Absolute braking and relative distance braking - train operation control modes in moving block systems

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Abstract

With development of modern telecommunication, computer and control techniques, train operation control system, particularly for high speed trains, will be transited from Fixed Block Systems (FBS) to Moving Block Systems (MBS). MBS is an intelligent, comprehensive and modern train operation control system and its development reflects the trend of train operation control and management system in the future. There are two train operation control modes in MBS: Absolute Distance Braking Mode(ADBM) and Relative Distance Braking Mode (RDBM). The two different control modes are with the different efficiency and the different risk. At present, the concepts for RDBM has been widely applied in the control systems for road traffic. However, it is the first time that the idea is tried to be implemented in train control systems. The definitions for ADBM and RDBM and their relevant concepts are given and explained firstly in the paper. The mathematics model for " Car Following Theory (CFT)" is applied to describe the performance of MBS for ADBM and RDBM with different conditions. A " Train Following Theory " is put forward and it is one of the key mathematical theories to be established for MBS before RDBM is implemented. Under the conditions of train operation safety, the two strategies are compared in terms of train operation efficiency. The factors to affect safety and efficiency of train operation for RDBM in MBS are analyzed.

1 Introduction

Moving Block System (MBS) is an intelligent, comprehensive and modern train operation control and management system based on modern, digital and mobile telecommunication, computer and control techniques. The development of MBS reflects the trend of train operation control and management system in the future. In MBS, there should be two kinds of train operation control modes: Absolute Distance Braking Mode (ADBM) and Relative Distance Braking Mode (RDBM). Compared with ADBM, RDBM is with high efficiency and risk.

At present, the concept of RDBM has been already accepted by car control [5] in the road traffic control system. Due to the complexity of train operation control, it has not been implemented in train control system. However, with development of modern techniques, such as mobile telecommunication, computer control etc., MBS provides with the possibility of RDBM implementation for train operation control. Moreover, the great potential of RDBM in capacity increase encourages people to consider the new mode implementation although there exists psychology obstacle for the people with traditional railway control concepts in terms of risk. The definitions of ADBM and RDBM are given firstly. Based on the analysis of the factors to affect RDBM in MBS, the mathematics mode of train following theory is tried to be established. Finally, the confidence should be built that RDBM is a safe and more efficient train operation mode in MBS, which is one of the new train operation modes that should be accepted by modern railways.

2 Definition of Absolute Distance Braking Mode

In MBS, a railway line is no longer divided into block sections. The distance between two operation trains is not fixed. Shown in the figure 1, train A and train B are the two following trains in the same direction on the same line. When the train B run at the position at the speed V_B, the control speed curve V_A for the train A is decided by the position of the train B. The speed control curve V_A is calculated for the train A according to many factors such as position of the train B, speed of the train B and its braking capacity, gradients and radius of the line between the two trains, position of the train A, speed of the train A and its braking capacity etc..

For the front train B, if its position is only considered during the

calculation of the speed control curve for the rear train A ,and its speed and its braking capacity are neglected, the control mode is called as Absolute Distance Braking Mode (ADBM) in MBS. This is the definition of ADBM. In the figure 1, P_0 is the tail position of the front train B and the train B run at the speed V_B. When the speed control curve V_A for the rear train A is calculated, the speed of the train B is considered to be zero and stop there.
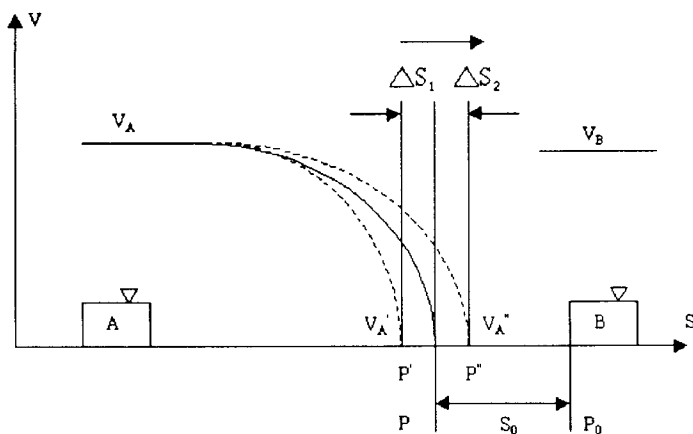

Figure 1

In addition, in the figure 1, the point P is the calculated stopping point for the train A. The distance S_0 between P and P_0 is the safe protection distance and ΔS_i is braking error. Since the factors to affect braking process are complicated, the actual braking curve is the curve V_A' or V_A'' and not V_A. But max $| \Delta S_i |$ must be less than S_0. Safe protection distance must be considered when the calculated stopping point is decided since braking error exists [1][7].

3 Definition of Relative Distance Braking Mode

In fact, in the most circumstance, when the speed control speed for the rear train is calculated, the front train is in motion. In other words, the speed, position and braking capacity of the front train should be considered when the speed control curve for a rear train is calculated. The following distance between the two following trains can be shorter and increase train

operation efficiency. This is the main idea of Relative Distance Braking Mode (RDBM). It is obvious that ADBM is a special case of RDBM, i.e. the speed of a front train is zero.
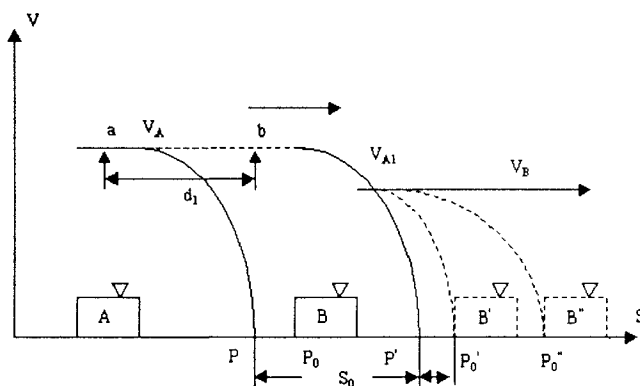

Figure 2

The definition of RDBM in MBS is described that when the speed control curve for a rear train is calculated the stopping point of the rear train is the point where a front train stops after an emergency braking is actuated at the its current speed. As shown in the figure 2, when V_A is calculated, the stopping point is P for ADBM, and the stopping point is P' for RDBM. The train B runs at the speed V_B at the point P_0. When an emergency braking is actuated for train B, it stops at the point P_0'. When a service braking is actuated for train B, it stops at the point P_0''. The distance between P' and P_0' is the sum of safe protection distance and fluctuation protection distance. Safe protection distance is the same as that in ADBM and caused by braking error. Fluctuation protection distance is considered in order to avoid the situation that the speed of a following train changes with normal speed fluctuation of its front train. After the distance tolerance is considered, a following train can run smoothly and not be affected when the speed of its front train changes in normal range.

Compared with ADBM, RDBM makes the following distance between two following trains be shorter. In the figure 2, the distance S_0 is the shortened distance between train A and B. For the train A, the start point of braking changes from a to b. The distance d_1 equals to S_0. The higher the speed of train B is, the longer the distance d_1. For a high speed passenger railway line or light rail line where MBS is equipped with, RDBM can increase line capacity very much [8].

To make the comparison for ADBM and RDBM be easier, the figure 1 and the figure 2 are combined to give the figure 3. The distance S_0 in the figure 2 is the sum of S_1 and S in the figure 3. It is seen from the figure 3 that train braking process is very complicated. RDBM is still a conservative strategy for train braking. In the most cases, a front train runs at the speed V_B and does not be actuated by service or emergency braking.
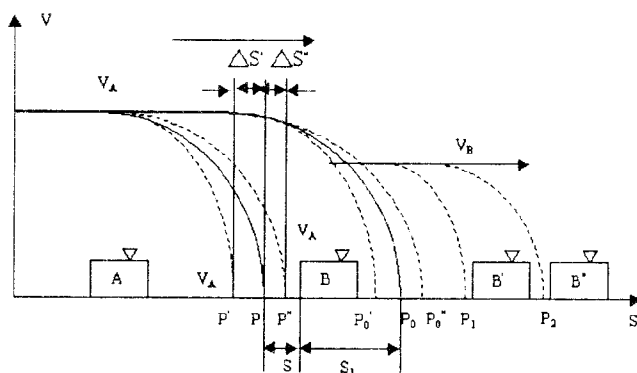

Figure 3

4 Factors to Affect Relative Distance Braking Mode

It can be seen from the above definition of RDBM that implementation of RDBM in MBS is based on some of conditions. Reliable moving telecommunication between following trains is one of the conditions. In MBS, a moving train must communicate continuously with trains in its front and its rear, the two adjacent stations of the block where it runs. For each train, it must know its own speed and position, speed and position of its front train at any time. In the light of braking capacity of each train, train parameters and line parameters, a speed control curve is continuously calculated in real time way. The distance between the two following trains changes with many factors. It is a multi-variable function [2]. It can be expressed in the follow formula:

$$D (t) = F (P_1, P_2, V_1, V_2, d_1, d_2, \gamma_1, \gamma_2, \Psi, \eta) \tag{1}$$

Among the formula (1), D (t) is the distance between the two

following trains at the time t. P_1 and P_2 are respectively the positions of the two following trains. V_1 and V_2 are the current speeds of the two following trains. d_1 is the safe protection distance. d_2 is the fluctuation protection distance. γ_1 and γ_2 are respectively braking capacity of the two following trains. Ψ is the parameters of the line where the two trains run, such as gradient and curve. η is some of non-anticipant factors such as whether condition (wind, rain and snow), earthquake forecast, flood and temporary speed restriction due to line construction and maintenance.
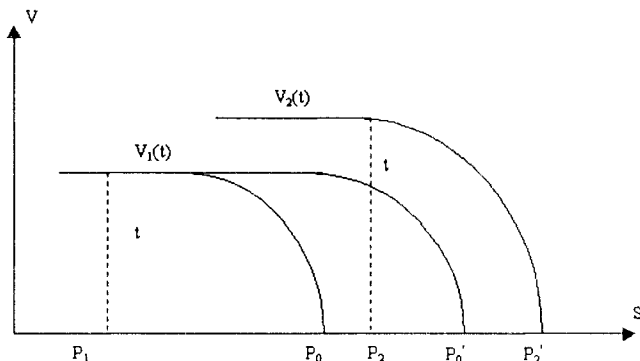

Figure 4

When a front train runs at the time t at the position P_2 at the speed V_2, it is assumed that the train is actuated by emergency braking at the point P_2 and it is known that the distance D_s the train covered in the light of its braking capacity γ_2, line parameters etc. it stops at the position P_2' Then, a speed control curve for a following train at the time t at the position P_1 with the speed V_1 is calculated according to its own braking capacity γ_1 and line parameters etc. Shown in the figure 4, all the positions P are considered as the tail of a train.

$$V_1(t) = \frac{\delta \cdot V_2(t) \cdot \gamma_1}{\gamma_2} \tag{2}$$

The relation between the speed of a following train at the time t and the speed of its front train, braking capacity of the two trains can be expressed as the formula (2):

The speed V_1 (t) of the rear train is proportional to the speed V_2 (t)

of its rear train and its own baking capacity γ_1. It is inversely proportional to the braking capacity γ_2 of its front train. β is a constant which changes with kinds of trains such as passenger train, freight train, high speed train and ordinary train etc. That means when the speed of a front train increases, the speed of a rear train can be raised and vice versa. This is called as " following feature" of RDBM in MBS. For a train, if its braking capacity is big, its speed can be relatively high; if its braking capacity is small, its speed can not be high. For a following train, if braking capacity of its front train is big, its braking distance is short. It means that the braking distance for its following train be short and its speed should be lower. The formula (2) can reflect the relation between the two following trains.

The higher the speed of a train is, the longer its necessary braking distance. The shorter the following distance between the two following trains is, the greater the line capacity. In terms of train operation efficiency, the shorter the following distance between the two following trains is, the better. However, no matter how high line capacity is persuaded, an safe braking distance must be ensured to make a train stop in front of its calculated stopping point. It is an absolute condition for any of train control strategies. This is one of the key technical principles of RDBM in MBS. After the above factors are fully considered, the principle can be satisfied [4].

It can be seen from the above description that reliable communication between the two following trains can not be interrupted during train operation. A following train must know at any time the speed, position and braking capacity of its front train to calculated its own control speed curve. Once the communication is interrupted, the following train must be actuated by emergency braking to ensure train operation safety.

5 Mathematics Mode ------ Train Following Theory

It is known that " Car Following Theory "[5] has been put forward for road traffic control system for many years where the dynamics is applied to describe a following car running state at the one direction lane where taking over can not happen. In MBS, a following train operation state is similar to the above situation. A train following theory is put forward in this paper to describe RDBM in MBS.

The figure 5 gives the three trains (T_1, T_2 and T_3) running at the same direction on the line. At the time t, $V_1 > V_2 > V_3$. $V_1 (t)$, $V_2 (t)$ and

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V_3 (t) are respectively the speed control curves for T_1, T_2 and T_3 calculated according to RDBM strategy. The train stream is analyzed and three features must be pointed out.

(1) Interaction. A following train will follow its front train and make the interval to be as short as possible. However, there are two conditions which must be satisfied in terms of safety. It is not possible for the speed of the following is higher than the speed of its front train for a long time, finally it is equal to or less than the speed of its front train. The enough safe braking distance must be considered. In other words, speed of the front train restricts speed of its rear train, i.e. speed of T_1 restricts speed of T_2, and speed of T_2 restricts speed of T_3.
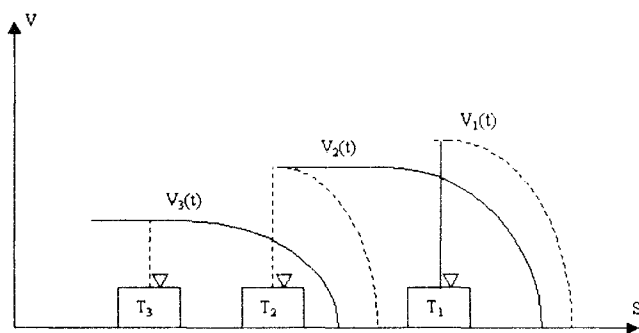

Figure 5

(2) Delay. According to interaction of the following trains, when the state of a front train changes, its rear train state will change. However, the changes for the two trains do not happen at the same time. Due to the information transmission delay, its confirmation and action, the state change for a following train will later than the state change of it front train. The delay time T can be called as the reaction time. It relates with determination of fluctuation protection distance.

(3) Transmission. It can be seen that from Interaction the first train affects the second train and the second train affects the third train, i.e. the nth train affects (n + 1)th train. This is the transmission. Due to delay, the transmission of information is not smooth. It is discontinuity like pulse. The fluctuation protection distance is considered to make the transmission to be as smooth as possible.

In the figure 6, T_n is the front train and T_{n+1} is the following train. S (t) is the interval between the two trains at the time t. x_n (t) and x_{n+1} (t)

are respectively the position of train n and Train n +1 at the time t. $x_n'(t)$ and $x_{n+1}'(t)$ are the speed of train n and train n + 1 at the time t. d_1 is the distance T_{n+1} runs during the reaction time T after T_n begins to be braked. d_2 is the braking distance for T_{n+1} and d_3 is the braking distance for T_n. D is the distance between the two train heads after they stop
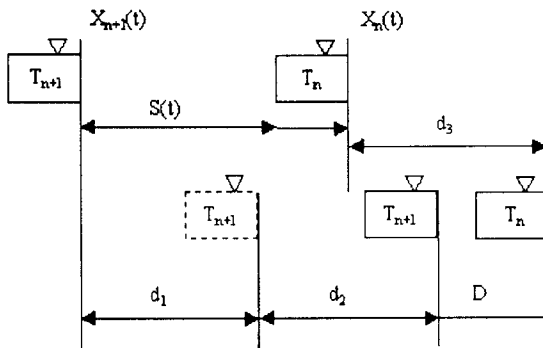

Figure 6

In the light of the above description, the following formulas are:

$$S(t) = x_n(t) - x_{n+1}(t) \qquad (3)$$

$$d_1 = T x_{n+1}'(t) = T x_{n+1}'(T + t) \qquad (4)$$

It is assumed that $d_2 = d_3$, then,

$$S(t) = d_1 + D = T x_{n+1}'(t + T) + D \qquad (5)$$

The above equation is differentiated to t

$$x_n'(t) - x_{n+1}'(t) = T x_{n+1}''(t + T) \qquad (6)$$

$$x_{n+1}''(t + T) = 1/T [x_n'(t) - x_{n+1}'(t)] \qquad (7)$$

In the above formula, $x_{n+1}''(t + T)$ is the acceleration of the rear train T_{n+1}. $1/T$ is called as the sensitivity. The formula (7) is induced under the special conditions that the speed of the rear train does not change during the time T and the braking distances of the two trains are equal etc.

The real situation is much more complicated than the above assumption. Therefore, the formula (7) can be changed as follow to reflect the more general cases:

$$x_{n+1}''(t+T) = \alpha [x_n'(t) - x_{n+1}'(t)] \qquad (8)$$

In the formula (8), α is called as reaction coefficient. The formula (8) is called as a linear train following mode [6].

6 Conclusion

In MBS, the possibility of RDBM implementation has existed. Compared with ADBM, RDBM can greatly increase train operation efficiency under the condition of train operation safety. At the same time, it makes the dispatching of train operation in the mixed traffic line to be more flexible. Based on reliable moving telecommunication between the two moving trains, RDBM can be applied in railway control system after the accurate mathematics mode is established. As matter of fact, there is no safety problem for the new control strategy. It can been seen that there is enough consideration and tolerance in this aspect, such as safe protection distance, fluctuation protection distance, emergency braking for the front train and service braking for the rear train etc. The Train Following Theory is put forward and its analysis is very initial. Research on mathematics mode establishment must be carried out further before RDBM implementation in MBS for railways. With confidence, it can be predicted that RDBM can be accepted and implemented by railway in MBS in the near future although it is still controversial topic at present.

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