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Traction Calculation for Metro B-cars

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Abstract: ***Traction calculation of urban rail transit vehicles is an important means to confirm the traction quality, running speed, running time and energy consumption, and it can also improve the safety of subway operation. In this paper, the train control system is introduced, and the basic train resistance, train traction characteristics, train regenerative braking characteristics, train comprehensive braking characteristics model and simulation calculation model are established.***

Keywords: Train traction calculation; Security; Train control system; Simulate.

1. INTRODUCTION

With the rapid development of urbanisation, the demand for urban transport continues to grow, while the problems of urban road traffic congestion, traffic accidents and traffic pollution are worsening. The way out for solving urban traffic problems is to give priority to the development of urban public transport systems with rail transport as the backbone. In the field of urban passenger transport, under the guidance of the policy of "people-oriented, public transport priority", urban rail transit has become the first choice of the general public for travelling because of its large capacity, high speed, safe and punctual, environmental protection, energy saving and land saving, etc., which is very popular among the people. At present, China's urban rail transit is in a period of great development and construction, Beijing, Shanghai and other big cities have entered into network operation from single-line operation, and the construction of rail transit in other cities is also deepening and improving.

The basic task of urban rail transit is to transport passengers safely and efficiently, and it is necessary to adopt safe and reliable train operation control equipment and reasonable transport organisation. Train operation control system is the central nerve of urban rail transit scheduling command and operation management, which is the key system equipment to ensure the train operation safety, realise the modernization of train command and train operation, and improve the transportation efficiency. According to the line conditions and actual situation, the train operation control system can supervise, control and adjust the train operation speed to ensure safe and smooth operation and complete the transport task with high quality, thus bringing better economic and social benefits.

The train operation control system of urban rail transit has high technical content, is a comprehensive application of computer technology, communication technology and control technology, and has the technical characteristics of a modern system of networking, integration, digitalisation and intelligence. In order to meet the rapid development of China's urban rail transit, it is necessary to make more staff master the basic knowledge and basic skills of the train operation control system, and give full play to its role and advantages, so as to make the urban rail transit scheduling and command and operation management work efficiently and accurately.

The automatic train operation control system of urban rail transit is an important equipment to ensure the safety of train operation and improve the efficiency of train operation. It adopts traditional and new control technology, traditional in its control concept: must meet the "fault-oriented safety" principle; new in its use of the most advanced computer information technology. The "on-board signal" of urban rail transit replaces the traditional "ground signal"; the content of "on-board signal" is the target distance or target speed of the train; the train is directly controlled by the on-board computer, which realises the automatic operation of the train, the overspeed protection and the station's programmed stopping. Especially the automatic train operation control (CBTC) system based on wireless communication technology creates conditions for further shortening the interval between trains and realising automatic train operation. Urban rail transit signalling system is a "closed-loop" automatic control system, which also needs to work closely with operation management, line, vehicle control, power supply, driving and other professions to accomplish the important mission of train operation safety control and adjustment and overspeed protection.

Train traction calculation is a railway application discipline, the study of direct action on the train, and the train running direction parallel to a variety of external forces (including locomotive traction, train resistance, train braking force), as well as the relationship between these forces and train operation, solve a series of practical problems related to train operation. Urban rail transit vehicle traction calculation is an important means to confirm the operation indexes such as traction quality, running speed, running hours and energy consumption, and at the same time, it is also an effective method to verify the traction and electric braking characteristics of new locomotives and the passing capacity of trains. The rail vehicle traction calculation system is required to be able to calculate the running hours and various operation indexes of the train according to the longitudinal section conditions of the line and the formation of the train, in order to evaluate the performance of the traction system and the effect of the changes in the line conditions or the formation of the train.

Improve the quality of train traction and running speed, to ensure the safety of railway operation and save the energy consumption of locomotives as far as possible, is to expand the railway transport capacity to improve the efficiency of the railway work of the important content. To this end, we must pay attention to scientific management and economic manoeuvring, improve transport management and train handling level; good study of the train's traction quality, running speed, braking distance and locomotive energy consumption and other factors related to how to ensure safety and energy saving under the condition of "pulling more fast".

2. TRAIN OPERATION CONTROL SYSTEM FOR URBAN RAIL TRANSIT

2.1 Overview of urban rail transport development

In the process of the wheel of history moving forward, with the development of urbanisation in all countries of the world, the problem of urban traffic is getting more and more serious. The transport history of cities in economically developed countries has proved that only the adoption of high-capacity urban rail transit systems can fundamentally improve the problem of urban traffic congestion.

In 1827, the world's first urban rail public carriage appeared on Broadway in New York, so that carriages travelling on steel rails, improved speed, increased smoothness, and became the prototype of modern urban rail transport. After nearly 40 years of continuous evolution, on 10 January 1863, the world's first underground urban railway (Metropolitan Railway) officially opened for business in London, using steam locomotive traction, the total length of the line is only 6.5km, but in the first year it carried 9.5 million passengers, which set a successful example for solving the traffic congestion in the city, and also for the densely populated, traffic demanded cities. In 1897, the successful development of electric-powered locomotives led to unprecedented improvements in the underground passenger environment and service conditions, and the construction of subways showed even stronger vitality. As a result, well-known large cities around the world have followed the example of London to build the underground, opening a new chapter in the way of public transport in the city.

China's urban rail transit development started late, marked by the official opening of Beijing Subway Line 1 in 1969, after nearly 50 years of development, and has entered a rapid construction phase in recent years. By the end of 2017, a total of 34 cities in mainland China had opened and operated urban rail transit, with a total of 165 lines and an operating line length of 5,033km. among them, underground was 3,883.6km, accounting for 77.3%; light rail was 240.8km, accounting for 4.6% of the total length of the line; monorail was 98.5km, accounting for 2.0%; and urban express rail was 502km, accounting for 10.0%; Modern tram 246.1km, accounting for 4.9%; magnetic levitation 57.9km, accounting for 1.1%: APM line 3.9km, accounting for 0.1%. The development trend of more urban rail transit operating lines, continuous growth of passenger flow, diversification of system modes and networking of operating lines has become more obvious.

During the "13th Five-Year Plan" period, the scale of lines under construction and planning will be further expanded, the amount of investment will continue to grow, and the construction speed will steadily increase. It is expected that by 2020, the total mileage of urban rail transport in operation will reach 900km.

At present, urban rail transit has become an important infrastructure for modern cities in all countries of the world, which safely, quickly, comfortably and conveniently transports passengers within the city and maximally meets the needs of residents' travelling, and has become the most effective and efficient method for cities to solve the problem of traffic congestion, difficulty of travelling, and decline in travelling speed.

2.2 Automatic Train Operation (ATC) based on track circuits

2.2.1 Overview of the ATC system

Urban rail transit adopts Automatic Train Control (ATC) system, which takes on-board signals as the main signals and automatically controls the train operation according to the information transmitted from the ground, such as speed or distance. ATC system is the key equipment to ensure the safety of train operation, to realize the command and automation of train operation, to improve the efficiency of transportation and to reduce the labour intensity of operation personnel. ATC system is the most important part of train operation control in urban rail transit, with high technical content and many important contemporary scientific and technological achievements.

ATC system includes three sub-systems: Automatic Train Protection (ATP), Automatic Train Operation (ATO) and Automatic Train Supervision (ATS), which is a complete set of management, control and supervision system. The three sub-systems are both relatively independent and interconnected, combining ground control and on-board control, local control and central control, constituting an automatic control system based on safety equipment and integrating the functions of train command, operation adjustment and train operation automation.

ATC system equipment is distributed in the control centre (Operation Central Control, OCC), station, trackside and train, ATC system structure is shown in Figure 1.

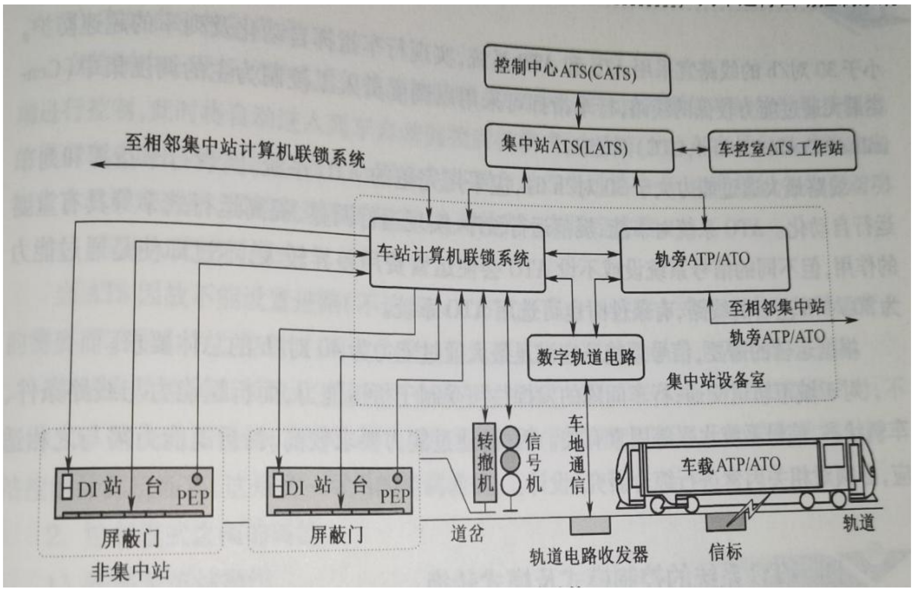


Figure 1: ATC system structure

The ATS of the control centre directs the train operation, realizes real-time data and information exchange between the control centre and the equipment rooms of the stations along the whole line, and the dispatcher gives the train control commands through the dispatcher's workstation. On-site train online information, train number information and status information of turnouts and signals are displayed on the large screen and CRT at the dispatcher's workstation.

The equipment room of the interlocking centralised station receives the control instructions from the dispatcher, and through the interlocking devices, arranges the approaches, opens the signals, and transmits the train on-line information and the status information of the signalling equipment, etc. to the control centre. Through the trackside equipment of the ATP system, it sends train detection information to check whether there is any train occupying the track section, and sends speed limit orders or target distance information of permitted operation, gating orders, and alignment stopping orders, etc. to the train.

The on-board ATP/ATO equipment receives dispatching commands and ATP speed commands or distance information from the ground, completes the automatic speed adjustment and station programmed stopping, and realises the automatic operation of the train; and transmits the train's operation status and equipment status information to the control centre.

The ATC system consists of five principle functions: the ATS function, the interlocking function, the train detection function, the train operation control function and the Positive Train Identification (PTI) function.

(1) ATS Function

Enables automatic or manual control of approaches, conducts train scheduling commands, and provides information to the train dispatcher and external systems.The ATS function is implemented primarily by equipment located within the OCC (control centre).

(2) Interlocking Function

Responds to commands from the ATS function and manages the control of approaches, turnouts and signals, providing ATC with information on the status of approaches, track circuits or axle counting equipment, turnouts and signals, subject to safety guidelines being met at all times.The interlocking function is implemented by equipment distributed alongside the track.

(3) Train detection function

Generally performed by track circuits or axle counting equipment.

(4) Train operation control function

Under the constraint of the interlocking function, the control of train operation is realised according to the requirements of the ATS. The train operation control function has three subfunctions: the ATP/ATO trackside function, the ATP/ATO transmission function and the ATP/ATO on-board function. the ATP/ATO trackside function is responsible for train spacing and message generation; the ATP/ATO transmission function is responsible for the sending of inductive signals including messages and other data required by the on-board equipment; and the ATP/ATO on-board function is responsible for the train safety, train operation and train autopilot and provides an interface to the signalling system and the driver. The ATP/ATO on-board function is responsible for the safe operation of the train, the automatic driving of the train, and provides an interface to the signalling system and the driver.

(5) Train identification function

Transmits and receives various data through multiple channels and passes them to the ATS at specific locations to report train identification information, destination and crew numbers, and train position data to the ATS to optimise train operations.

The ATC system consists of the following control modes (classes): automatic control mode at the control centre (CA), manual intervention control at the time of automatic control at the control centre or manual control mode using the CTC system (CM), automatic control mode at the station, and manual control mode at the station.

Each mode describes the level of control to be applied to the operation of trains in a given station and attributed control lot, however, a system can only be in one mode at a time. The principles to be followed for each level of control are: manual control at the station takes precedence over manual control at the control centre, and manual control at the control centre takes precedence over automatic control at the control centre or automatic control at the station.

Control Centre Automatic Control Mode In the Control Centre Automatic Control Mode, train approach orders are issued by the ATS Approach Setting System (ATSAS), which is fed by the timetable and the Automatic Train Operation Adjustment System (ATOAS). The control centre dispatcher can manually intervene in the ATS to make the train run according to the dispatcher's intention.

Manual intervention control during automatic control at the control centre or using the manual control mode of the CTC system During automatic control at the control centre, the control centre dispatcher may turn off the automatic approach setting of an interlocking zone, or part of the signals within an interlocking zone, or of a specified train, and control the train approach directly from the control centre's workstations. When the automatic approach setting for an interlocking zone is turned off, the control centre dispatcher can issue a command to use the automatic approach control function of the interlocking equipment to automatically arrange a fixed approach for a subsequent train with the operation of the preceding train. In the event of a failure of the automatic approach function, the dispatcher can set the approach manually. In CM mode, manual control of the station is transferred to the ATS system. Once the station is operating in this mode, control is initiated by the ATS system and not by the station control computer. However, the station control computer continues to receive instructions, update displays, and collect data.

Station automatic control mode In case of control centre equipment failure or communication line failure, the control centre will not be able to control the remote control terminal of the interlocking station, at this time, it will automatically enter into the train automatic monitoring backup mode, the train number information with the direction of the train going sent by the train number sending system on the train, the approach command is automatically generated through the remote control terminal, and the approach is automatically set by the automatic function of the interlocking equipment, i.e. Automatically arranging a fixed approach as the train runs.

Station Manual Control Mode When the ATS is unable to set up the approach (either manually or by automatic approach) for any reason, or cannot be controlled from the centre due to some operational necessity, it can be changed to in-place manoeuvring mode. The approaches are manually arranged at the in-place manipulator. Automatic station control and manual station control may be collectively referred to as station control (LC). When the station is operating in LC mode, control cannot be initiated by the ATS system. However, the ATS system will continue to receive instructions, update displays, and collect data. For the station control computer, this is the only control mode available.

2.2.2 Basic concepts of ATP systems

ATP system is an important equipment in ATC system to ensure the safety of train operation, shorten the travelling interval and improve the efficiency of train operation, it is the core of ATC system and must comply with the principle of fault-safety.

The ATP system continuously transmits information from interlocking equipment and operation level, line information, distance to the target point ahead and permitted speed information, etc., from the ground to the train through track circuits and other equipment, so that the current permitted speed is calculated by the on-board computer, or the target speed is calculated by the control centre and transmitted to the train, and the actual speed is measured by the on-board equipment, so that the speed of the train is supervised and always operated under the permitted speed. always run under the permitted speed. When the train speed exceeds the speed allowed by the ATP equipment, the ATP on-board equipment issues a braking command to slow down the train automatically; when the train speed drops below the speed allowed by the ATP, it can be relieved automatically.

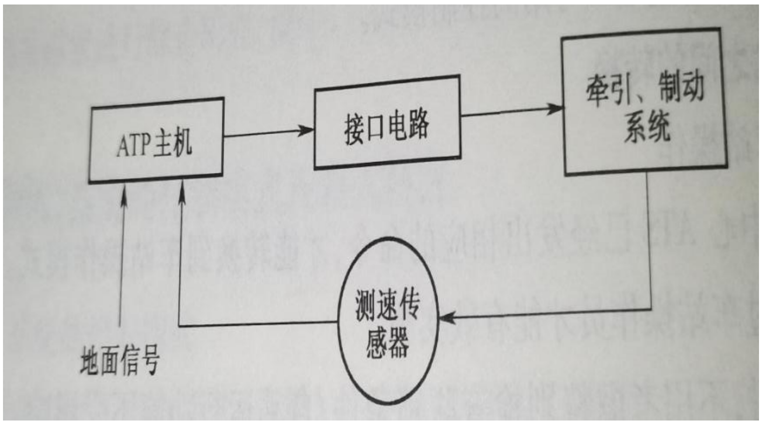


Figure 2: Connection between the ATP system and the train

ATP host and the train's own traction system and braking system are connected by special interface circuits, as shown in Figure 2. ATP host receives signals from the ground signal equipment in real time, and sends control instructions to the train's traction system or braking system in real time through real-time analysis and calculation, and the train's traction system or braking system applies traction or braking force on the train after receiving the control instructions, in order to control the running speed of the train, so that the train runs within the permitted speed range.

The equipment of the ATP system consists of two parts: on-board equipment and trackside equipment.

The on-board equipment of the ATP system mainly consists of the on-board mainframe, driver status display unit, speed sensors, train ground signal receivers, train interface circuits, power supply, and auxiliary equipment, etc., as shown in Figure 3.

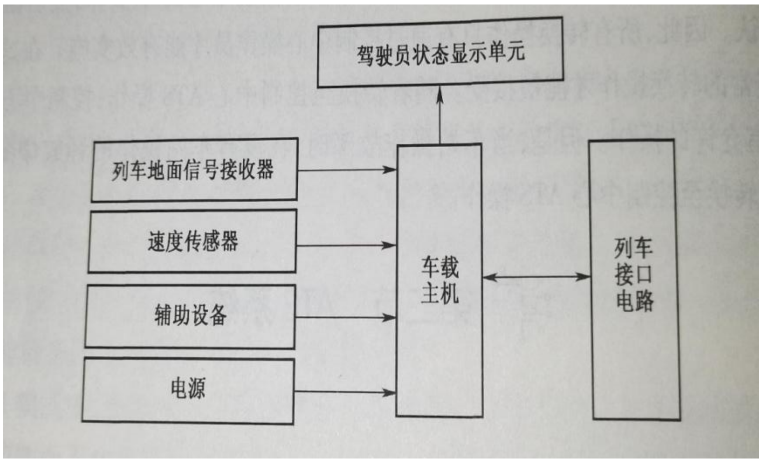


Figure 3: Composition of ATP vehicle-mounted equipment

The core equipment of ATP system is installed on the train, but the main information it needs comes from the ground equipment. According to the different systems of urban rail transit signalling systems, the ground equipment of the ATP system can be set up with point transponders, track circuits or axle counting equipment to transmit the relevant information to the train, and the equipment installed on the train receives and processes such information.

2.3 Communication-based automatic train operation control system (CBTC)

2.3.1 Overview of the CBTC system

The CBTC system is a continuous automatic train control system that utilises high-resolution train positioning determination independent of track circuits; high-capacity vehicle-to-ground bi-directional data communications; and on-board and trackside processors capable of implementing fail-safe functions.

Communication-Based Train Control (CBTC for short) is a train operation control system that supports mobile occlusion, which is not only applicable to newly built urban railways, but also to the reconstruction of old lines; it is also applicable to the operation of different train formations, as well as the cross-line operation between different lines. It is not only applicable to the new urban rail transit, but also applicable to the reconstruction of old lines; it is also applicable to the operation of different train groupings, and also applicable to the cross-line operation between different lines. In recent years, with the rapid development of wireless communication technology, computer network technology and digital signal processing technology, the redundancy and fault-tolerance technology of signal system is perfected, which lays the foundation for the development of CBTC system, and CBTC system has been gradually recognised, and the mobile occlusion system based on the inductive loop communication is firstly used in the urban rail transit lines in Wuhan and Guangzhou of China. And based on wireless (Radio) communication, virtual occlusion of CBTC system, also in many of China's urban rail transit lines have been used, in principle, also will be CBTC system, as the future development direction of urban rail transit signalling system.

Classification of CBTC systems:

(1) Classified from the realisation of occlusion zone: ①Communication-based fixed automatic occlusion operation control system (CBTC-FAS) (occlusion zone is fixed; vehicle-ground information exchange is realised through two-way communication by wireless interrupter; track circuit is only used to detect the occupation of the train and its completeness); ② Communication-based mobile automatic occlusion operation control system (CBTC-MAS) (the length of the occlusion zone can be change, calculated in real time according to the parameters

of the train itself and line data; the blocking partition moves with the train; in CBTC-MAS, ground signals are no longer applied and are not needed, it indicates on the on-board display screen the distance of the car from the preceding train, or the distance from the next station).

(2) Classified according to the vehicle-ground communication mode: ① Track crossing cable mode, IL CBTC; ② Omission cable or waveguide mode; ③ Query transponder (active) + ATP mode (through the current transponder, to the next transponder to give information on the passage of the train); ④ Satellite communication system (Japan has used, geostationary orbit satellites, the distance from the ground of 37,000km; commonly used in low-speed, low-density, low capacity areas); ⑤ Full mobile wireless communication mode (with the application of communication technology, the use of open space wireless access is the future direction of vehicle-ground communication development). Satellite communication system (used in Japan, geostationary orbit satellite, 37,000km from the ground; commonly used in low-speed, low-density, small-volume areas); ⑥ Whole mobile wireless communication method (with the application of communication technology, the use of open-space wireless access is the direction of the future development of vehicle-ground communication).

(3) Classified according to the application interval blocking method: ① CBTC - semi-automatic blocking; ② CBTC - automatic inter-station blocking; ③ CBTC - electronic road sign blocking.

The CBTC system has some of the following main features compared to the track circuit based ATC system:

The position of the train on the line is determined automatically by the train, which can reduce the interval between trains The lines of the CBTC system are no longer divided into track segments; the train's precise position on the line is determined by means of locating beacons set on the ground, and then the train determines its relative position on the line by automatically counting the running distance through the on-board equipment; the train reports its position on the line to the control centre and the regional controller on an uninterrupted basis with a cycle of data transmissions. the position of the train on the line. The minimum distance between the forward train and the following train can be ensured as long as the safety braking distance plus the safety protection distance is ensured; thus, the train running interval can be reduced and the running efficiency can be improved.

Always maintain uninterrupted two-way communication between car and groundThe train and ground adopt wireless mode to maintain uninterrupted two-way communication. This ensures real-time and reliable information, and the control centre can transmit dispatch adjustment information to the train in a timely manner, unlike the previous ATC system where two-way communication between the train and the ground could only be achieved in the platform area of the station. The train also transmits continuously updated train position information to the control centre and the zone controller in a timely manner; the zone controller can transmit updated distance commands (Limit of Train Movement Authorisation - LMA) to the train in a timely manner. Figure 4 shows the schematic diagram of the train movement authorisation limit. As shown in the figure, the limit of movement authorisation (LMA) for a subsequent train is the tail of the subsequent train up to the tail of the forward train, but the tail of the forward train, which is the tail of the actual train plus a safety envelope distance, is included in the distance of the LMA. The uninterrupted bi-directional communication characteristic between vehicle - ground is the key of CBTC system, so the safety and reliability of the communication, as well as timely data processing, determines the performance of the CBTC system.

The control centre grasps train data information such as the precise position and speed of each train running online. Through the two-way communication between the vehicle and the ground of the CBTC system, the control centre can grasp in real time the precise position, running speed and other data information of all the trains running online, and the position information includes the specific position of the head and tail of the train; based on the position and running speed of the tail of the preceding train, as well as the speed and head position of the following train, the LMA start and end points are determined for the following train. position, combined with the approach map information of the area where the train is located, the train movement authorisation limit is calculated for the subsequent train, and the start and end points of the LMA are determined. As shown in Figure 4.3, by clicking on the train number of a running train, the control centre dispatcher can see the train's operating status data information, which includes, in addition to the train's specific position on the line, the following: train operating mode, operating direction, door status, EB status, train length, driver ID number, and next station.

Trains of different formations (of different lengths) can run on the same line with the highest density. Trains running on the line report to the control centre the specific position of the train on the running line, which is not the formation information of the train, but the length information of the train's head position and tail position, so trains of different formations can run on the same line with the highest density. CBTC systems of different lines, if equipped with a unified standard data structure and interfaces, and the train on-board equipment is the same, the train can be achieved across the line operation (intermodal transport); the train can be operated on different lines, which is very favourable to the vehicle scheduling. The premise is to develop a unified CBTC standard, different vendors can provide different subsystems, at present, to really achieve cross-line operation is still very difficult.

Train operation control system from a hardware-based system, to the evolution of software-based system, as shown in Figure 5. CBTC system is no longer physically divided into track segments, so there is no need to configure the track circuit reception. Sending equipment; ground equipment is mainly used for train positioning of a variety of "beacon" and AP access points for wireless communication; vehicle hardware equipment, only wireless receiving and sending antenna and beacon receiving antenna; and more importantly, the CBTC system is the regional controller and vehicle controller software configuration.

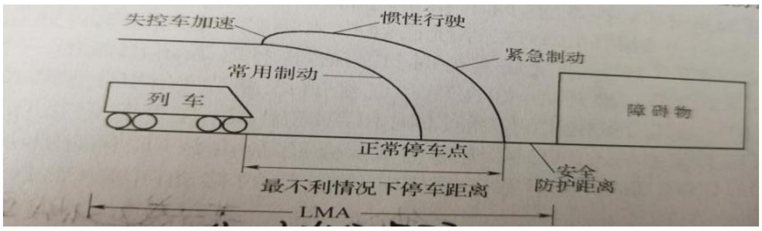
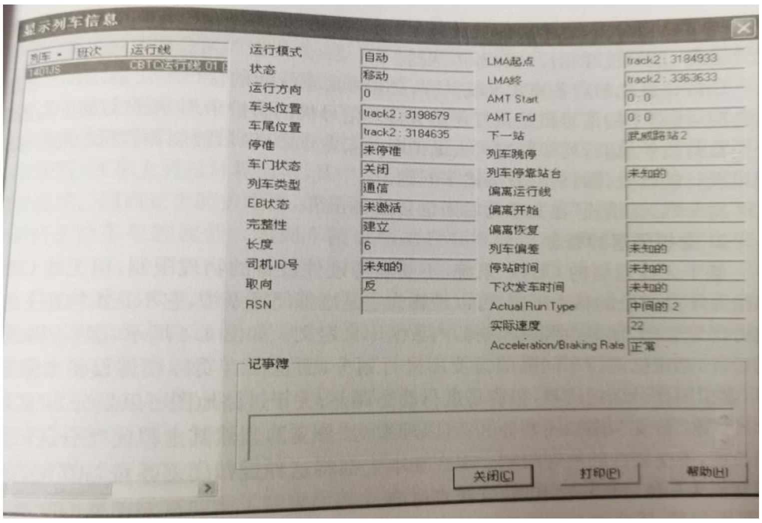


Figure 4: Schematic diagram of train movement authorisation limits



列车	班次	运行线
1401JS		CBTC运行线 01

运行模式	自动
状态	移动
运行方向	0
车头位置	track2 : 3198679
车尾位置	track2 : 3184635
停准	未停准
车门状态	关闭
列车类型	通信
EB状态	未激活
完整性	建立
长度	6
司机ID号	未知的
取向	反
RSN	

LMA起点	track2 : 3184933
LMA终	track2 : 3363633
AMT Start	0 : 0
AMT End	0 : 0
下一站	武威路站2
列车跳停	
列车停靠站台	未知的
偏离运行线	
偏离开始	
偏离恢复	
列车偏差	未知的
停站时间	未知的
下次发车时间	未知的
Actual Run Type	中间的 2
实际速度	22
Acceleration/Braking Rate	正常

记事簿

Figure 5: Schematic diagram of train information display in the control centre

2.3.2 CBTC system components

The standard CBTC consists of the following modules: the Automatic Train Supervision (ATS) system, the Computer Interlocking Subsystem (CI), the Zone Controller (ZC), the Database Storage Unit (DSU), the Data Communication Subsystem (DCS), the Trackside Equipment, and the Vehicle-On-Board Controller (VOBC).

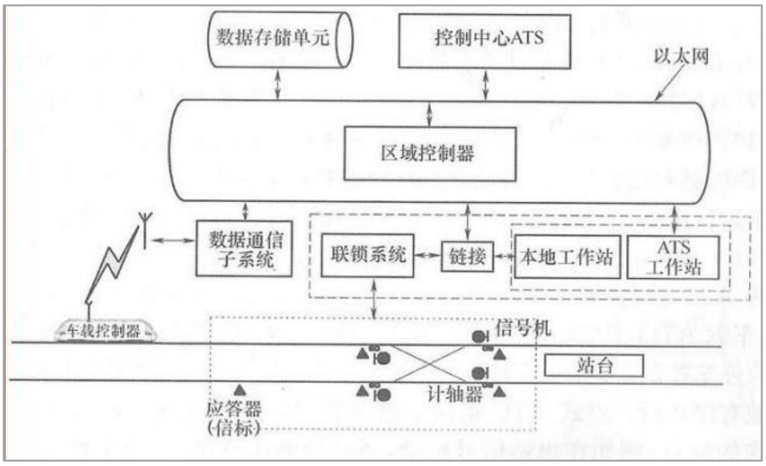


Figure 6: Block diagram of the basic structure of the CBTC system and its backup mode

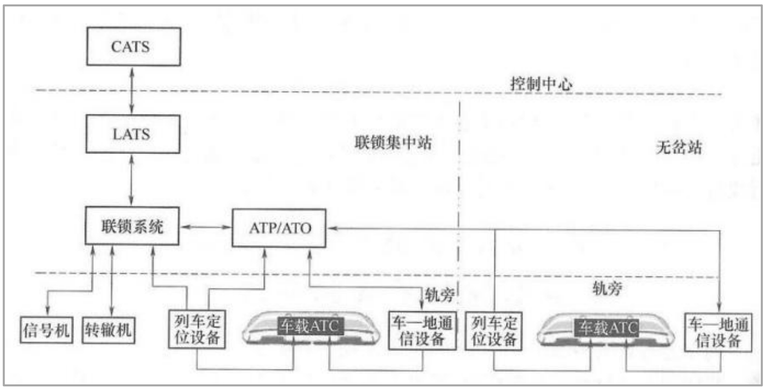


Figure 7: Schematic diagram of the basic structure of the ATC system

ATS sub-system: It displays the train operation status and equipment status within the control area in the control centre. According to the requirements of CBTC system, the setup of ATS system includes operator workstations, timetable workstations, training workstations and other corresponding equipment and networks.

CI subsystem: Supervision and direct control of turnouts, track sections, signalling machines and other outdoor equipments to achieve the correct interlocking relationship between various equipments to ensure the safety of train operation; effective protection capability for incorrect operation from equipments; capable of handling and cancelling the approach according to the beginning and terminal of the approach.

ZC sub-system: receives various status and data information from VOBC, CI, ATS and DSU, generates MA for the trains within the ZC range, and sends the MA to the on-board VOBC equipment through DCS system in time to control the train operation.

VOBC subsystem: In order to ensure safe train operation, the train must make accurate judgements about its position and direction of travel. The on-board computer works with tachometers, speed sensors, accelerometers and trackside positioning transponders to achieve accurate train positioning.

DSU subsystem: database system shared by on-board and ground equipment.

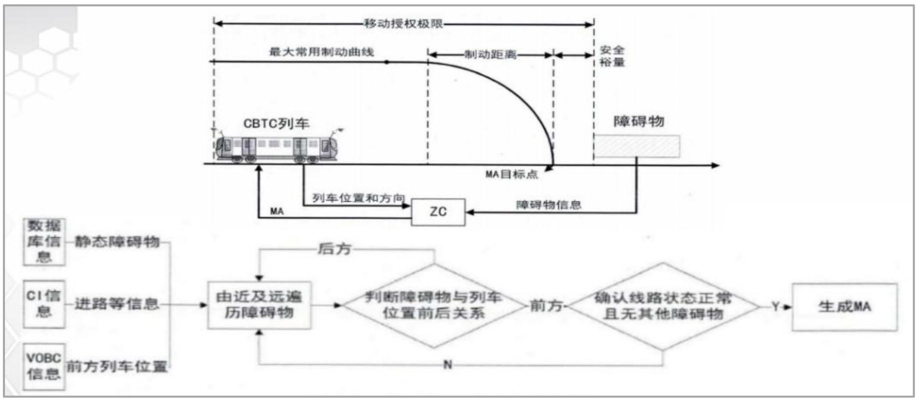


Figure 8: Generation of mobile authorisation

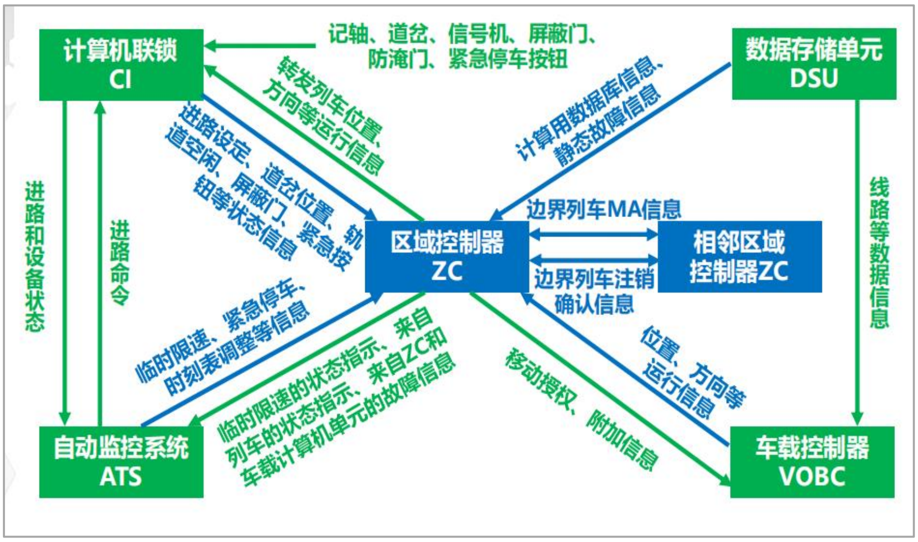


Figure 9: CBTC Subsystem Data Interaction

2.2.3 Analysis of information flow in the CBTC system

The basic functional principle of the CBTC system is shown in Figure 9, from which the basic information flow between the control centre ATS, the regional controller, the data storage unit, and the on-board controller can be seen.

Command information of the control centre ATS: this information is processed by the server and transmitted to the area controller or on-board controller through the secrecy device of the transmission system and the firewall. Information content of train commands: arranging CBTC approaches for trains or cancelling CBTC approaches; assigning running lines for communication trains or cancelling the assignment order; withholding or cancelling the withholding of trains at platforms; transferring or cancelling stations; closing or opening platforms as well as adjusting accelerating and braking rates of trains and so on. The information content of track command: open or close a track section; adjust the train stopping time (including withholding); achieve the transfer of control; according to the train running line control turnouts, arrangement of approach; for the uncontrolled train arrangement of the signal machine to the signal machine running approach; to ensure the safety of the premise of lifting the lock or cancellation of the crossing locks and so on. Of course, the execution results of these command messages should be fed back to the human-machine interface of the control centre as status information.

Information from the area controller to the on-board controller: The Mobile Authorisation Unit (MAU) of the area controller calculates the mobile authorisation limits for all trains in the area and transmits the respective mobile authorisations to the individual trains, in addition to forwarding the ATS adjustments sent to the trains by the ATS of the control centre.

Information from the on-board controller to the regional controller and control centre ATS: An important feature of the CTBC system is the automatic and accurate identification of the train's position on the line, which is the basic information for the safe operation and control of the train, so all the communicating trains calculate the exact position on the line based on the beacons and speed sensors' information; and transmit this position information, including the position of the headstock and the tailstock, according to the transmission cycle, in real time to the regional controller and the control centre ATS. The on-board controller calculates the speed profile of the train operation according to the LMA transmitted by the mobile authorisation unit of the area controller and displays the target speed in the driver display unit. It also transmits the train operation mode, direction of operation, actual speed of train operation, terminal station, next station, train type, train alignment stop status, door status, emergency stop status of the train, driver's number, train formation, start and end positions of the movement authorisation limit being executed by the train, start and end points of the manually controlled train, and train jump-stop.

2.2.4 Zone controller ZC functions

Secure communications with all trains in the area under their jurisdiction.

Train tracking based on train location reports.

Determine movement authorisations for each train.

Control and status monitoring of turnouts.

Turnout interlocking: prevents the turnout from moving when a train passes over or approaches it; ensures that the train cannot enter the section until the turnout is properly in place and locked.

Arrange and lock the train approach.

Control and status monitoring of signalling machines.

Monitor train movements.

Control and status monitoring of platform screen doors.

Communication with neighbouring ZCs: enables handover of trains between controllers in two neighbouring zones; extends train movement authorisation from one controller's precinct to neighbouring controllers.

Communication with automatic monitoring ATS: processing train approach commands from ATS; reporting status of turnouts and signalling machines; error message reporting.

The control of a train by a single ZC is shown in Figure 10.

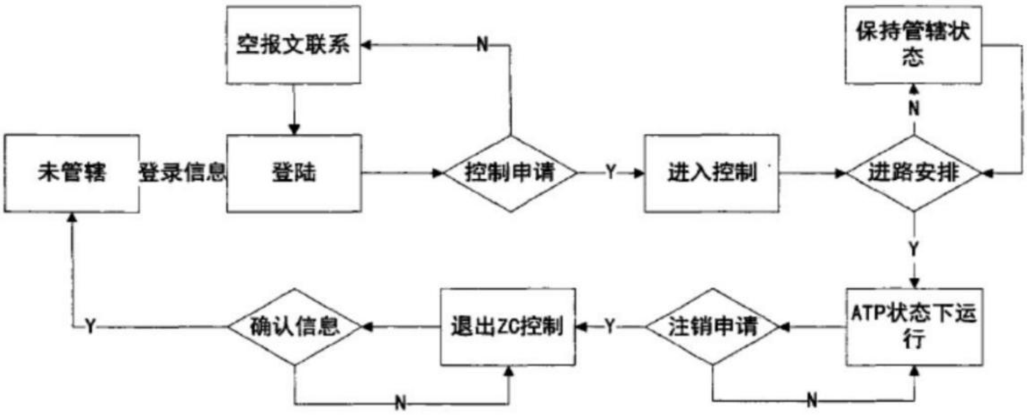


Figure 10: Control of a train by a single ZC

The control states of ZC over trains include: un-jurisdictional state (whether the train enters ZC or not); logged-in state; control state under ATP; and logged-out state.

The ZC boundary control handover is shown in Figure 11 and Figure 12.

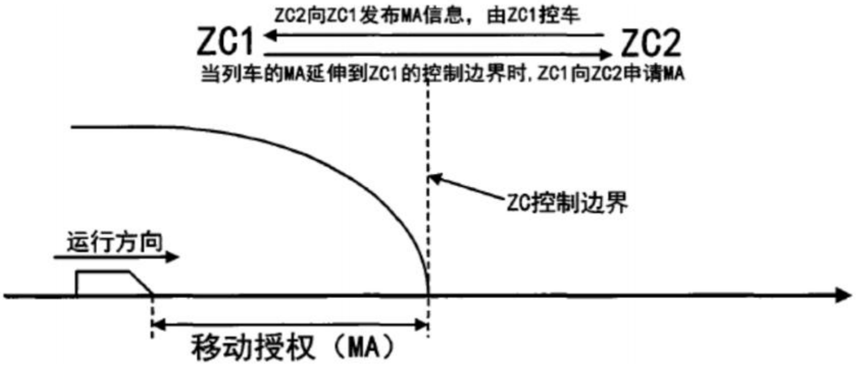


Figure 11: ZC Border Control Handover

When the MA of the train extends to the ZC control boundary, at this time ZC1 requests MA information from ZC2, and ZC2 responds and passes the MA to ZC1, at which time the MA of the train will cross the boundary of the control area, but the train is still actually controlled by ZC1.

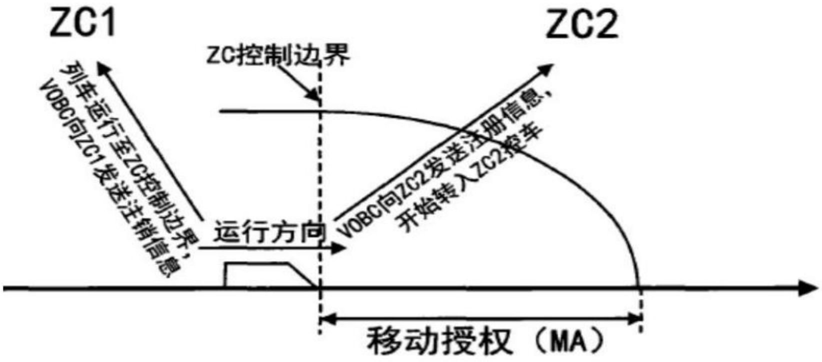


Figure 12: ZC Border Control Handover

The head arrives at the ZC control boundary, parses the information from ZC2 in the MA, and sends the login message;

When the rear end has not finished crossing the boundary, the train stays logged in ZC2 with a null message connection, and ZC1 still receives the MA message from ZC2 and forwards it to the train;

When the rear end of the car completely crosses the boundary, the train sends a control application to ZC2, sends a cancellation application to ZC1, and after agreeing to the cancellation, sends a cancellation message to the train, and at the same time notifies ZC2 that the train has been cancelled, and after ZC2 receives the cancellation confirmation message from ZC1 and the train's control application, it transitions the train into the control state and releases the MA message to the train, and thus completes the process of the control handover at the boundary of the ZC.

3. BASIC THEORY OF TRACTION CALCULATION

3.1 Train force analysis

Trains are subjected to numerous forces during operation, as shown in Figure 13, including the main ones:

Traction force F or braking force B.

Operating resistance W, including basic resistance and additional resistance such as slope value and curve.

Train gravity G.

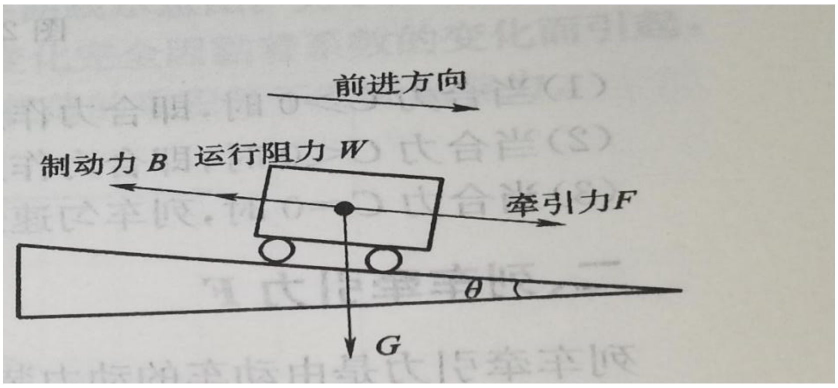


Figure 13: Schematic diagram of train force analysis

Generally, when designing the train operation design, the transverse force of the train is not considered for the time being, and only the longitudinal force of the train in the forward direction along the track is studied.

Traction, drag, and braking forces generally do not act on the train at the same time, and their combination will vary with the state of the route and the working conditions of the train. If the combined force on the train is expressed in terms of C (positive in the direction of the traction force), then:
During traction operation, the traction force F and the train running resistance W act on the train at the same time, and the combined train force is: C=F-W When F>W, the train accelerates; when F=W, the train runs at a constant cruising speed.

When the train is inert, neither traction nor braking force is applied to the train, and the train is only subjected to the action of the running resistance W, whose combined force is the running resistance: C=-W According to the different conditions of the line in which the train is located, when the train is subjected to resistance and the train running in the opposite direction, then decelerate the operation; when the train is subjected to resistance and the train running in the same direction (such as downhill), then accelerate the operation; ideal conditions, the train is not subjected to resistance to run at a constant speed.

During braking operation, the train braking force B and the train running resistance W act on the train at the same time, and the combined train force is: C = - (W + B) As the traction force F, train braking force B, train running resistance W are with the train running speed and change, so its combined force C also change with the speed. Train speed depends on the size and direction of the combined force, the typical conditions shown in Figure 14, the train running process according to the different forces, the state of motion is also different.

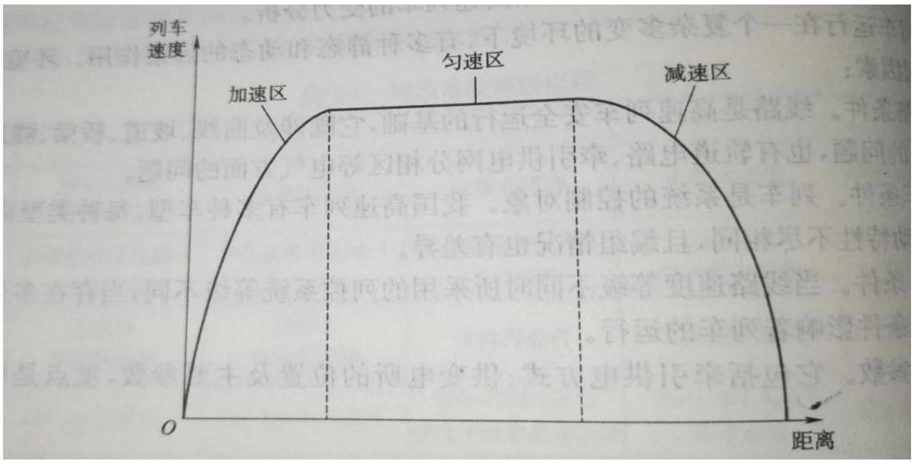


Figure 14: Typical working conditions of train operation diagram

When the combined force C>0, i.e. the direction of action of the combined force is the same as the direction of train operation, the train accelerates.

When the combined force C < 0, i.e. the direction of the combined force is opposite to the direction of train operation, the train slows down.

When the combined force C = 0, the train runs at a constant speed.

3.2 Locomotive traction force F

Locomotive traction is generated by the power transmission device, and the train running in the same direction, driving the train operation can be adjusted by the driver according to the needs of the external force.

Power transmission: steam, internal combustion, electricity.

Description: It is the internal force issued by the locomotive power unit, through the transmission device, through the adhesion between the wheel and rail and the tangential force generated by the rail reaction on the locomotive dynamic wheel axle.

Figure 15 is a depiction of the interaction between the train's wheelsets and the rails, i.e., a schematic diagram of the moving transmission part of a moving train set. The power shaft is equipped with a traction motor, which transmits the torque Md to the moving wheels through the gearing, while the torque M on the moving wheels is still an internal torque to the train, which does not allow the train to move forward. According to the principle of mechanics, can be the same direction of rotation and equal size of a pair of force couples (F 1,F2) instead of torque M, where F = M / R, R is the radius of the moving wheel. F2 in the centre of the moving wheel (i.e., axle bearings on the wheel), and F1 acting on the rails in an attempt to move the rails, the rails are stationary, and thus the wheel center O point and the wheel-rail contact point C must have a counter-force couples, and the size of its M and M are equal and the opposite direction. Opposite direction. Force F3 for the bearing acting on the axle reaction force, F for the rail acting on the wheel reaction force. F3 and F2 are internal forces, equal in size and direction, the two are balanced each other. Obviously F is caused by the power transmission device, and the train running in the same direction of the external force, because it acts on the periphery of the wheel, so also known as peripheral traction. Peripheral traction force exists only on the moving wheel, it is the basic reason for the train to produce movement.

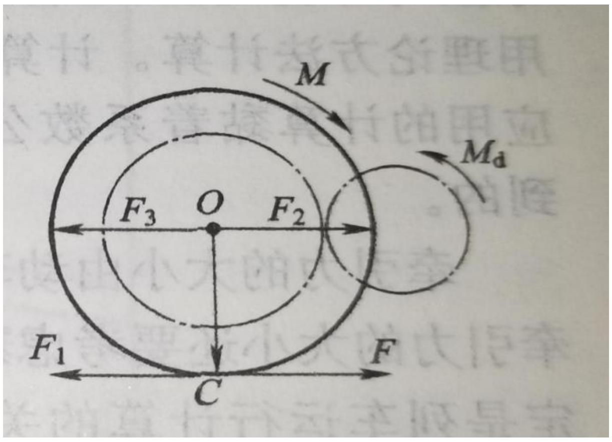


Figure 15: Schematic diagram of dynamic wheel force analysis

The reality of train operation is very complex. Wheels and rails in the pressure under the action of deformation, wheel-rail contact is actually elliptical surface contact rather than point contact, so there is no ideal instantaneous centre of rotation. At the same time the train running process is inevitable to occur in the impact and all kinds of vibration, the wheel tread is actually conical, so the wheel rolling on the rail must be accompanied by a small amount of longitudinal and lateral sliding, that is, the actual situation is not pure "static friction state", but "static in the micro-action" or "rolling in the micro-slip" state. As the traction force and inertia force is not acting in the same horizontal plane, resulting in the front and rear wheels of the moving car acting on the rail vertical load is not evenly distributed. Therefore, the maximum value of the longitudinal horizontal force between the wheel and the rail is actually related to the state of motion, but also than the physics of the "maximum static friction" is much smaller. Therefore, when analysing the longitudinal force between the wheel and rail, the term "static friction" is replaced by "adhesion". In the adhesion state, the maximum value of the longitudinal horizontal force between the wheel and rail is defined as the adhesion force, adhesion force and the ratio of the vertical load between the wheel and rail is called the adhesion coefficient, Figure 16 for the adhesion characteristics curve schematic. In order to facilitate the application, it is assumed that the vertical load between the wheels and rails during train operation is fixed, that is, the change of the adhesion force is entirely due to the change of the coefficient of adhesion, and thus the coefficient of adhesion is actually a hypothetical value. The product of it and the assumed constant vertical load is equal to the actual adhesion force.

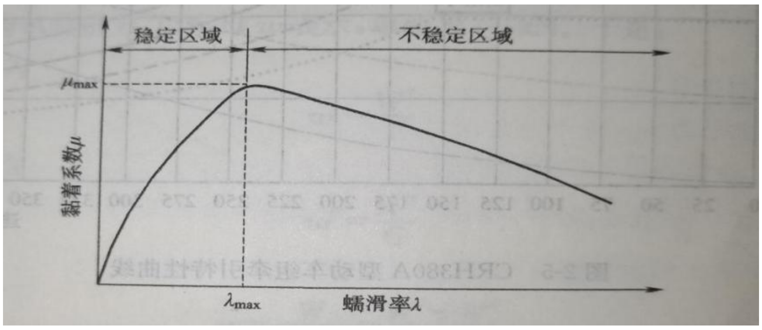


Figure 16: Schematic Adhesion Curve

In order to keep the moving wheels of the moving train from idling, the main force F1 must be controlled within the range of the adhesion limit, and the adhesion tractive force is the train traction force limited by the adhesion between the wheels and rails. According to Figure 15, the size of the traction force can be changed by changing the manipulation mode to change the torque M to adjust, that is, F1, F2 increase, the external force F will increase. However, F is the adhesion force generated by the moving wheel pressed on the rail, the maximum value of which is the product of the gravity of all the moving wheels pressed on the rail and the coefficient of adhesion between the wheel and the rail. The adhesion coefficient is related to many factors such as environmental climate, running speed, train structure, line quality and surface condition of the wheel and rail, which is difficult to calculate by theoretical method. Calculation of the adhesion coefficient in relation to train speed and climatic conditions. The formulae for calculating the coefficient of adhesion used in the traction calculation process are based on a large number of experiments, combined with the use of experience, according to the average value of the calculation.

The size of the traction force is determined by the traction characteristic curve of the moving train, and its value is related to the train running speed and the position of the manoeuvring handle. The magnitude of the traction force also takes into account the limitations of the adhesive force, i.e. $F=\mu0*WL$, $\mu0$ is the coefficient of the adhesive traction force, the determination of the traction force is the key to the calculation of the train operation, and its value needs to be as accurate as possible and in line with the actual situation. Generally speaking, when the train speed is below 2.5km/h, it is considered to be the starting state, and the viscous traction force can be used; when the speed exceeds this speed, the value of the traction force can be taken according to the traction characteristic curve in principle.

3.3 Train resistance

Train sets in the operation process due to various reasons naturally occurring and the train running in the opposite direction, impede the train operation and can not be manipulated by the external force is called the train resistance, referred to as the train resistance, with the letter W said. According to its cause, train resistance can be divided into two categories: basic resistance and additional resistance.

Basic resistance refers to the resistance that exists when the rolling stock is running on any line (level road, ramp or curve, etc.). The basic resistance mainly comes from the locomotive, vehicle journal and bearing friction resistance; wheels rolling on the rail resistance; wheels and rails between the sliding friction resistance; shock vibration resistance; air resistance and so on.

Additional resistance refers to the train in the non-ideal line conditions on the operation of the additional resistance, such as the train running on the ramp when the ramp additional resistance Wi; through the curve when the curve additional resistance Wr, the train starts when the start of the additional resistance Wq; through the tunnel when the tunnel air additional resistance Ws and so on. Additional resistance and the basic resistance is different, by the train vehicle type of influence is very small, mainly depends on the operation of the line conditions. Additional resistance is not divided into moving vehicles, trailers, but according to the train calculation.

Trains run on a level track with only basic resistance and no additional resistance. Due to the extremely complex factors affecting the resistance, it is difficult to calculate the theoretical formula, often based on a large number of experimental data, a comprehensive empirical formula for calculation.

Tests have shown that the resistance acting on the train is proportional to its weight, so the resistance per unit weight is commonly used in traction calculations, which is called the unit resistance and is expressed by the letter w in units of N/kN. Thus:

The unit resistance of the moving car is $w'=W'/P$;

Trailer unit resistance as $w''=W''/G$.

The train unit resistance is $w = W/(P+G) = (W'+W'')/(P+G)$.

Where W' is the moving vehicle resistance (N); W" is the trailer resistance (N); P is the calculated weight of the moving vehicle (kN); and G is the trailer hauling weight, referred to as the hauling weight (kN).

According to the "Train Traction Calculation Regulations", the relevant formula for the resistance is: the train set is a fixed formation consisting of moving cars and trailers, so the unit operation of the basic resistance does not distinguish between moving cars and trailers, according to the results of a large number of tests, the calculation of the unit operation of the basic resistance formula: $w0 = a + b * v + c * v * v$, in which w0 is the unit operation of the basic resistance, the unit of N / kN; a, b, c are constants. c are constants. Different models a, b, c parameters vary.

3.4 Train braking force

Produced by the braking device, and the train running in the opposite direction, hindering the train running, the driver can be adjusted according to the needs of the external force known as the braking force. The purpose of train braking is to regulate the speed of the train or to stop the train.

As far as the moving car is concerned, the braking power can be generated by mechanical braking device or electrical braking device in two ways; as for the trailer braking power, it is still commonly used to generate the braking power by mechanical braking. Train braking force generated by many methods, in addition to the widely used brake, there are disc braking, resistance braking, regenerative braking, hydraulic braking, magnetic track braking, eddy current braking and so on. Due to the brake is easier to control, and can produce a huge braking force, so China's moving car, trailer on the current use of the main brake is the brake, that is, compressed air as the prime mover, push the brake cylinder so that it produces thrust, and then amplified by the lever system to the brake tile, the brake tile compression wheel tread, the friction of the wheels and the brake tile will be the train's kinetic energy into thermal energy, thus generating braking effect. For electric locomotives, there is a kind of electric braking power, it is the use of traction motors can be forward or reverse running mechanism, in traction as a motor to generate power, and in braking the motor will be reconnected to the generator will be converted into kinetic energy into electrical energy, or consumed in the braking resistor on the (resistive braking), or return to the grid (regenerative braking), China's high-speed rolling stock trains are widely used in the regenerative braking method.

Formation of braking force and the basic principle of traction is the same, are relying on the adhesion between the wheel and rail. But the formation of traction must be a power unit acting on the wheel pair of moment Mp, the moment through the rail and the static friction of the moving wheel to produce forward propulsion F and the same direction of train operation, that is, the train traction. Formation of braking force, it must be the case that the wheel pair is rolling, relying on the action of the brake tile pressure to produce a prevent the wheel pair of positive rotation of the counter moment MB, therefore, the static friction of the rails acting on the moving wheel with the train running in the opposite direction, that is, for the train braking force B, which is the opposite direction of the train running. As shown in Figure 17, moving cars, trailers, traction and braking force can not exceed the adhesive force, otherwise, there will be "idle" or "hold dead slip" phenomenon, thereby losing traction and braking force.

For rolling stock, the importance of braking has long been more than just a safety issue, it has become an important factor in limiting the further increase in train operating speed. To achieve high train speed, in addition to large traction power, there must be enough braking power, to ensure that the high-speed, safe operation of the rolling stock has a vital significance. Braking power calculation, just according to the braking characteristic curve of the rolling stock, from which to find out any speed and braking level under the braking force, you can calculate the braking force of the rolling stock at this time. The calculation of regenerative braking force of rolling stock generally refers to the braking characteristic curve of rolling stock, and uses linear interpolation method, curve fitting method and other interpolation methods for interpolation calculation.

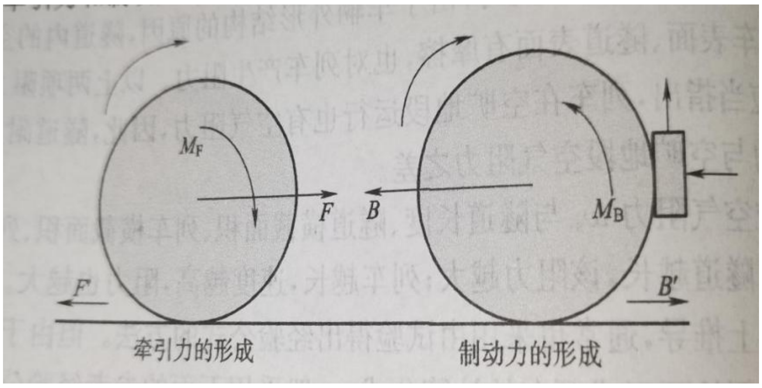
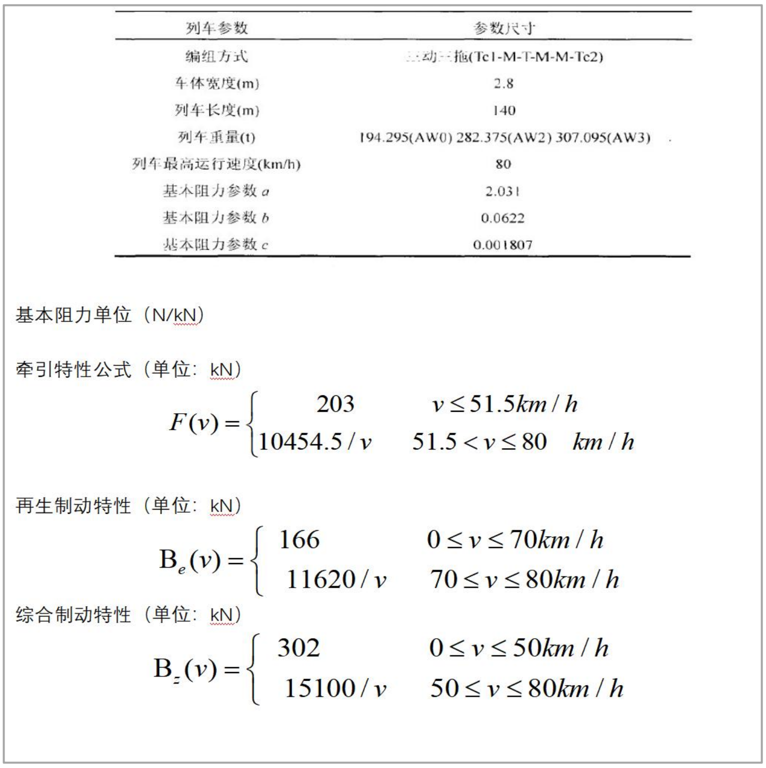


Figure 17: Schematic diagram of train traction and braking force formation

4. TRACTION CALCULATION SIMULATION

Taking the metro B-type car as an example, the train parameters are shown in Figure 18.



列车参数	参数尺寸
编组方式	三动三拖(Tc1-M-T-M-M-Tc2)
车体宽度(m)	2.8
列车长度(m)	140
列车重量(t)	194.295(AW0) 282.375(AW2) 307.095(AW3)
列车最高运行速度(km/h)	80
基本阻力参数 *a*	2.031
基本阻力参数 *b*	0.0622
基本阻力参数 *c*	0.001807

基本阻力单位（N/kN）

牵引特性公式（单位：kN）

$$F(v)=\begin{cases}203 & v\le 51.5km/h\\ 10454.5/v & 51.5<v\le 80 \quad km/h\end{cases}$$

再生制动特性（单位：kN）

$$B_e(v)=\begin{cases}166 & 0\le v\le 70km/h\\ 11620/v & 70\le v\le 80km/h\end{cases}$$

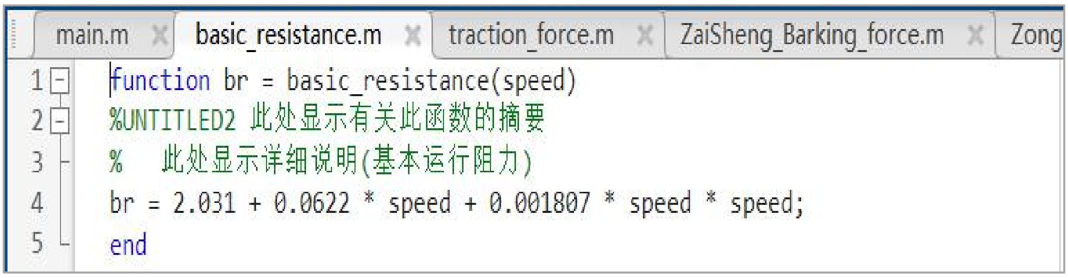
综合制动特性（单位：kN）

$$B_z(v)=\begin{cases}302 & 0\le v\le 50km/h\\ 15100/v & 50\le v\le 80km/h\end{cases}$$

Figure 18: Metro B Parameters

Double click to run the matlab programme, click on New-Script and create a new script file named main.m as the main programme.

Click New Function to create a new function file named basic_resistance.m, which is used to calculate the basic resistance of the train, note that the function name is consistent with the file name, and the input variable of the function is the running speed of the train, named speed, with the unit of km/h, and the output variable of the function is the basic resistance, named br, with the unit of kN, as shown in Figure 19. The output result of basic resistance is shown in Figure 20.



```
function br = basic_resistance(speed)
%UNTITLED2 此处显示有关此函数的摘要
%   此处显示详细说明(基本运行阻力)
br = 2.031 + 0.0622 * speed + 0.001807 * speed * speed;
end
```

Figure 19: Basic_resistance function procedure

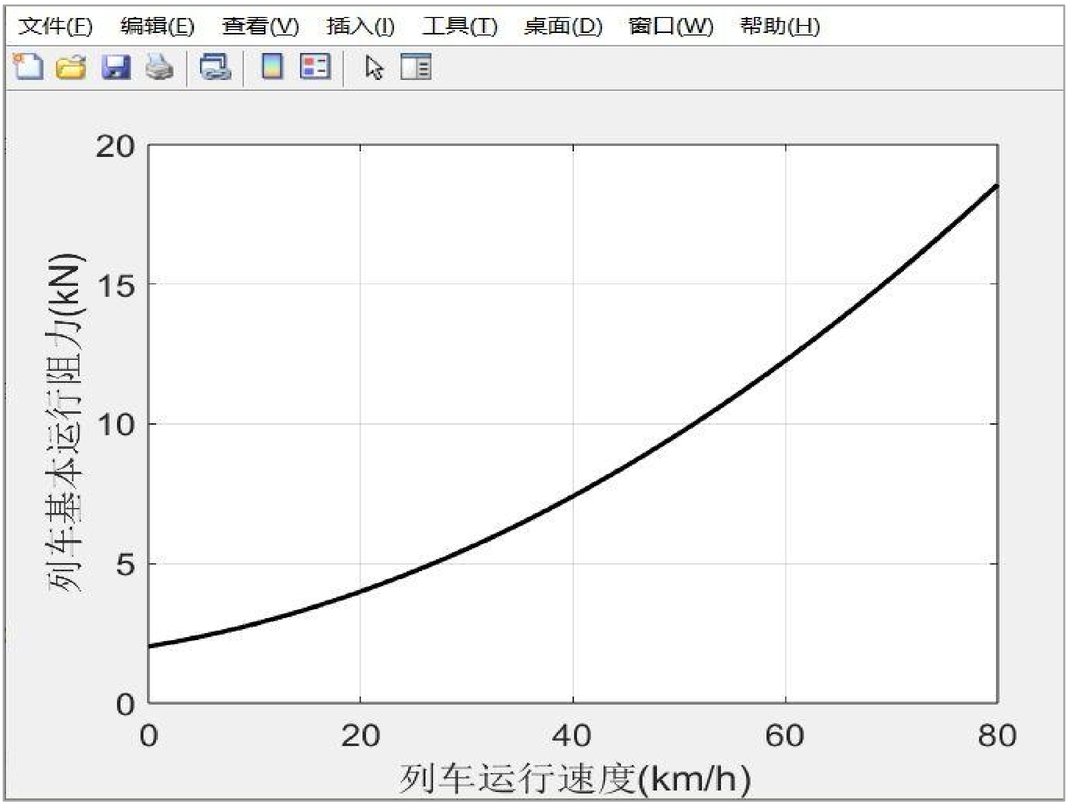
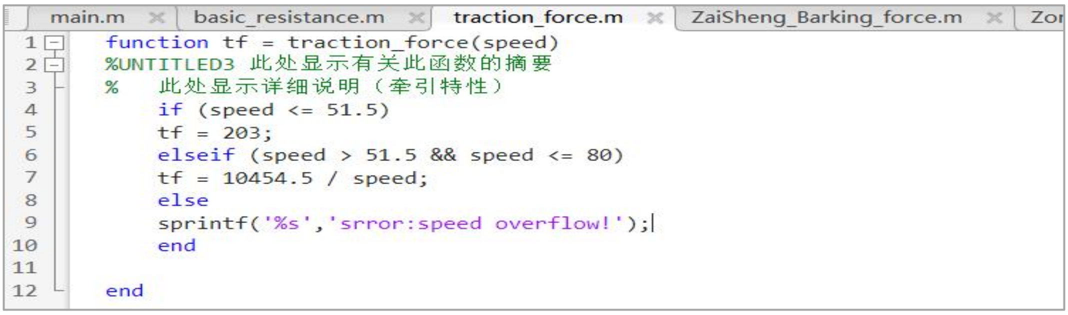


Figure 20: Schematic diagram of the output results of the train's basic operating resistance

Click New Function to create a new function file named traction_force.m, which is used to calculate the train traction force, note that the function name and the file name are consistent, the input variable of the function is the train running speed, named speed, the unit is km/h, and the output variable of the function is the size of the traction force, named tf, the unit is kN, as shown in Figure 21. The output result of the train traction force is shown in Figure 22.



```
function tf = traction_force(speed)
%UNTITLED3 此处显示有关此函数的摘要
%   此处显示详细说明（牵引特性）
    if (speed <= 51.5)
    tf = 203;
    elseif (speed > 51.5 && speed <= 80)
    tf = 10454.5 / speed;
    else
    sprintf('%s','srror:speed overflow!');
    end

end
```

Figure 21: Traction_force function procedure

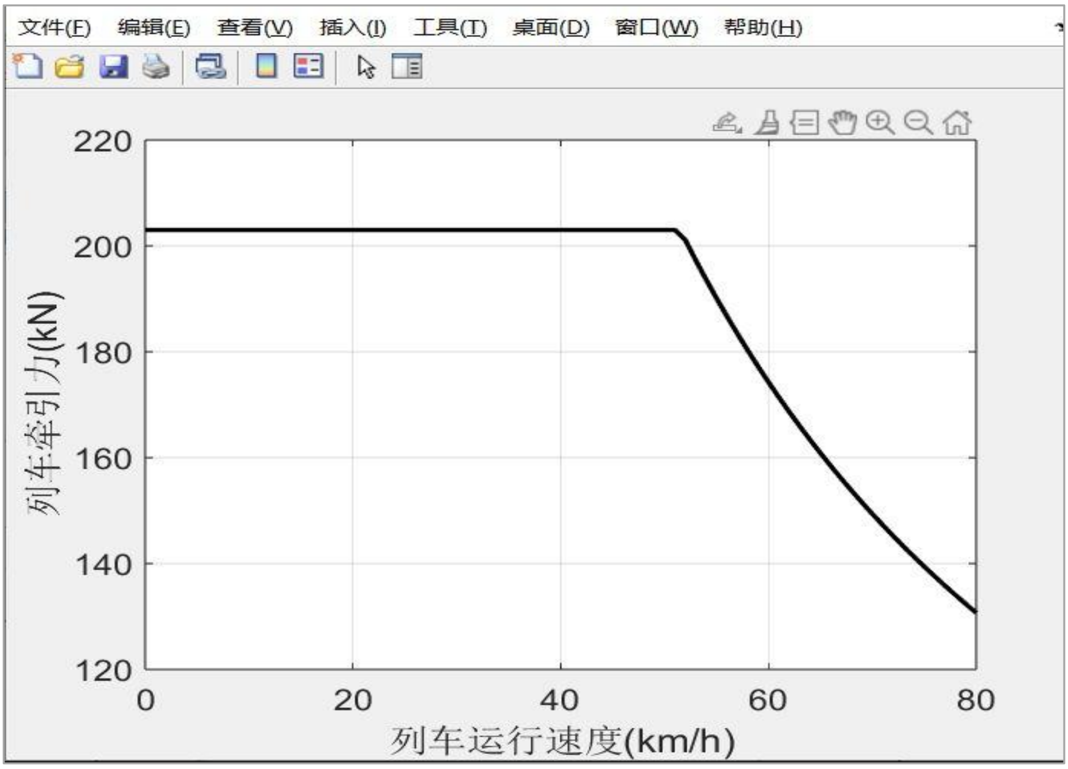
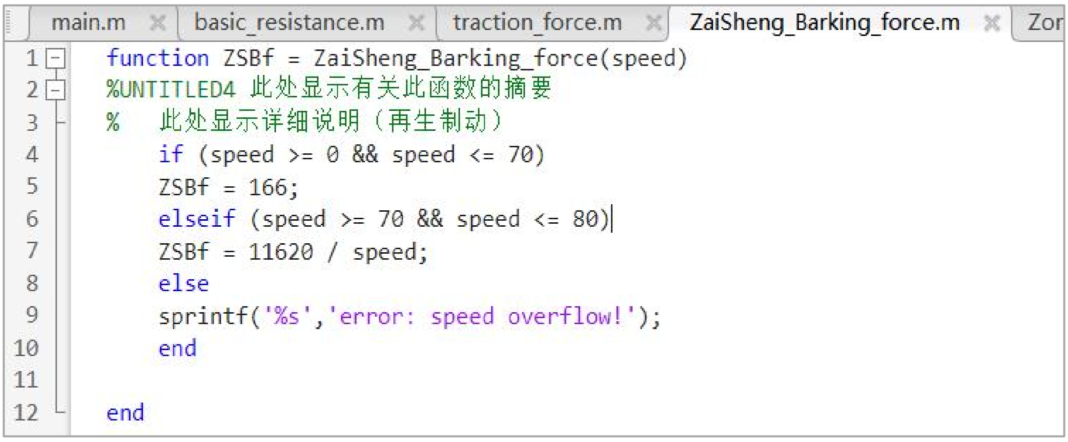


Figure 22: Schematic diagram of train traction output results

Click New Function to create a new function file named ZaiSheng_Barking_force.m, which is used to calculate the regenerative braking force of the train, note that the function name and the file name are consistent, and the input variable of the function is the running speed of the train, named speed, with the unit of km/h, and the output variable of the function is the size of the regenerative braking force, named ZSBf, with the unit of kN , as shown in Figure 23. The output result of the regenerative braking force of the train is shown in Figure 24.



```
function ZSBf = ZaiSheng_Barking_force(speed)
%UNTITLED4 此处显示有关此函数的摘要
%   此处显示详细说明（再生制动）
    if (speed >= 0 && speed <= 70)
    ZSBf = 166;
    elseif (speed >= 70 && speed <= 80)
    ZSBf = 11620 / speed;
    else
    sprintf('%s','error: speed overflow!');
    end

end
```

Figure 23: ZaiSheng_Barking_force Function Procedure

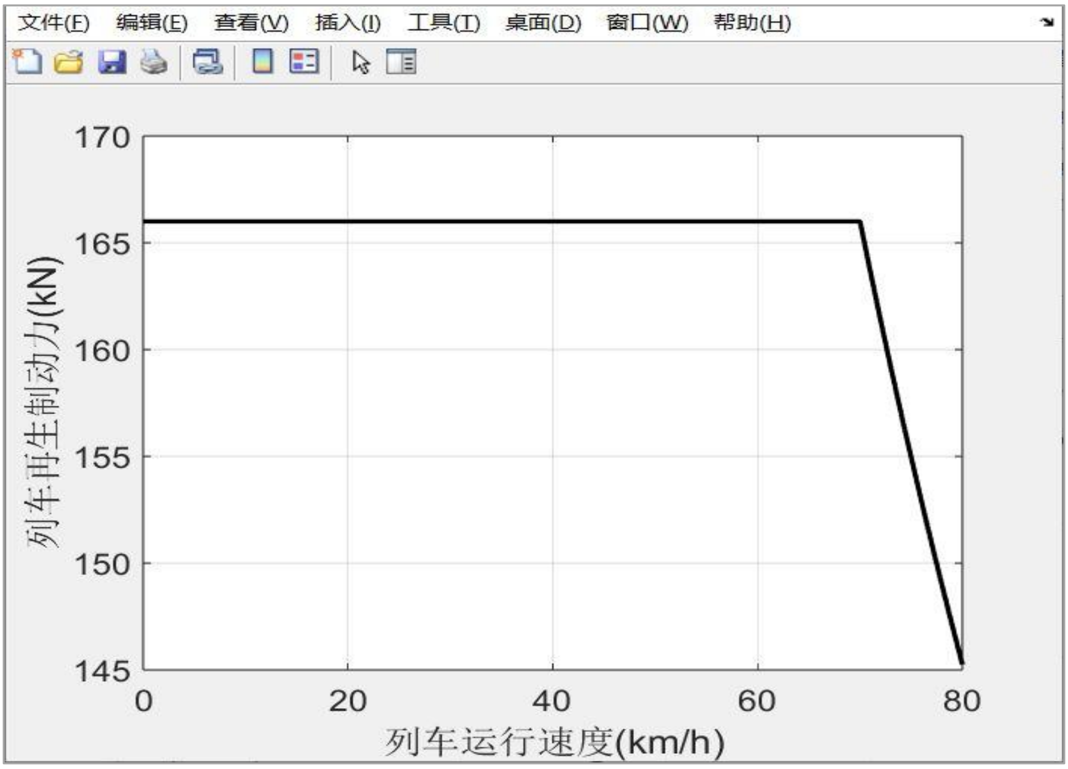
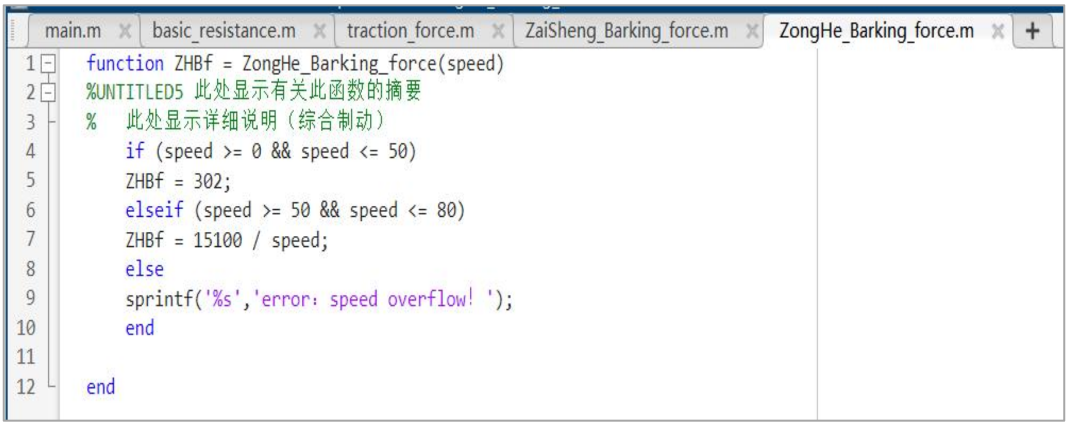


Figure 24: Schematic diagram of train regenerative braking force output results

Click New Function to create a new function file named ZongHe_Barking_force.m, which is used to calculate the integrated braking force of the train, note that the function name and the file name are consistent, the input variable of the function is the running speed of the train, named speed, the unit is km/h, and the output variable of the function is the size of the integrated braking force, named ZHBf, the unit is kN, and the output variable of the function is the size of the integrated braking force, named ZHBf, the unit is kN. As shown in Figure 25. The output result of train regenerative braking force is shown in Figure 26.



```
function ZHBf = ZongHe_Barking_force(speed)
%UNTITLED5 此处显示有关此函数的摘要
%   此处显示详细说明（综合制动）
    if (speed >= 0 && speed <= 50)
    ZHBf = 302;
    elseif (speed >= 50 && speed <= 80)
    ZHBf = 15100 / speed;
    else
    sprintf('%s','error：speed overflow！ ');
    end

end
```

Figure 25: ZongHe_Barking_force Function Procedure

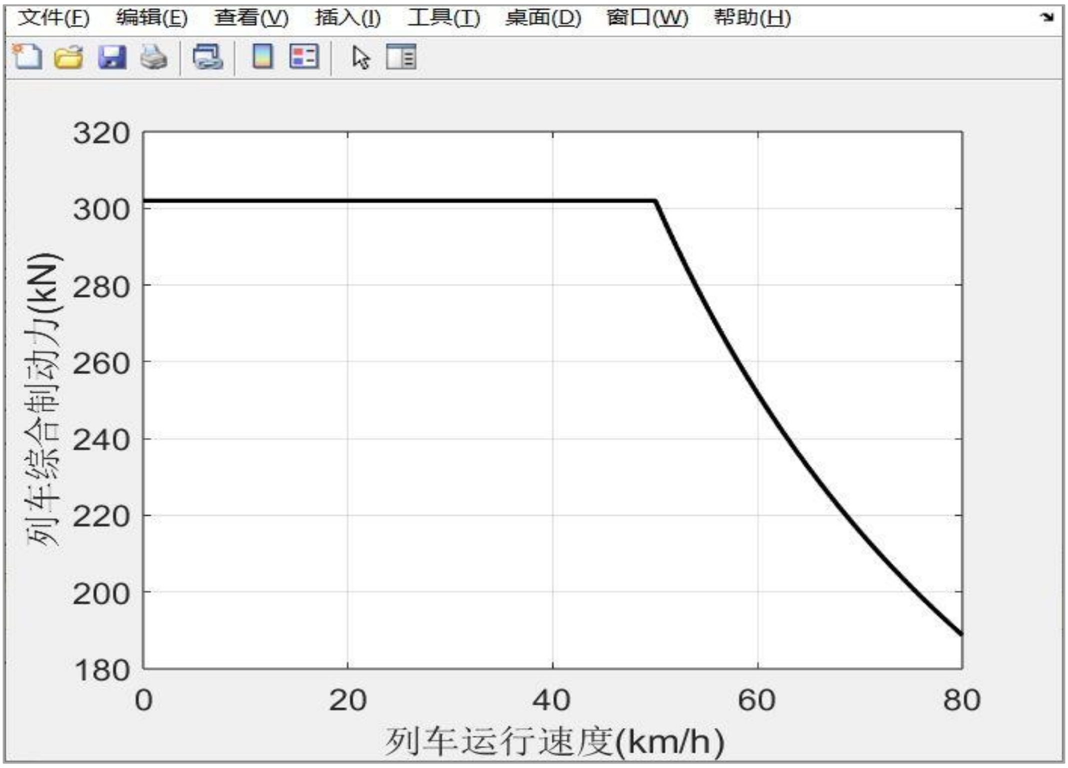


Figure 26: Schematic diagram of the result of integrated braking force output of the train

5. SUMMARY

Train traction calculation is an important element in the study of train traction. It deals with aspects of train operation, energy consumption and efficiency. In this thesis summary, I will give an overview of the main elements of train traction calculation.

Firstly, train traction is the force required to propel a train forward during operation. The amount of traction depends on the mass of the train, operating speed, grade, and other factors. Calculation of traction force helps us to determine the appropriate power system and energy consumption for efficient train operation.

Secondly, there are various methods for train traction calculation. Common methods include mechanical calculation based on Newton's second law, power balance method and energy consumption modelling. Among them, the mechanical calculation method calculates the traction power by considering factors such as mass, friction and gradient. The power balance method is based on the equilibrium relationship between traction power and resistance. The energy consumption model, on the other hand, estimates the traction energy consumption by modelling the energy loss during train operation.

In addition, the specific needs of different types of trains and different operating conditions need to be taken into account in train traction calculations. For example, trains operating in mountainous areas or on steep slopes require greater traction, while high-speed trains require more powerful power systems to meet operational requirements. Therefore, in practical applications, it is necessary to select the appropriate traction calculation methods and parameters according to the specific conditions.

Finally, train traction calculation is important for train design, energy management and transport planning. By reasonably calculating train traction, train operating efficiency can be optimised, and energy consumption and environmental impact can be reduced. At the same time, traction calculations also provide a reference for train manufacturers to design and produce trains adapted to different operating conditions.

In summary, train traction calculation is a key technology that can be used to evaluate train traction, energy consumption and efficiency. It has important application value in the fields of train design, energy management and transport planning, and plays a positive role in enhancing the efficiency of train operation and environmental sustainability.