478.77 s) and the tractive time is shorter (258.00 s). In terms of
energy consumption, although the regenerative braking feedback energy consumption of Cruise (time saving) mode is large (-9.00 kWh), the total energy consumption is the largest (47.54 kWh) due to the larger tractive energy consumption (45.75 kWh). The total energy consumption of cruising (energy saving) mode and traction-coasting mode is similar, but in cruising mode, when the train reaches the speed limit, it will run at a constant speed, and its operation will be more stable and comfortable.

5. Summary

In this paper, the traction calculation simulation algorithm of the maglev train is designed and the simulation system is developed, and the actual line is taken as an example to simulate the traction calculation.

The results show that there are some differences in running time, tractive time and energy consumption under different operation modes, among which the running time of Cruise (time saving) mode is shorter, the comprehensive evaluation effect of Cruise (energy saving) mode is better on total energy consumption, running time and comfort, and different operation modes can be selected according to the needs in the process of engineering design.

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