Development of a Simulation Software for Subway Train Traction and Braking Process Based on Simulink and Lab VIEW

XIAODONG WANG, MENGLING WU and CHI LEI

ABSTRACT

The simulation software for subway train traction and braking process is composed of a GUI based on Lab VIEW and an underlying model based on Matlab/Simulink. An underlying model consists of a traction system model and a braking system model, which is used to achieve simulation of traction and braking process. A GUI of the software is mainly be used to input model parameters, display operation status and simulation data. This software integrates the simulation of traction and braking process which can simulate the real status of train and provides a reference for setting subway stations and route optimization. In addition, the simplification of traction model and braking model shortens the operation time of the software, so as to achieve a real-time simulation.¹

INTRODUCTION

Studying of train traction and braking is of great significance to high-speed railway trains and urban rail transit. This paper simulates the traction and braking process by establishing a traction system model and braking system model, so as to research the process and status of train traction and braking. Compared with real vehicles’ online experiment, simulation the simulation method has the following distinct advantages: low cost, easy to operate and implement. Currently, Wenli Lin [1], Ruigang Song [2] have already built train traction system model, and Piechowiak [3,4] has already developed a simulation model of train braking system. But no one has established a model integrating the traction with braking process by far. This paper develops a simulation software for subway train traction and braking process based on Simulink and Lab VIEW, of which main features are: 1. The

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software integrated the train traction with braking, which can simulate different conditions of traction and braking, and provides a reference for setting subway stations and route optimization meanwhile; 2. The software can simplify the train model so as to achieve a real-time simulation and keep the main parameters for the research of train traction and braking at the same time.

SOFTWARE CONFIGURATION AND PARAMETER CONFIGURATION

![Diagram of software configuration]

The configuration of the software is shown in Figure 1. The whole software consists of a graphical user interface (GUI) and an underlying model. The underlying model is composed of traction system model and a braking system model, which accomplish traction and braking under the control of GUI.

The GUI is a computer code based on Lab VIEW, and the underlying model is built based on Matlab-Simulink. A software interface, called Simulation Interface Toolkit (SIT), originally developed by the National Instruments (NI) Corporation, is used to facilitate the communication between the GUI and the underlying model.

The software is used to simulate the traction and braking process of a type of subway train. The subway train contains four motor cars and two trailer cars:

\[ Tc * Mp * M * M * Mp * Tc = (1) \]

Definitions:
- \( = \): Coupler
- \( Tc \): Trailer Car
- \( Mp \): Motor Car with Pantograph
- \( M \): Motor Car

The voltage of subway network is DC1500V. The maximum operation velocity is 80km/h. According to JIS Standard, the basic operation resistance is:
R=(16.18+0.2422V) Wm+(7.65+0.0275V)Wt+(0.275+0.0765(n-1))V^2 (2)

Definitions:
R: Basic Operation Resistance
Wm: Weight of Motor Car
V: Velocity
Wt: Weight of Trailer Car
n: Number of Car

The train load under different simulation conditions is shown in TABLE I.

**TABLE I. TRAIN LOAD.**

<table>
<thead>
<tr>
<th></th>
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<th>Mp2</th>
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**TABLE II. MODIFIED WEIGHT OF CALCULATION.**

<table>
<thead>
<tr>
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<th>M1</th>
<th>M2</th>
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</table>

In traction and braking calculation, considering the inertia, the train load can't directly be used in the calculation. The train load must be modified as a weight of calculation. The formula is:

\[ W' = L + (W \times n) \]

Definitions:
W': Modified Weight of Calculation
L: Load
W: Empty Vehicle Weight
n: Inertial coefficient

Modified weight of calculation is shown in TABLE II.
TRACTION SYSTEM MODELING

Principle Of Traction Modeling

The traction calculation model of urban rail transit vehicles can be divided into single-particle mode and multi-particle mode [5]. In order to achieve a real-time simulation, single-particle is selected as a simple modeling method. When the controller sends out the traction instruction, the traction control system obtains the traction force (Fd) in the current velocity from the traction characteristic curve (shown in Figure 2). Then the system calculates the traction acceleration (a) according to the calculation load of train (W') and the basic running resistance (R). According to the integral of the traction acceleration, the system gets the velocity of next moment(V). The closed-loop control based on velocity is completed. The control principle is shown in Figure 3.

![Figure 2. Traction characteristic curve.](image)

![Figure 3. Control principle of traction.](image)
Logic Of Traction Control

The software simulates the generation and transmission of the train traction instructions, and generates the corresponding traction force with implementation of the traction limit after the judgment of the starting state, traction effective and constant velocity traction. The logic of traction control is shown in Figure 4, and the specific functions are as follows:

TRACTION LEVEL

Traction level isn't step less, and there are totally ten traction levels. In the process of traction, the system treats the traction characteristic curve as the tenth traction state, and the rest of the traction levels state are linear interpolation from zero to the traction characteristic curve.

STARTING STATE

In order to simulate the train starting state as a real traction condition, the system is regarded as starting state when the train velocity is less than 5km/h. And the running resistance of the train is composed of the basic running resistance and the starting resistance. The starting resistance is 39.2N/t.

Figure 4. Logic of traction control.
STATE OF CONSTANT VELOCITY

The system sets a constant velocity signal. When the signal is effective, the train runs with constant velocity. When the train velocity closes to be greater than 80km/h, the constant velocity signal becomes effective, and the train runs with constant velocity, in order to achieve the limit of maximum operating velocity.

COASTING STATE

The system sets a traction effective signal. When the signal is invalid or the traction level is zero, the train enters the coasting state.

TRACTION LIMIT

The system considers the traction limit. When the traction force is greater than the maximum traction limit, the traction force can't be increased anymore.

ADHESION LIMIT

According to the calculation under the normal rail condition, the maximum traction force can't be more than the maximum adhesion focus anytime. So the system doesn't consider the adhesion limit, and it always meets with adhesion condition.

BRAKING SYSTEM MODELING

Principle of Braking Modeling

The braking system also uses single-particle mode. When the controller sends out the braking instruction, the braking control system obtains the braking force (Fb) through look-up. Then motor car gets electric braking force (Feb) in the current velocity from the braking characteristic curve (shown in Figure 5), and obtains pneumatic braking force with further calculation. The system calculates the braking deceleration (a’) according to the calculation load of train (W’) and the basic running resistance (R). According to the integral of the braking acceleration, the system gets the velocity of next moment (V). The closed-loop control based on velocity is completed. The control principle is shown in Figure 6.
Figure 5. Braking characteristic curve.

Figure 6. Control principle of braking.
Logic of Braking Control

The software simulates the generation and transmission of the train braking instructions, and can complete the function of service braking, emergency braking. And the system considers electro-pneumatic. The logic of braking control is shown in Figure 7, and the specific functions are as follow:

BRAKING LEVEL

Server braking level isn't step less, and there are totally seven braking levels. The target deceleration of corresponding level is shown in Figure 8[6]. The target deceleration of prompt braking is set to 1.2m/s². Electric braking and pneumatic braking are both activate in the braking mode of server braking and prompt braking. The target deceleration of emergency braking is set to 1.2m/s², but only pneumatic braking is active.
Figure 8. The target deceleration of different levels in the velocity of 0~70km/h and 70~80km/h.

ELECTRO-PNEUMATIC

TABLE III. LIMIT OF TRAILER PNEUMATIC BRAKING FORCE.

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Figure 9. Electro-pneumatic.
When server braking or prompt braking applies, the system calculates the target deceleration according to the actual load, and compares it with the maximum electric braking force in the current velocity. If electric braking force isn’t enough, the braking force will be supplemented by pneumatic braking force of trailer (two trailer equally) firstly. If braking force is still not enough (the limit of trailer pneumatic braking force is shown in TABLE III), it will be supplemented by pneumatic braking force of motor car (four motor car equally) secondly. Electro-pneumatic is shown in Figure 9.

**GRAPHICAL USER INTERFACE**

A GUI designed by Lab VIEW computer code is to satisfy the following purposes:

- Display of state: running state of software, train.
- Setting parameters: chosen of working condition, chosen of level, displacement, the brake shoe friction coefficient, leverage ratio, efficiency, effective area, brake cylinder number, etc.
- Drawing curve and display date: mainly draws the velocity-time curve and the acceleration-time curve; displays the traction force, the electric braking force, the pneumatic braking force, the trailer pneumatic brake force, the motor car pneumatic braking force, the running distance, the running resistance, the trailer CV pressure, the motor car CV pressure, etc.
- Other functions: controls the effectiveness of traction or braking function, achieve the function of constant velocity operation.

The whole process of the train traction, constant velocity operation and braking under the condition of AW3 are simulated by using this software. The parameters configuration state and results of data are shown in Figure 10. The results show that the software has the ability to simulate traction and braking as well. The velocity-time curve in the figure is the same as the mode of subway train operation. It can be proved that the software can simulate the running state of the subway train, which provides the possibility for the subway station setting and railway line optimization.
CONCLUSION

The simulation software for subway train traction and braking process consists of GUI and underlying model. Underlying model is composed of a traction system model and a braking system model based on Matlab/Simulink, which is used to achieve simulation of traction and braking process. And the GUI of the software based on Lab VIEW is used to input model parameters, display operation status and simulation data.

The software, integrating the simulation of traction with braking, can simulate the actual state of the train operation, and provides a reference for the subway station setting and railway line optimization. In addition, the simplification of the traction model and the braking model can shorten the operation time of the software, so as to realize the function of real-time simulation.

ACKNOWLEDGMENT

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REFERENCES