Research on urban rail train control system based on train to train communication

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Abstract. The new train control system VBTC based on train to train communication adopts the idea of on-board centralization, regards switches and sections as trackside resources, integrates the functions of interlocking and zone controller into on-board, and the train independently manages line resources and determines the train operation control scheme. Compared with the existing CBTC system, VBTC system not only simplifies trackside equipment, but also improves operation efficiency, reduces operation and maintenance costs, and can better solve the problems of shortage of commissioning time and limited room space during overhaul and reconstruction of old lines. This paper analyzes the key technologies of train control system under train to train communication technology, designs the structure of VBTC system on-board module and object controller, and analyzes the control line resource flow of trackside object controller. VBTC train control system breaks through the inherent mode that all rail transit train control systems rely on station and trackside equipment to realize train operation control, and completely relies on on-board train control, which is in line with the development trend and direction of train control system.

1. Introduction
In recent years, the mature application of CTCS-3 (Chinese train control system level 3) and CBTC (Communications Based Train Control) systems in China indicates that China's rail transit technology has made remarkable achievements. With the increase of population and passenger flow, the rail transit train control system will face higher challenges. How to reduce trackside equipment, reduce operation and maintenance costs, and how to increase traffic density while improving operation speed will be the main problems to be solved by the signal system at present. With the development of automation and communication technology and the increasing demand for railway operation, new train control systems are vigorously studied at home and abroad. Developed countries such as Europe and the United States started earlier in the research of new train control systems. At present, there are many mature project research, such as the next generation train control (NGTC) and ERTMS regional project in Europe [1], ERTMS regional simplifies trackside equipment, cancels the occupation inspection of track circuit on train, completes train positioning and integrity inspection independently by on-board, and uses object controller to control the switch [2]. The urbails fluence system of French Alstom company has simplified the ground equipment and cancelled the ground interlocking and area controller; The ground target controller shall cooperate with the on-board equipment to complete the route arrangement function, and the on-board equipment shall submit an application to the target...
controller; Independently calculate the movement authorization and update the speed control curve in real time to ensure the safe operation of the train [3]. The active train control (PTC) system in the United States has accurate train tracking and operation management capabilities in order to shorten train interval, increase transport capacity, reduce workload and reduce trackside equipment [4]. PTC system consists of three subsystems: trackside equipment, on-board equipment and dispatching control unit [5].

In recent years, many domestic scholars have invested in the research of new train control system projects and have achieved some research results, including literature monographs and laboratory simulation software research and development. Literature [6-7] summarize and prospect the functional characteristics, ground configuration scheme and technical implementation mode of the next generation train control system by studying foreign new train control systems, combined with the operation experience and railway characteristics of China's train control system; Document [8] defines the overall technical requirements of the next generation train control system based on train vehicle communication, and puts forward the composition scheme of train operation control system with improving the intelligent level of on-board equipment and reducing trackside equipment as the main development direction. In addition, a large number of scholars have studied and designed the key technologies of the new train control system. For example, literature [9] has simulated the key technologies such as moving block, integrity inspection and train positioning of the new train control system, which shows that the new train control system has improved in safety, performance and cost, and the operation is more stable and efficient.

2. Introduction of VBTC system structure with train as the center

2.1. Structure analysis of VBTC system

VBTC system includes intelligent train monitoring system (ATS), resource management unit, wireless communication management system (DCS), on-board controller (VOBC), object controller (OC), trackside switch machine, etc. It is divided into four layers according to different logical functions and layout locations: center layer, station layer, trackside layer and on-board layer, as shown in figure 1.

![Figure 1. The diagram of VBTC system structure](image)

VBTC train control system takes on-board controller as the core to minimize ground equipment and facilitate line equipment layout. ZC, interlocking, LEU and variable balise are removed from the ground equipment, the section axle counter and signal are reduced, and the information interaction between the train and trackside equipment is realized only through the OC. It simplifies trackside equipment and shortens data interaction cycle and complexity. The train no longer obtains the operation information through ZC, and the on-board controller can independently plan the safe
operation path and calculate the MA, so as to realize the fast operation control of the train. By simplifying station and trackside equipment, investment and maintenance costs are reduced. The costs of construction, commissioning, power consumption, equipment room, etc. are reduced accordingly. The construction, maintenance and commissioning of the main equipment of the system are concentrated on the vehicle, which can work during the day in the depot, reducing the installation and commissioning at night, and solving the problems of high reconstruction cost and high maintenance cost of the existing CBTC system. The vehicle communication system takes the on-board controller as the core, and the whole life cycle cost is reduced by more than 22%.

VBTC system breaks through the traditional centralized train operation control theory of regional controller and establishes a new system control model with train autonomous control as the core. Break through the train to ground to train operation control mode of the traditional CBTC system structure, directly communicate between trains, obtain the real-time status (position, speed, acceleration, etc.) of the front vehicle through train to train communication, and calculate the safety protection speed of the two vehicles without displacement overlap in combination with the prediction of the driving track of the front vehicle, So that it can match its deceleration according to the braking rate of the following vehicle, so as to realize the safety protection (hitting the soft wall) based on the relative speed braking tracking model. In this way, on the basis of ensuring the safe distance between the front and rear of the train, two adjacent trains can run at the maximum allowable speed and small interval. Compared with CBTC system, the main line tracking interval of train communication train control system is shortened by 11% to 80s, and the turn back interval is reduced by 29% to 85s, which greatly improves the operation efficiency. The speed curve is shown in figure 2.

![Figure 2. Comparison diagram of CBTC and VBTC system speed curve](image)

2.2. Introduction to VBTC system on-board module

Trackside equipment of train control system based on train communication includes control center ATS, resource management unit, OC, etc; On board equipment includes on-board management center module (VOMC), on-board mobile authorization module (VOMA), on-board interlocking module (VOCI), front vehicle identification module, speed protection module, electronic map, etc. Its structure diagram is shown in figure 3. The on-board movement authorization module calculates the movement authorization in combination with the front vehicle position, speed, direction and other information sent by the On-board Information Center and the route information sent by the on-board interlocking module. On board interlocking functions include: analyzing train operation plan; Route control function, including resource status query function, route resource search function, resource control function, virtual signal control function, route condition check function, etc; Route unlocking function [10].
3. The process of line resource control

3.1. Structure design of object controller

The ground equipment of VBTC system has only object controller, which is mainly responsible for receiving and responding to the commands of train and ATS, and providing the collected trackside equipment status to train and ATS. The main process is as follows: the train handles the route independently according to the operation plan issued by ATS. Firstly, the on-board VOCI module needs to check the line resource status, and the trackside object controller sends the resource status information to VOCI; Secondly, VOCI sends a resource operation command to OC according to the resource status, and the object controller switches the turnout to the specified position and gives VOCI the information of successful resource acquisition; Finally, the on-board equipment releases resources after passing the route [11]. The structure diagram of object controller is shown in figure 4.

3.2. Analysis of switch controlled by object controller

The switch controlled by the OC can include the following four situations:

1. The front and rear trains in the same running direction in front of the switch apply for the use of the switch at the same time, and the train close to the switch can obtain the priority. As shown in figure 5, when there is a switch in front of trains A and B, A and B send the command of requisition of No. 1 switch to straight stock to OC in the same cycle. After receiving the command, OC judges that train a is close to the switch according to the positioning information of the two trains and the distance to the switch. OC sends the information of "train a obtains the priority to control the switch" to train B. At the same time, the information of "No. 1 switch can be requisitioned, No. 1 switch is in positioning / reverse position, and whether No. 1 switch is locked" is sent to vehicle A. After receiving the information, vehicle B can calculate the safety tracking speed and movement authorization end point through relative speed tracking. After receiving the information, vehicle a sends the command of "No.
1 switch operation to positioning" to OC. After receiving the command, OC turns the switch to positioning and locking, and finally sends the information of "No. 1 switch has been converted to positioning and locking" to train A. After receiving the command, train A calculates the running speed.

(2) If the train running in the same direction on two tracks, as shown in figure 6, train A requires switch straight strand and train B requires switch bent strand, and the two trains apply for switch in the same cycle, the OC can judge whether the two trains have priority conditions. If train B has priority, train B will go first; If there are no priority conditions, OC will judge the switch position. If the switch is positioned, train A applying for positioning will go ahead. If the switch is in the reverse position, train B applying for reverse position will go ahead. In this way, the switch switching time can be saved and the switch passing efficiency can be improved.

As shown in figure 7, two opposite trains located on both sides of double acting switch, vehicle A and vehicle B need to use 1 / 3 switch in the same cycle. In this case, vehicle A can only pass through the switch first and vehicle B can pass later, otherwise head-on collision will occur. The object controller sends the information that "train A obtains the priority to control the switch" to train B, and sends the information that "No. 1 / 3 switch can be requisitioned, No. 1 / 3 switch is in positioning / reverse position, and whether No. 1 switch is locked" to train A. After receiving the information, train B can calculate the safe running speed and moving authorization end point to ensure that when train B passes through No. 3 switch, train A has passed No. 1 switch, and the switch has been turned to the reverse position and locked. Figure 8 similarly, in this scenario, only vehicle A can go first and vehicle B can go later. The object control first turns the No. 1 / 3 switch to the reverse position, and then turns to the positioning after vehicle A passes to let vehicle B pass.

(4) Since trackside resources (section, switch, annunciator, platform and other equipment, etc.) are controlled by the OC, and the OC needs to receive commands from the two control sources of train and ATS, it is necessary to specify the priority of train control commands and ATS operation commands. Under normal circumstances, the priority of manual operation of ATS is higher than that of train command. However, if the equipment operated by ATS has been requisitioned, ATS can operate only after the equipment is used. If the train is passing through a switch, the operation command of ATS for the switch is invalid.

4. Conclusion
Compared with the traditional CBTC system, the train control system based on vehicle communication has great differences in both system architecture and vehicle control process. How to ensure the
operation safety of the new train control system will inevitably become a key research problem. This paper presents the theoretical framework of VBTC system, analyzes the functions of on-board equipment of train control system based on train to train communication, constructs the train operation control process under train to train communication, and analyzes the line resources controlled by object controller under different operation scenarios. With the improvement of the stability and reliability of communication technology, the moving block system based on vehicle communication will become one of the development directions of urban rail transit signal system in the future.

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