Invited Paper

A new train overspeed protection system based on multi-microprocessors and distributed configuration

X. Wang, B. Ning, T. Tang & Y. Liu

Northern Jiaotong University, Beijing, 100044, P.R. China

Abstract

Adoption of multi-microprocessors and distributed configuration in train overspeed protection system can increase system flexibility to be suitable for the requirements from varieties of transport modes. In order to ensure the system reliability, fault-tolerant techniques in hardware and software must be applied in the system. Communication among the microprocessors, namely, mutual communication between the subsystems, reliable and standardized models are used, and redundant method is adopted in the communication network which is the key issue to the reliability of the whole system. In the paper, the multi-microprocessors configuration is discussed in details. The configuration of the system has been applied in a new train overspeed protection system which is being developed for Chinese Railways. It has proved that the configuration is reliable, flexible and easy for system functions to be extended. In addition, it is universal.

1 Introduction

Automatic train control (ATC) system and automatic train operation (ATO) system have been adopted in control systems for high speed railway, subway and light rails in many countries in the world. It plays an important role in ensuring train operation safety and increasing transportation efficiency. However, at present, these advanced systems can not be applied in railway network with conventional speed owing to some reasons such as passenger and freight trains mixed transportation mode, complicated station configuration, frequent shunting operation at stations and great dispersivity in braking performance and concerned parameters for locomotives and wagons. Therefore, automatic block system and automatic train protection
(ATP) system are depended to ensure train operation safety and capacity.

Application and dissemination of automatic block system has been more than eighty years. Although it has been giving full play to the role of raising railway capacity and ensuring train operation safety, there are still trains collision accidents occurring. This shows that automatic block system is not a perfect closed-loop system. There exist a man-machine interface in the system. Reliability and safe performance of the system depend on reliable operation of train drivers. According to the statistics [1], driver’s reliability expression is \( R_H = R_e \cdot R_n = 0.9909 \div 0.9998 \). That is the reason why ATP, ATC and ATO system are developed. At present, there still exists the difficulties for ATC and ATO system to applied in railway networks. Therefore, the combination application of automatic block system and ATP system become more important in terms of increasing capacity and guaranteeing safety of train operation.

In many countries in the world, there are many kinds of ATP systems which have been developed for many years. The multi-microprocessor based and distributed configuration ATP system described here is developed by modern microelectronic techniques for the Chinese Railway Networks according to the features of special railway transport mode in China.

2. Main functions analysis of multi-microprocessor based and distributed configuration ATP system

In the Chinese Railway Networks, there exist various of automatic block systems which by track circuits sends information about train operation speeds to cab signaling to instruct train drivers’ operation. The ATP system could make use of continuous information transmitted in rails. The fundamental functions of the ATP system are described as follows.

(1) When a train is over its permissive speed, the ATP system should issue firstly an alarming signal to driver to require him to take the corresponding action. If train driver does not take action to slow down train speed in the given time, the ATP system will actuate braking automatically.

(2) Train must be braked to stop before any of absolute stop signals.

In implementation of the above two functions, the common issue is train braking. At present, emergency braking is a kind of braking way which is adopted in many ATP systems in the world. It is an easy way and related hardly to other train operation parameters. Due to the probably damage to passenger and freight train caused by emergency braking, the ATP system should actuate firstly service braking when train braking is needed. Emergency braking is only used in case of emergency state.

Braking control model is required to realize train service braking. In the light of Chinese Railway Standard[2], train braking distance consists of two portions, i.e. the equivalent virtual braking distance \( S_k \) and effective braking distance \( S_e \).
where $t_k$ has the following expression for freight train under the condition of service braking:

$$ t_k = (2.8 + 0.14 \, n \, r) \left(1 - 0.1 \, i_j\right) \quad (2) $$

$n$ is the number of wagons hauled by locomotive and $r$ is the decreasing pressure value of train pipe. For passenger trains, $t_k$ is

$$ t_k = (2.8 + 3.8 \, r) \left(1 - 0.03 \, i_j\right) \quad (3) $$

Among the formula, $V_1$ and $V_2$ are the initial speed of braking and target speed respectively, $\omega_{od}$ is the unit fundamental resistance of train coasting, $\delta_h$ is the converted braking coefficient of train, $\psi_h$ is the converted friction coefficient of braking shoes and $i_j$ is the equivalent gradient.

It can be seen from the formulas (1) -- (3) that many real-time parameters are required when service braking is actuated for trains with conventional speed on railway networks. Among them, the important parameters are given as follows.

A. Train types: Passenger train or freight train. B. Number of wagons and total weight hauled by a freight train. C. Real-time speed of train. D. Line parameters such as slope, curve etc. E. Converted braking coefficient of train.

In addition, there are also signal indication in front of train operation and real-time distance to the target speed point and so on. As long as the above parameters are obtained, the ATP system could decide if a service braking is required to be actuated and how much the decreasing pressure value of train pipe should be.

Some of parameters required by train service braking can be input manually before train starts its operation by special device. While most of them are obtained by train sensors. The problems to be resolved difficulty are the parameters dispersivity. For example, for freight trains there are some wagons whose valve on braking pipe to its braking air cylinder are closed, and no one knows how many wagons for a freight train are like this. However, the parameter has great influence on theoretical calculation and actually braking of train service braking. Wear and tear of wheel, idle wheels, snake-shape operation of wheels and wheels stopping to turn owing to too great shoes stress, these factors make the data obtained from speed-distance measurement system be error. In order to have correct braking distance, the parameter must be revised by means of real-time feedback calculation.
There are two methods to realize service braking control in the ATP system. One is the table searching method, another is real-time calculation method. The first method is to carry out a great amount of calculation beforehand according to the formulas (1) -- (3), then as a database, the calculated results are stored in an on-board microprocessor. In the method, there is an important problem how to decide the parameter level value for the calculation, which includes gradient level, haul weight level of freight train, train speed level, distance level and so on. It is obvious that the smaller the level, the more accurate the control. However, the calculated results will increase non-linearly with decrease in the level, and it required a great amount of memory space. This will affect the selection of on-board microprocessor, and bring about the reliability problem of data obtained by table searching.

Real-time calculation is a better and quick method by which the corresponding software is designed by assemble language in line with formulas (1) -- (3). There is no level division problem for the method, and control accurate could be made to be optimal. In terms of reliability, real-time calculation can be carried out repetitively.

3. The analysis on multi-microprocessor based and distributed configuration for the ATP system and its advantages

![Hardware configuration block diagram of the ATP system](image-url)

(0) Central processor. (1) Cab signaling subsystem. (2) Train parameters input subsystem. (3) Speed measurement subsystem. (3') Distance measurement subsystem. (3'') Pressure measure subsystem (4) Intermittent information subsystem (5) Train operation recording subsystem (6) Indication and operation subsystem for driver (6') Audio warning subsystem (7) Automatic control subsystem for braking machine. (8) Ring communication channels with dual redundancy.

Figure 1 Hardware configuration block diagram of the ATP system
In the ATP system developed for the Chinese Railway Networks, real-time calculation control method is adopted to implemented train service braking. There are two kinds of train real-time parameters about train operation, which are static and dynamic parameters required by the ATP system. Static parameters include train types (passenger or freight train), train haul weight, train braking coefficient and so on. Dynamic parameters can be described as real-time train speed, signal indication in front of train operation, real-time distance to a target speed point in front of train operation, the pressure of train braking cylinder, line parameters where trains run.

The hardware configuration block diagram of the ATP system is shown in the figure 1. It is a multi-microprocessor distributed structure. In the figure, (1) --- (8) denote the different subsystems with their own microprocessor. The ATP system has the following advantages: (1) Easy to add functions of the ATP system. (2) Raising reliability and availability of the ATP system. (3) Easy to extend the ATP system. (4) Realization of information resource share. (5) Enhancing the real-time feature of data acquisition.

In order to implemented information resource share, communication between the central processor and each subsystem is an important link in which some of special measures are taken. (a) Ring-shape communication channel is adopted for communication between the central processor and each subsystem to ensure that communication can be performed from another direction if the channel is broken at one point. (b) Dual ring-shape communication channels are designed to guaranteed that communication can not be interrupted owing to a channel failure. (c) Standard communication protocol (HDLC / SDLC) is applied for the communication. The corresponding error-detection and error-correction code are added. (d) Communication control is performed by communication dispatching and management software in the master system.
Information resource share task of the whole system is realized in the ATP system. Each subsystem has their own operation of receiving and sending information. To avoid the conflict and competition of communication, the corresponding hardware, mailbox and its management key are designed in each subsystem except for communication management software. In other words, a dedicated microprocessor for communication control and dual-port RAM are added. The figure 2 is the communication control diagram.

There is a minimum limitation control for communication dispatching and management frequency, i.e. communication frequency which is determined by the number of subsystems, information amount, maximum speed of train operation and the comprehensive accurate of the ATP system. It can be found by segment division method.

In multi-microprocessor distributed structure, another important issue is system synchronization for which there are three choices: (1) Asynchronous. (2) Synchronization. (3) Long-distance calling type. For the ATP system, Asynchronous way is a better choice, because a great amount of high speed information need to be transmitted in the channel, and there is coherence between successively sending data. Coherence method can be used to remove error data caused by interference and other reasons to ensure system reliability.

In order to raise system reliability, dual redundant configuration is applied in the central processor and subsystems which are related to train operation safety, which are shown in the way of double circles in the figure 1.

4. Software structure of the ATP system

Software hierarchical structure of the multi-microprocessor distributed ATP system is shown in the figure 3. They can be roughly divided into the five hierarchies.

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Application software

Diagnosis software

Communication management and processing software

Data acquisition and processing software for subsystems

Dispatching and management software
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Figure 3 Software hierarchical structure of the ATP system
(1) Data acquisition and processing software is designed for each subsystem which are shown in the figure 1, such as cab signaling subsystem, speed-distance-pressure subsystem and so on.

(2) Communication management software for the whole system is used to realize the function shown in the figure 2.

(3) Dispatching and management software for the system can perform the functions to coordinate operation between the master system and subsystems and between application software and diagnosis software.

(4) Diagnosis software is designed for system fault-diagnosis, which can be classified into static diagnosis, dynamic diagnosis and power-on diagnosis to ensure the system itself to be reliable and fail-safe.

(5) System application software is used to carry out calculation of train braking curve, train speed monitoring and various parameters comparison etc.

It should be pointed out that implementation software of train service braking is the key software in system application software, which is required to calculate train service braking distance in the light of formulas (1) - (3), and the start point of service braking to be actuated should be decided by some of important data, such as real-time distance from speed-distance measurement subsystem, indication of cab signaling and line parameters provided by intermittent information subsystem, and so on. For some special block section, such as approaching section, the situation becomes more complicated, because the length of an approaching section is generally smaller than the distance required by service braking and the situation of the station must be considered. Therefore, it needs more information and it is possible for service braking to be actuated in advance.

5. Conclusion

By theoretical analysis and initial spot experiments, the multi-microprocessor distributed ATP system developed for the Chinese Railway Networks have been proved to be suitable for the Chinese railway transport mode. It can perform control of train service braking and emergency braking to ensure train operation safety and efficiency. By means of fault-tolerant design and fault-diagnosis method, the ATP system itself can be guaranteed to be reliable and fail-safe. Due to dispersivity of train parameters, in particular for freight train, calculation and control accuracy of train service braking still needs to be raised. In this aspect, there are many things to be explored.

Application of ATP system for train to run in convectional speed in the Chinese Railway Networks, together with automatic block system, is a leap in the history of train control in terms of system reliability, safety and efficiency. It eliminates man-machine interface in train control system where only automatic block system is depended. It is also to lay foundation for ATC and ATO system to applied in railway networks. In the near future, The ATC and ATO system for Chinese Railway Networks will be developed and
applied. This is the development road of train operation control in China.

6. References

(1) Cao, Q "Man-machine engineering" 1991

(2) The Railway Ministry Standard of the People’s Republic of China "Train Haul Calculation Regulation TB1407 --- 82" 1982