E3S Web of Conferences **438**, 01024 (2023)
APEE 2023 https://doi.org/10.1051/e3sconf/202343801024

Research on Headway of Ventilation Shaft Design under Different Control Modes

Mingfeng Li [1,*]

Shanghai Tunnel Engineer & Rail Trainsit Design and Research Institute, Shanghai, China

Abstract. Tracking headway time is an important target the Metro capacity. In order to meet the 150 second design capacity in the Shanghai Chongming Line long tunnel section, this article firstly analyzes the train tracking headway time under different ventilation shaft control modes. Then, it develops a simulation tool for optimizing the location of ventilation shafts in long tunnel sections. And it develops different tracking control model algorithms for train in the ventilation shaft sections. Finally, it takes the long tunnel section between Changxingdao Station and Chenjiazhen Station in the Shanghai Chongming Line as an example to demonstrate the usability of this simulation system and the reference value of simulation results.

1. Introduction

The location of ventilation shaft within the long tunnel section is a very important issue for the construction of urban rail transit tunnels. According to the "Design Specification for Urban Rail Transit", the location of ventilation shaft should consider the operational safety and strictly follow the design requirements to ensure the safety in tunnel sections. At the same time, the location of ventilation shaft should also fully consider cost factors and minimize investment and operating cost as much as possible.

At present, the train control systems used in urban rail transit are mainly communication based on train control systems (CBTC). According to subway design principles, only one train is allowed to run between ventilation shafts. Because tunnel sections usually do not provide emergency parking environment. Stricter train control measures need to be taken to limit the speed of trains and prevent accidents such as rear end collisions between trains in order to ensure safety. Therefore, in the long tunnel sections CBTC design, it is necessary to pay special attention to the balance between train operation safety and efficiency.

Headway is an important target for evaluating the CBTC system and serves as a reference and basis for updating the movement authority (MA) of trains. The continuity of updating the MA endpoint directly affects the headway between stations. The endpoint of MA extension that is calculated by the onboard subsystem in the CBTC, is determined by the train's obstacles. There are two types of obstacles: static obstacles and dynamic obstacles. Among them, static obstacles mainly include resources that are not locked (such as switches, blockes, platform safety doors, and signals etc.), while dynamic obstacles mainly refer to trains.

Therefore, this article takes the position of the ventilation shaft as static obstacle and the moving train as dynamic obstacle. It discusses and analyzes the train MA update model. thereby elaborates the impact by the ventilation shaft under different control models on the train tracking function.

2. Calculation and analysis of the headway capability

The metro headway is defined as the time interval between two consecutive trains passing through the same location. The obstacle of the rear train MA may be the rear of front train or the location of the ventilation shaft during the train tracking between stations. Regardless of the obstacle type, the end of the safety braking curve of the rear vehicle is in front of the obstacle and a certain safe distance margin is maintained from the obstacle. So the train tracking process is shown in Figure 1.

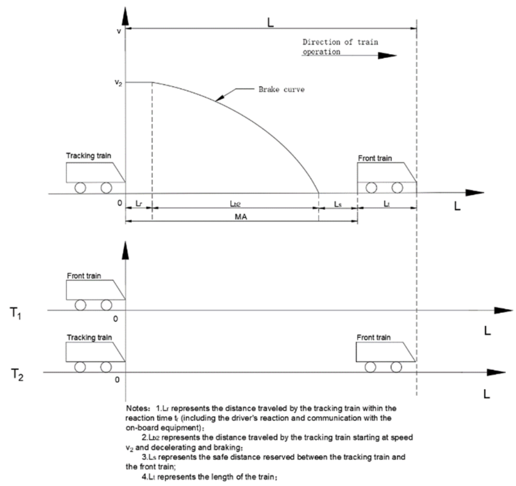

Figure 1. Diagram of safety tracking model.

* Corresponding author: limingfengvip@163.com

The train tracking safety distance is expressed as

$$L = L_r + L_{b2} + L_s + L_t \quad (1)$$

The headway is expressed as

$$T = \frac{L_s + L_t + L_r}{v_2} \quad (2)$$

In the formula: v_2 - the train average speed
Record the time when the front train reaches location 0 as T_1, and record the time when the front of the tracking train reaches location 0 as T_2, then the headway time is expressed as $T = T_2 - T_1$.

3. Train tracking scenario model design based on the constraint condition of the ventilation shaft

According to design regulations, only one train is allowed to run between the continuous ventilation shafts. Therefore, it mainly considers the different processing methods of ventilation shafts in CBTC, and designs two control processing modes:
1. The MA of following train is prohibited from extending to the interior of the ventilation shaft section.
2. The MA of following train is allowed to extend to the interior of the ventilation shaft section.

3.1 MA non-extension model

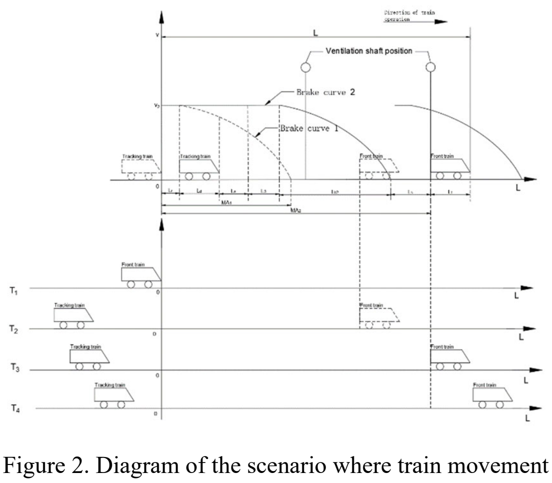

Figure 2. Diagram of the scenario where train movement authorization does not allowed to extend.

When considering the effect of ventilation shaft location on train tracking, a typical scenario can be considered:
At time T1, a front train and a following train successively enter the long tunnel zone, and the distance between the two trains is a safe distance. At this time, the front vehicle has reached the starting location of the long tunnel zone (assuming location 0).
At time T2, if the front vehicle enters the ventilation shaft section and the following train's MA is not updated due to the CBTC logic issue. It's MA remains at the boundary of the ventilation shaft, as shown in the figure 2. At this time, the following vehicle needs to maintain safe distance to avoid entering the ventilation shaft section. It means that the target distance from the ventilation shaft zone entrance position needs to be greater than the braking distance of the following vehicle. If the distance between the continuous vehicles is not enough, the following vehicle cannot operate with the normal ATO curve and needs to "kowtow", braking to ensure safety. This also indicates that a long distance needs to be left between the following train and the boundary of the ventilation shaft to ensure that the tracking train can operate with the normal ATO curve, and there is also sufficient safety distance for the following train.
At time T3, the rear of the front train leaves the ventilation shaft section, while the tracking train just reached the 0 position with distance of braking curve. At this time, the suddenly updated tracking train movement authorization extends to the exit location of the ventilation shaft. the headway value T can be expressed as $T = T_3 - T_1$.
In fact, in order to ensure the train operation safety, the tracking train's MA is only updated after the front train leaves the ventilation shaft section for certain distance. This can reserve more braking distance for the tracking train and ensure that the train has sufficient safety distance when driving near the ventilation shaft.
At time T4, the MA for the following train will suddenly extend to the exit location of the ventilation shaft. In this model, the tracking interval between the front vehicle and the following train is longer, therefore the tracking headway time is also longer. The headway T can be expressed as $T = T_4 - T_1$.

3.2 MA extended model

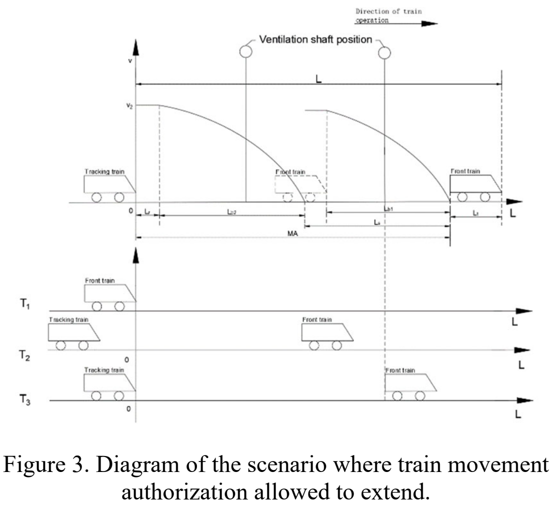

Figure 3. Diagram of the scenario where train movement authorization allowed to extend.

At T1 time, the front train had reached location 0.
At T2 time after T1, the positions of the front and following vehicles are shown in the Figure 3. At this movement, the entire front vehicle is within the ventilation shaft zone, while the MA for the following vehicle has been allowed to extend.
In this situation, as the following vehicle has received the updated MA, it can continue to move forward according

to the normal ATO curve. However, it should be noted that due to the limited movement speed of the front vehicle within the ventilation shaft zone, it is necessary to maintain sufficient safety distance when the following vehicle passes through the ventilation shaft section to ensure safety.
At T3 time, due to the rear of the front train leaving the ventilation shaft boundary, the movement authorization of the following train can be updated and extended normally. So the following train can continue to drive without "kowtow". Therefore, the headway time T can be expressed as $T = T_3 - T_1$.

4. Case study

According to the above principles, this article has developed a ventilation shaft layout optimization tool based on ATO operation curve. The simulation software system structure is shown in Figure 4.

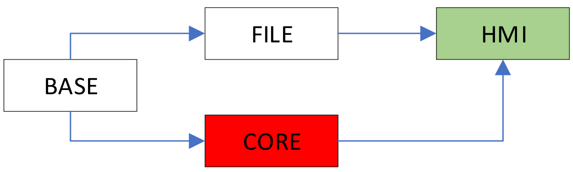

Figure 4. Simulation System Module Structure Diagram.

The simulation system mainly consists of 4 functional modules: HMI, FILE, CORE, and BASE.
The HMI module is mainly a human-computer interaction interface, where users select and input relevant line data to prepare for simulation. The main HMI is shown in Figure 5. The FILE module mainly reads the basic data files of simulated routes, including grade, speed limit, kilometer markers, and other data. The CORE module is the core of the entire simulation system, mainly implementing various algorithms, including calculation of ATO curves, calculation of train tracking headway, and other algorithm functions.

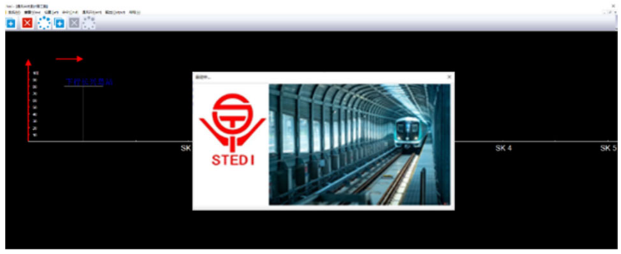

Figure 5. Simulation System Main Interface.

Taking Changxingdao Station - Chenjiazhen Station as an example, It's about 13 kilometers long in Shanghai Rail Transit Chongming Line.

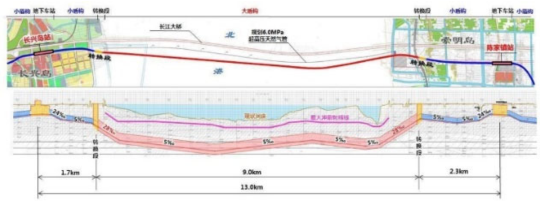

Figure 6. Zone between Changxingdao Station and Chenjiazhen Station.

Taking the simulation tool for the section from Changxing Island to Chenjia Town as an example, the simulation results obtained are shown in Figure 7.

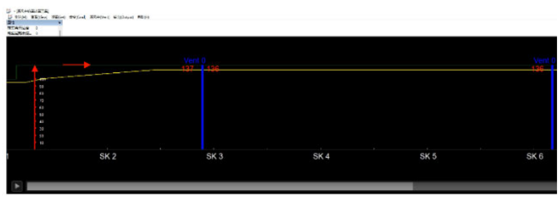

Figure 7. Example of simulation curve.

The headway time for each ventilation shaft is shown in Table 1 under the two control mode of using mobile authorization to cross the ventilation shaft and strictly limiting the control mode at the boundary of the ventilation shaft when 3 ventilation shafts are arranged in this section.

Table 1. Simulation Results.

Ventilation shaft name	MA Extended Model		MA non extension model		Percentage reduction	
	Headway on the left side(s)	Headway on the right side(s)	Headway on the left side(s)	Headway on the right side(s)	Headway on the left side(s)	Headway on the right side(s)
Vent0101	137	136	109	111	26%	23%
Vent0102	136	138	111	108	23%	28%
Vent0103	138	135	112	112	28%	21%

It was found that the average headway of trains in the section was saved by 25%, using the control mode of MA allowing passage through ventilation shafts, through the analysis of simulation results. This control mode improves the tracking ability of trains in the long tunnel section.

5. Conclusion

Headway is an important indicator for the Metro capacity. In order to meet the 150 seconds's capacity required by the Shanghai Chongming Line, this article analyzes and develops a simulation tool for optimizing the location of ventilation shafts in long tunnel sections. It also develops different train tracking control model algorithms in ventilation shaft section. Through the simulation tool system, it is possible to quantify the tracking headway time in different ventilation shaft section tracking control models. It demonstrates that the control mode that allows MA to cross the ventilation shaft section is more efficient. However, the control mode of prohibiting MA crossing the ventilation shaft section is safer and more reliable at fault scenarios.
At the same time, the simulation tool for optimizing the location of ventilation shafts in long tunnel sections designed and developed can serve as a reference and basis for metro related designers to determine the location of ventilation shafts.

Acknowledgments

This work was financially supported by Shanghai Tunnel Engineering Rail Transit Design and Research Institute Research Plan.

References

1. Zheng Xiang, Xu Sifan, Jiang Zhibin, et al . Calculation method of tracking interval of urban express train based on CBTC[J]. Shanghai Construction Technology, 2022, No. 250(02) : 21-24.
2. Li Qianshe. Research on signal train control system for regional railways [J] . Engineering technology of railway communication signal, 2020,17(02) : 10-15.
3. Zhang Youbing, Liu Ling, et al . Research on signal train control system for regional railways [J] . Journal of Railway Engineering, 2022,39(03) : 94-100.
4. Zeng Xiaoqing. Study on train headway and protection of ATP subsystem [J] . Technology in railway operations, 2021,27(02) : 24-25.
5. Zhang Hai, Ni Shaoquan, Chen Tao, et al . Study on tracking operation model and tracking interval of rail transit trains [J] . Computer simulation, 2022,39(09) : 172-176 + 402.
6. Zhu Zhongyi, Peng Qiyuan, Lu Gongyuan, et al . Simulation and comparative analysis of train tracking interval under different automatic blocking modes [J] . Research in railway economics, 2020, No. 158(06) : 27-33.