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Analysis of train braking accuracy and safe protection distance in automatic train protection (ATP) systems

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Abstract

Train braking accuracy and safe protection distance are the two main technical indexes in the system design of an automatic train protection system. They are closely related to safety and efficiency of train operation. When a train is actuated automatically to be braked by automatic train protection (ATP) system, no matter it is service braking or emergency braking, a proper safe protection distance must be considered because of limited braking accuracy. If the safe protection distance is too long, it will reduce train operation efficiency and disturb normal train operation controlled by drivers. If it is too short, train operation can not be ensured to be safe. Optimal safety protection distance is one of the main tasks during the system design of an ATP system. Safe protection distance is determined by braking accuracy, while braking accuracy is affected by many factors, such as initial speed of braking train, the control way, braking system dispersion, the reaction time of ATP systems, the influence on wheel-rail adhesion under different whether and so on. As long as the above factors are analyzed, the safe protection distance can be determined correctly to make ATP systems ensure train operation safety and raise train operation efficiency. Meanwhile normal train operation is not disturbed. The paper describes the analysis of train braking accuracy and safety protection distance during the development of the ATP system for Chinese Railways.

1 Introduction

Safe protection distance has been always the important issue in the design of an automatic train protection (ATP) system. It is affected by train braking accuracy which are determined by many factors, such as the control way of an ATP system, train braking system accuracy, the reaction time of an ATP system and so on. In terms of mathematics, it is a multi-variate function.

The design for safe protection distance is closely related to safety and efficiency of train operation. If the safe protection distance is too short, a train could overran a closed signal or a following train could conflict with the front train. As a result, train operation safety can not be ensured. If it is too long, train operation efficiency will be affected since the distance between the two following trains must be long. At the same time, the ATP system could disturb the normal operation of train controlled by driver if safe protection distance is too long.

The optimal design for safe protection distance become a key issue in the design of an ATP system development. In fact, it is a matter of system design. No matter it is high speed train or ordinary train, no matter service braking or emergency braking is applied in the ATP system, no matter it is TVM430 system in France or LZB system in Germany or in Spain, the design for safe protection distance of the system is an inevitable issue. It is a pity that a paper describing the issue has not been read up to now.

During the development of an ATP system for Chinese Railways, all of factors affecting train braking accuracy are analyzed, and the optimal design for safe protection distance was carried out so that safety and efficiency of train operation are ensured at the same time, and normal operation of train controlled by driver is not disturbed. It is considered that the above analysis and design are common for all kinds of ATP system design.

2 Definition

As shown in the figure 1, the distance S_0 is defined as the safeprotection distance of an ATP system. Train A and Train B are the two following trains in the same direction on the same track. If the train A stops at the position shown in the figure, the train B must stop before the point T. When the braking curve C for train B is calculated in real-time way by the an on-board computer, the point T_0 is used as the calculated stopping point of the train B instead of the point T. The distance S_0 between T and T_0 is the safe protection distance [1] of the ATP system.

If T_0 is the calculated stopping point of the train B and the curve C is the braking curve for train B, the train B should stop theoretically at the point T_0. However, in fact, it is not possible for the train B to stop exactly at the point T_0 due to various kinds of the complicated reasons. The real braking curve for the train B could be C' or C'', and the real train stopping point

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could be T_0' or T_0''. ΔS_1 is called as the positive error and ΔS_2 is called as the negative error. The importance of the safe protection distance of an ATP system is indicated clearly. The train B could run into the train A if there is no such a safe protection distance and the negative error occurs when train is braked by the ATP system.

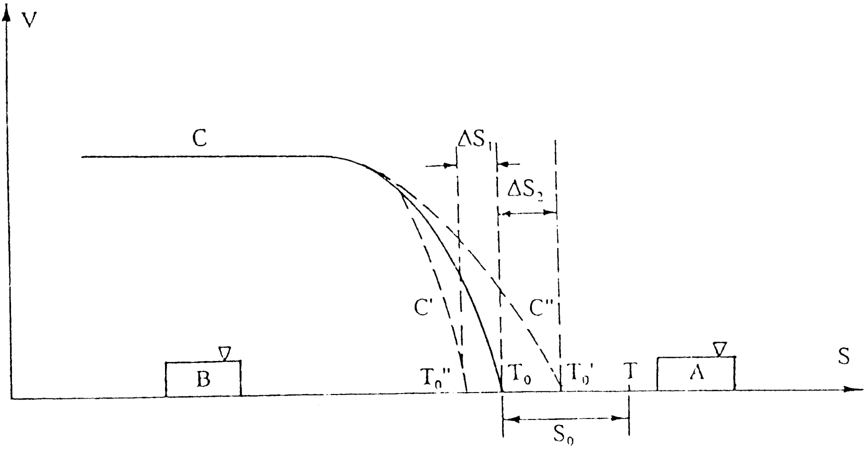

Figure 1

When the safe protection distance is determined, the following equation must be satisfied:

$$\text{Max}\ \{\ |\ \Delta S_i\ |\ \} \ \leq \ S_0 \qquad (1)$$

It is to say that the safe protection distance must be larger than the absolute value of the maximum errors which could happen at any situation when train is braked by an ATP system. If the safe protection is too short, it could cause the following trains to collide; If it is too long, the distance between trains could be very long to affect train operation efficiency, in particular, the positive error is relatively big when a train is braked.

By computer simulation and analysis, it can be found what the maximum error value is when trains are braked at the worst conditions. As a result, the safe protection distance of the ATP system can be determined.

It should be pointed out that the concept of safe protection distance here is different with the overlap protection section in the TVM300 system in France. The overlap protection section is required by the control mode in the TVM 300 system. For the TVM430 system, in theory, the overlap protection section is not necessary. It is enough for the safe protection distance is considered in the system. Because there are different control modes to be applied in the TVM300 system and the TVM430 system [3].

The former uses the steps control mode, and the latter uses the distance-to-go mode. In both of the systems, TVM300 and TVM430, the issue of the safe protection distance still exists.

3 Factor analysis

According to the definition of the safe protection distance of an ATP system, it is obvious that the safe protection distance is determined by train braking accuracy. There are many factors which affect train braking accuracy. All of the factors must be analyzed carefully in order to find an optimal safe protection distance of the ATP system.

The factors affecting train braking accuracy can be classified as the two types: uncertain factors and certain factors. Weather influence on braking accuracy belongs to the uncertain factor. Because there is different adhere degree between wheel and rail for different weather. There are also other uncertain factors which are caused by random events, such as braking coefficient dispersion of rolling stock. For these uncertain factors, artificial intelligent software must be designed for the ATP systems to raise braking accuracy. They are not considered during the design of the safe protection distance. The certain factors can be analyzed as follows.

(1) The accuracy of speed and distance measurement. Generally speaking, in an ATP system, there is a subsystem which is called as speed and distance measurement part. Real speed and target distance are the two main parameters which are used by ATP system to calculate braking curve.

Therefore, the accuracy of speed and distance measurement subsystem is one of the key factors to affect train braking accuracy. It is required that the accuracy of speed and distance measurement must satisfy the stipulated index. Normally, according to the real speed measured by odometer, by wheel diameter conversion, the distance a train covers can be obtained. Due to wheel detrition, idling and sliding, the distance conversion error always exists when the target distance is calculated [2].

When the safe protection distance is determined, it must be larger than the maximum error of distance measurement at least.

(2) Initial speed. Field test and computer simulation have shown that there is different safe protection distance with different speed. Safe protection distance D_s' should be the function of initial braking speed. It can be expressed as follows

$$D_s' = f(V_0) = C + a V_0 \qquad (2)$$

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among the above formula, C is a constant of safe protection distance. In Chinese railways, the constant is 50 meters. a is a conversion coefficient. Normally, it is 0.4 to 0.6. By computer simulation, the optimal value for a can be found.

(3) Reaction time of the ATP system. When the train operation information changes, the ATP system needs time to confirm the change, which is called as reaction time of the ATP system and affects train braking accuracy. The influence can be considered in calculation of braking curve. However, it is not a constant due to the interference from information transmission channel. In the design of the safe protection distance of the ATP system, the factor should be considered.

(4) Distance position correction. Safe protection distance of an ATP system also relates to distance position correction. There are some of distance position correction point to be installed along the line so that the accumulation error of distance measurement can be eliminated. The insolation points of track circuits, beacons and the cross-points of loops in rails can be used as the correction points.

(5) Braking coefficient error. It is different with braking dispersion of rolling stock. For the braking system of locomotives or wagons, it indicates the permissive error of the braking systems at the normal conditions.

In addition the above factors, there are also other factors affecting train braking accuracy, such as calculation error of braking curve and mathematic mode error etc. Although the influence of these factors is very smaller than one of the above factors, a certain redundance must be considered when the safe protection distance of an ATP system is decided.

4 Design principle of safe protection distance

In general, design principle of safe protection distance of an ATP system can be described as

(1) to ensure the safety of train operation;

(2) to raise the efficiency of train;

(3) not to disturb the normal train operation controlled by drivers.

It is obvious that train operation safety is put in the first place. On the condition of the safety, train operation efficiency must be ensured. Finally, a train could be stopped by the ATP system far from the train stopping point if the safe protection distance is too long. It is not allowed yet that the normal train operation controlled by drivers is disturbed.

During the development of the ATP system for Chinese Railways [5], the following formula is used to design the safe protection distance of the ATP system [4]:

$$D_s = \beta\,(c + a \cdot V_{max} + \sum_{j=1}^{n} \Delta S_i) \qquad (3)$$

Among the expression, β is a redundance coefficient, the range of β is about 1.1 to 1.4 which reflects the unforeseen and uncontrollable factors affecting train braking accuracy. c has the same meaning with the c in the formula (2). V_{max} is the highest permissive train speed. ΔSi is the distance error caused by the certain factors, such as speed and distance measurement, braking coefficient error, etc. In one word, the distance error caused by the factors can be calculated.

The safe protection distance obtained by using the above formula is generally conservative. It can ensure train operation safety, but have the influence on train operation efficiency and could disturb the normal train operation controlled by drivers. For example, in Chinese Railways, when a longer train stops at station where the length of the main tracks is relatively short, the tail of the train could have not cleared the switch areas after the train stops. It will affect the carrying capacity at station.

The formula (3) is still an experience expression. In particular, the optimal values for the parameters β and a have not been found. The further computer simulation and field tests of an ATP system are required to obtain the optimal values. Therefore, the formula (3) can only give the reference safety protection distance of an ATP system. By computer simulation and field test of the ATP system, the proper and optimal safety protection distance can be obtained.

In the above analysis, safe protection distance of an ATP system is a fixed value. However, it could more reasonable if safe protection distance is a variable. The formula (4) is used for the design of safe protection distance of an ATP system:

$$D_s(t) = \beta\,(c + a \cdot V_0(t) + \sum_{j=1}^{n} \Delta S_i) \qquad (4)$$

Among the formula (4), $V_0(t)$ is the initial speed when a train is braked by the ATP system, and the other parameters have the same meanings in the formula (3).

Safe protection distance is a function of the initial speed of the train when it is braked at the time t. If safe protection distance is a variable, the complication of the calculation will increase. In this way, train operation efficiency is raised. In the calculation of safe protection distance, there is no need to consider the balance between high speed trains and ordinary trains[6]. In fact, safe protection distance of an ATP system becomes safe protection distance of a train.

To conclude, the design of safe protection distance is a matter of a complicated system design. The design for any ATP system or any train can not avoid the issue.

5 Conclusion

The safe protection distance of the ATP system is a matter of the system design. It relates closely to safety and efficiency of train operation. The safe protection distance is mainly determined by train braking accuracy. As long as the factors affecting train braking accuracy are analyzed thoroughly, the safe protection distance can be determined and optimized to ensure train operation safety and raise train operation efficiency. In fact, the further research on safe protection distance of an ATP system or a train have to be done in the future.

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