Model-based Simulation and Verification on Typical Function Scenes of High-Speed Maglev Vehicle Operation Control System

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Abstract. Under the new situation, high-speed maglev transportation has gradually become the new development direction of the railway field in the future. Its vehicle operation control system (VOCS for short) as a key subsystem has a great impact on the safety and stability of the entire high-speed maglev train control system. The high-speed maglev VOCS has the characteristics of complex system structure and frequent interaction between its modules. Finding hidden safety hazards and design errors in the system design and development process and ensuring the safety and efficiency of system design and development has become an important task of related projects. On this background, modelling and simulation of typical scenarios of high-speed maglev VOCS are absolutely necessary in the early stage of project development, drawing on the traditional wheel-rail vehicle system simulation verification research results, with the help of advanced computer simulation methods. Using Simulink / Stateflow tools for the parking point stepping functional scenario as an example, the validity and correctness of the high-speed maglev VOCS were verified to ensure the operation safety of the high-speed maglev train through.

1. Introduction
High speed maglev is a new type of transportation system. Due to its advantages of high safety, high speed, low energy consumption, advanced technology and long track life, maglev technology has gradually become a new development direction in the railway field in the future. With the new requirements of the Ministry of science and technology in the 13th five-year plan to build 200 km/h medium speed maglev traffic project and 600 km/h high-speed maglev traffic project [1], the development of high-speed maglev technology to ensure the safe and efficient operation of high-speed maglev train has become the core of the project. The train operation control system is one of the important technical equipment to ensure the safety of train operation and improve the efficiency of train operation on high-speed railway in China. Maglev train and wheel rail train are similar in the principle of specific train operation control technology, but they are different in the specific control implementation. Therefore, it is very important to study the train operation control system in the whole maglev transportation system. The main function of high-speed maglev vehicle operation control system (VOCS for short) is to realize train speed protection control. As a key subsystem of train operation control system, its performance has a great impact on the safety and stability of the whole high-speed maglev train control system.

In order to study high-speed maglev vehicle operation control method, it is necessary to carry out the corresponding function, performance and joint test for each subsystem. The VOCS is a distributed
complex system, and its field test work has practical problems of high cost and difficult to carry out. With the rapid development of computer technology, simulation technology plays an increasingly important role in the corresponding research of wheel rail train control system. Therefore, in the early stage of the project development, the validity and correctness of the high-speed maglev VOCS can be verified by means of advanced computer simulation means in the form of simulation and test. At present, with the increasing complexity of the studied system, new simulation methods are emerging, such as qualitative simulation, distributed interactive simulation, object-oriented simulation, etc. [2-4], to meet the needs of complex system simulation.

At present, there is a lack of research on simulation and formal verification of high-speed maglev VOCS in China. Therefore, in the aspect of simulation and verification of the corresponding operation scenario of high-speed maglev vehicle system, this study uses the simulation and verification research results of the traditional wheel rail vehicle system for reference, and studies the technical means of using simulation and verification to ensure the safety of high-speed maglev train.

2. Overview of typical functional scenarios
As an important subsystem of the maglev train operation control system, the main task of the high-speed maglev VOCS is to ensure the safe and efficient operation control of the train together with the ground subsystem. Its two major functions are train protection control and speed protection. Train protection control involves train start and login, train status management, train suspension and landing, door control and safety braking; the speed protection function is the core function of train operation control, which realizes the acquisition of real-time speed and position of the train, real-time monitoring the current train speed within the safety range of maximum and minimum allowable speed. When the speed exceeds the safety range, the VOCS timely informs the train to take measures such as traction cut-off and eddy current braking to protect the train safety.

The parking point stepping is an important sub function of speed protection function in the high-speed maglev VOCS, which is the key to ensure the continuous operation of the train in the given route, as well as the speed curve calculation and protection. The parking point stepping scene of parking point is accomplished by ground subsystem and vehicle subsystem, which is a typical and complex operation scene. This scene highlights the interaction and control of information between ground equipment and vehicle equipment in high-speed maglev system. Therefore, this study chooses to carry out corresponding modeling and simulation work on the parking point stepping scene of parking point.

2.1. Parking point stepping
Each maglev train has a parking point that can be reached at the current position when it is running, so as to ensure that the train can stop safely only depending on its own kinetic energy and potential energy or emergency braking force in case of traction or normal braking failure.

In order to achieve continuous operation under normal conditions, when the train meets the conditions required to reach the next parking point, VOCS shall check the parking point stepping conditions of vehicle equipment, including whether it can receive the line data on the ground, whether the current train position is accurate, whether there is a stop command, etc. if the check results meet the parking point stepping conditions, VOCS shall sends the parking point stepping request to the decentralized operation control system (DOCS for short). After receiving the parking point stepping request from VOCS, DOCS also carries out a series of checks, once all conditions meet, DOCS replies to VOCS the response information allowing the parking point stepping. After receiving DOCS confirmation, VOCS will execute the parking point stepping, and take the next safe parking point on the route as the current reachable parking point. Then the above process is cycled through the continuous implementation of the parking point stepping, the final realization of the safe and efficient train to the final target point.
3. Formalized modeling and Simulation of Parking point stepping

3.1. SLSF model of parking point stepping scene
According to the detailed implementation process of the parking point stepping scene in the section 2 and the relationship between the speed curve and the parking point stepping, this chapter uses the Simulink / Stateflow tool to model the parking point stepping scene. The overall structure of the scene model is shown in figure 1. The model mainly includes VOCS model, DOCS model, train dynamics model and ground line database model.

![Figure 1. The overall composition of the SLSF model for the parking point stepping scene.](image)

3.1.1. Train dynamics model.
The train needs a power system to calculate the speed and distance in the running process. Because the power system is continuous, the continuous module in Simulink is used for modeling. The dynamic system model is shown in figure 2. The input of the model is acceleration, and the output is speed and distance. The dynamic module is responsible for generating speed and distance during simulation. In this model, two integration modules are used to integrate the acceleration and the velocity respectively to get the velocity and the distance.

![Figure 2. Train dynamics model](image)
3.1.2. VOCS model.
As the VOCS structure is relatively complex, this paper does not model the overall VOCS structure, but starts with the functional modules required for the parking point stepping scene to model the VOCS. The VOCS model is shown in figure 3.

In this scenario modeling, the main functions of VOCS model are as follows:
- According to the line data, calculate the maximum speed protection curve of the corresponding parking point.
- According to the speed, distance and parking point stepping information of the train, calculate the current acceleration of the train and transmit to the dynamic model.
- According to the real-time speed, distance and corresponding speed protection curve of the train, judge whether to send parking point stepping request to DOCS.
- If the conditions are met, a Parking point stepping request is sent to DOCS.
- After receiving the reply from DOCS to allow the parking point stepping, execute the parking point stepping.

![Figure 3. VOCS model.](image-url)
3.1.3. **DOCS model.**

In this study, the functions related to the DOCS parking point stepping scene are mainly modeled. When DOCS receives the parking stepping request sent by VOCS, it performs the judgment of the parking point stepping conditions. The conditions are as follows:

- The continuous route has been reserved for the track from the train to the parking point.
- The current train speed arrives at the minimum speed of the new parking point.
- There is no conflict between the maximum speed curve and the minimum speed curve.
- No compulsory parking request.
- There is no reason to prohibit stepping.

If the above parking point stepping conditions are met, DOCS will send the response to allow parking point stepping to the VOCS module, as shown in figure 4.

![Figure 4. DOCS model.](image)

3.1.4. **Ground line database model.**

The ground line database model stores the ground line data, such as line slope, number of stepping points, stepping point spacing, static speed limit, etc., and provides the line data to the VOCS. The VOCS calculates the corresponding speed protection curve according to the line data, and combines with the real-time train speed and distance to determine whether to request the parking point stepping.

3.2. **Simulation and analysis of parking point stepping scene**

According to the analysis and modeling of each module of the parking point stepping scene in section 3.1, a complete simulation model of parking point stepping scene is built according to the information of the system structure and the interaction between subsystems. As there is no actual line data available for simulation line at this stage, this paper constructs a specific line according to the characteristics of parking point stepping operation scene, and sets the train to run from station A at the beginning of the line to station B at the end of the line, which passes through three parking points, i.e. parking point 1, parking point 2 and parking point 3.

3.2.1. **DOCS allowed stepping.**

After the train departs from station A, corresponding parameters shall be set so that when the train speed meets the requirements, the parking point stepping conditions of DOCS meet, including: continuous route has been reserved for the track between the train and the parking point, the minimum speed when the train reaches the new parking point at the current speed, no conflict between the maximum speed curve and the minimum speed curve, no forced parking request, no DOCS forbidden stepping reason. At this time, DOCS will allow parking point stepping request, and the control curve will extend to the last parking point (station B). The simulation results are shown in figure 5.
3.2.2. **DOCS does not allow stepping.**

Change the corresponding parameters of parking point 2, so that DOCS cannot meet the conditions of parking point 2, then the train control curve can only be extended to parking point 2, as shown in figure 6.

Figure 5. DOCS allows stepping to station B.

![Allow Stepping](image)

Figure 6. DOCS does not allow stepping parking point 2.

![Don't Allow Stepping Parking 2](image)
Similarly, when DOCS does not allow parking point 3, the control curve can only be extended to parking point 3, as shown in figure 7.

Figure 7. DOCS does not allow stepping parking point 3.

4. Summary and Prospect
The high-speed maglev VOCS is a typical safety critical system, so it is very important to ensure the correct operation of the high-speed maglev train. This paper takes the typical function scene of the high-speed maglev VOCS as the research object, introduces the scene analysis method to describe the structure and working mode of the VOCS, uses Simulink / Stateflow to model and simulate the parking point stepping scene, and uses simulation verification means to ensure the safety of the high-speed maglev VOCS.

However, in the process of modeling the high-speed maglev VOCS, a lot of abstractions and simplifications have been made, which will affect the effectiveness of the verification of the characteristics of the high-speed maglev VOCS. Therefore, in the future, we will further improve the scene modeling of the high-speed maglev VOCS, and carry out more detailed and accurate formal verification based on the established model, and use the real line data as the bottom driver to ensure the reliability of the simulation results.

Acknowledgments
This work is supported by National Key R&D Program of China under Grant (No.2016YFB1200602) and Beijing Laboratory of Urban Rail Transit.

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