Research on Automatic Braking and Traction Control of High-speed Train Based on Neural Network

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Abstract. With the rapid development of economy and technology, people's quality of life has been continuously improved, which also makes people put forward higher requirements for the quality of transportation. As far as railway transportation is concerned, the running speed and route of trains in the past gradually failed to meet people's travel needs. Automatic train operation system (ATO), under the protection of automatic train protection system, realizes automatic train driving according to the instructions of automatic train supervision system, and can automatically control the starting, traction, cruising, idling and braking of trains. Traction drive system is the core part of high-speed train, and traction drive converter technology is one of the key technologies of high-speed train. In this paper, according to the different working mechanism of traction and braking, the dynamic model of train under traction and resistance braking is established by combining neural network algorithm, and the corresponding controller is designed by using nonlinear backstepping design method to realize automatic tracking of train speed and position.

Keywords: Train, braking, traction transmission system, automatic control

1. Introduction
With the development of industrial revolution, countries began to promote the development of railway. Railway transportation has gradually become one of the most important modes of transportation. Because of its advantages of high speed, large transportation volume, safety and stability, it is favored by people [1]. At present, most of the high-speed EMUs adopt the manual control mode, that is, under the guidance of the train operation control system, the EMU driver operates the train based on the actual line conditions and the given operation timetable between stations [2]. High speed EMU is different from traditional railway transportation, its power is scattered, and the whole train can not be disassembled and reorganized in the operation process, which is different from traditional railway rolling stock [3]. With the continuous improvement of train running speed, its dynamic environment deteriorates sharply, such as the aggravation of dynamic interaction between wheel and rail, the complication of high-speed pantograph catenary current collection, the aggravation of aerodynamic interaction, the requirement of rapid increase of train traction and braking power and high running stability [4]. Under the protection of the automatic train protection system, the automatic train operation system (ATO) realizes the automatic driving of the train according to the instructions of the
automatic train supervision system, and can automatically complete the control of the starting, traction, cruise, coasting and braking of the train, so as to ensure the designed interval and travel speed [5]. The operation technology and experience of the driver will have a greater impact on the operation state of the EMU. If the driver is inexperienced or misoperated, the train will be delayed, and even the train will exceed the speed limit, resulting in the emergency braking of the train, threatening the safety of passengers [6].

With the increase of train speed, many problems of aerodynamics are gradually exposed, especially in low-speed rail [7]. High speed EMU is different from traditional railway transportation in that its power is scattered and the whole train cannot be disassembled and reorganized in the operation process, which is different from traditional railway rolling stock [8]. With the help of EMU simulation platform, the related operation characteristics can be further studied, which provides an important reference for continuously improving EMU operation efficiency. The design and construction of railway lines have specified speed limits, so the simulation system must have the function of preventing EMUs from exceeding the speed limit of the track [9]. Train operation control is affected by many factors, such as train traction and braking performance, line condition, limited speed, onboard load, climatic conditions and so on [10]. Therefore, how to design the optimization algorithm of ATO system to make ATO get the optimal operation curve according to the known information, and how to use advanced control technology to design controller to make ATO system control the train to run along the optimal curve are the key problems of ATO system [11]. In this paper, according to the different working mechanism of traction and braking conditions, combined with the neural network algorithm, the dynamic model of train traction and resistance braking is established, and the corresponding controller is designed by using the nonlinear backstepping design method, so as to realize the automatic tracking of train speed and position.

2. Traction inverter and traction motor control

In the traction drive system, the traction inverter inverts the direct current of the intermediate circuit into three-phase alternating current with adjustable frequency amplitude for the traction motor under the traction condition, and transmits the alternating current generated by the traction motor to the grid-side converter to return to the power grid under the regenerative braking condition, which are closely related. High-speed train is a complex system, which often uses the method of multi-body system dynamics to analyze and study its complex dynamic characteristics. However, due to the limitation of theoretical methods and calculation methods, and the complexity of kinematics and dynamics under external loads, in most cases, the model has to be simplified, which leads to many important characteristics of high-speed trains cannot be quantitatively analyzed accurately, thus leading to a certain degree of deviation between theoretical research and experiment. The design and construction of railway lines have a prescribed speed limit, so the simulation system must have the function of preventing EMUs from exceeding the speed limit of the track. As long as the basic simulation system function can make the fixed acceleration and deceleration control EMU reach the interval speed limit and run stably, the complex simulation system needs to further provide convenient and intuitive details for adjusting and controlling the operation process of EMU [12]. Different routes will have different road conditions, and the actual running environment of trains is complex, which is greatly influenced by the outside world. When establishing the dynamic model, the model cannot be simply transformed into a linear model. The force analysis of trains is influenced by external environmental factors and physical differences. The dynamic model is nonlinear and cannot be calculated accurately.

The bogie of motor car is mainly composed of seven parts: frame, driving device including motor, gear box, foundation braking device, wheelset, axle box device, primary suspension and secondary suspension. When establishing rigid body model, all components are considered as rigid bodies. With the advancement of permanent magnet motor, when considering multiple traction converters, cross-coupling control strategy is mostly chosen to coordinate the speed of multiple traction wheelsets. Traction converter, as a current conversion device, converts AC received from pantograph network into AC/DC through current conversion device, and then outputs three-phase AC through inverter,
realizing DC-AC conversion, providing the required current for driving equipment, thus outputting driving torque. The motor is a three-phase asynchronous motor. When modeling, the motor stator and the machine body are considered as a body and suspended on the frame. The motor rotor is considered as a body separately. The rotor is rigidly connected with the pinion shaft in the gearbox. The electromagnetic torque generated by the motor is applied to the rotor from the stator and reacts on the stator. Under the driving anti-rotation and braking anti-skid conditions, due to the complexity of the electromagnetic torque control system of the motor, the torque value is calculated synchronously by the external control program. The network infrastructure of high-speed train braking and traction automatic control system is shown in Figure 1.

Figure 1. Network infrastructure

The pinion end of gear box body is connected with the frame by hanging, and the big gear end is hinged to the wheel shaft by using a rotating hinge, and the big gear is fixed on the wheel shaft by a constraint relationship. For the foundation brake device, considering the factor of solving time, the calculation and solution speed of Hertzian sliding friction element and unilateral contact force element is slow, and the friction element between wheel disc and brake disc is not established in the model, but only wheel disc is established. The traction control system is the signal command control part of the train, and the traction converter is also a part of its control. The conversion of current and power in the traction converter is controlled by the traction control system, and the transmission and conversion of commands are realized through real-time monitoring of information interaction with the bus. In the process of train running, when the running environment changes, as long as the neural network controller is trained with the new running environment according to the operating parameters of experienced drivers, ATO system can run in the new running environment [13]. The simulation system can simulate the running state of the EMU on the track and complete the simulation process by reading the handle level and converting it into the traction force or braking force generated by the traction braking system.

3. Analysis on operation process and automatic driving strategy of high speed EMU

In the running process of traction drive system of high-speed train, because of the AC-DC-AC conversion of grid current, harmonics with different frequencies will be produced, which will affect the key components of the system such as main transformer and traction motor, and may interfere with communication signals and pollute the grid. Therefore, it is necessary to analyze the harmonics on the rectifier grid side and put forward suppression measures. In the actual operation process, the high-speed EMU will be affected by many forces, and the forces acting on the train are complex. Therefore, for the convenience of calculation, we use the single point train model to analyze the train stress. The inductance of pulse rectifier in traction drive system includes AC side inductance and secondary filter loop inductance, which play an important role in improving the dynamic and static response of motor car, increasing power factor and reducing harmonic content. Many performance indexes such as safety,
comfort, punctuality, parking accuracy and energy saving need to be considered when the train runs automatically. Studying the automatic driving strategy of the train is the key to ensure the automatic running of the train to meet all performance indexes. The design of inductor should also consider the requirements of fast current tracking and harmonic current suppression. The larger the inductance, the greater the inductance, and the better the harmonic current suppression effect. Meanwhile, the lower the current change rate through the inductance, the worse the current following effect. On the contrary, the smaller the inductance, the worse the harmonic current suppression effect and the better the current following effect.

In the railway vehicle system, in recent years, due to the high speed of the vehicle and the continuous application of lightweight technology, the external disturbance of the vehicle will inevitably affect the dynamic performance of the system, such as the influence of the whole or local high-frequency vibration of the vehicle body on the passenger's riding comfort, the fatigue damage of the frame high-frequency vibration on various components, and the wheel wear aggravation caused by high-frequency vibration. When a train runs from a higher speed limit section to a lower speed limit section, the train needs to switch its current operating conditions to reduce its current running speed, so as to ensure that the train can safely enter the lower speed limit section. We can use the train traction calculation equation to accurately calculate the distance that the train runs from the speed of the higher speed limit section to the speed of the lower speed limit section.

According to the two-dimensional engineering drawing of the bogie frame, the geometric solid model of the frame is established in the three-dimensional modeling software and imported into. In the process of modeling, in order to divide the grid better and reduce the calculation time, some small holes and fillet transitions are properly processed without affecting the calculation accuracy. The interaction between automation objects and automation clients is shown in Figure 2.

![Figure 2. Interaction between automated customers and automated components](image)

When the train is running, the traction condition and braking condition cannot be directly switched between each other, and the idle condition is needed for intermediate transition when switching between these two conditions. Because the train keeps running by inertia under the idle condition, the idle condition can ensure the energy saving of train operation. It should be noted that when a train runs from a higher speed limit section to a lower speed limit section, it must be ensured that the actual running speed has dropped to the speed range allowed by the lower speed limit section. When a train enters a higher speed limit zone from a lower speed limit zone, it must be ensured that the front and rear of the train pass through the lower speed limit zone before accelerating [15]. Considering the complexity of the actual structure of the frame, it is necessary to simplify some structures and give attention to the accuracy of the calculation. In this paper, the solid shell element is mainly used to discretize the geometric model of the frame, and some accessories are integrated with the frame in the form of additional mass points.
When the train runs on the speed limit combination section, in order to ensure the driving safety, it is necessary to brake the train from the higher speed limit section to the lower speed limit section in turn. When the train length is longer than the first lower speed limit section, we need to merge the two lower speed limit sections. Similar to human neural network, the basic component of artificial neural network is neuron, and a simple neuron structure is shown in Figure 3.

![Figure 3. Simple neuron](image)

The neuron has three inputs $x_1, x_2, x_3$, where +1 represents the bias term and is input to the arithmetic unit $f$. The output of the entire neuron is

$$h_{w,b}(x) = f(W^T x) = \frac{1}{2} \sum_{i=1}^{3} W_i x_i + b$$  \hspace{1cm} (1)

Choose a 3-layer 5-input 5-output BP network controller, including 5 input nodes, 5 output nodes, and 1 hidden layer.

The calculation formula for the error of the $p$-th sample:

$$E_p = \left[ \sum_i (t_{pi} - O_{pi})^2 \right] / 2$$  \hspace{1cm} (2)

In the formula, $t_{pi}$ is the expected output value, and $O_{pi}$ is the actual network output value. The input of the input node is $x_j$, and the output of the hidden node is:

$$y_i = f\left( \sum_j W_{ij} x_j - \theta_i \right)$$  \hspace{1cm} (3)

In the formula, $W_{ij}$ is the connection weight, and $\theta_i$ is the node threshold. The output node output $O_i$ is:

$$O_i = f\left( \sum_j T_{ij} y_i - \theta_i \right)$$  \hspace{1cm} (4)

In the formula, $T_{ij}$ is the connection weight, and $\theta_i$ is the node threshold.

When the train enters the first lower speed limit zone from the higher speed limit zone, we can ignore the speed limit zone and directly control the train operation according to the speed limit of the second lower speed limit zone. Dynamic braking is usually used in the process of speed regulation braking of trains. When the actual running speed of trains approaches the speed limit of lines, trains...
need to decelerate and brake in time to ensure the safe operation of trains. In the process of train deceleration or stopping, in order to save train running time, air braking is usually used for braking. In order to ensure the safe operation of high-speed EMUs, the speed of trains running in speed-limited sections is lower than the speed-limited requirements of trains. Trains not only have the maximum speed limit requirements on different running line sections, but also have the maximum speed limit according to the train's own situation. Therefore, there are the following speed limits when the train runs on the line, including running speed limit, turnout speed limit, entrance and exit speed limit, curve speed limit, etc. In order to make the train run safely and smoothly, different operation control strategies should be adopted under different speed limit combinations, that is, according to the train operation conditions, self-conditions and speed limit combinations in the running line, the optimal control strategy of the train in corresponding situations should be adopted to control the train operation.

4. Conclusions
With the rapid development of China's economic capacity and technological level, China's high-speed rail is facing opportunities and challenges. China's high-speed rail has gradually gone abroad and gained worldwide recognition, becoming a new benchmark for Chinese manufacturing. Asynchronous traction motors can obtain fast torque response by adopting direct torque control technology. In the process of driving and braking control of high-speed trains, due to the small relative sliding between wheels and rails, this fast torque response capability is particularly important. The actual operation process of high-speed EMUs is very complex, and different traction control strategies should be adopted according to different line conditions and external environment, so as to produce the expected operation effect. In order to make the train run safely and smoothly, different operation control strategies should be adopted under different speed limit combinations, that is, according to the train operation conditions, self-conditions and speed limit combinations in the running line, the optimal control strategy of the train in corresponding situations should be adopted to control the train operation. Train speed control, energy-saving optimization and comprehensive conditions of various train safety factors are bound to be the trend of research and development. Moreover, the design of the algorithm is still in the stage of laboratory research, and more factors need to be considered in the actual application.

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