SAFETY CONTROL TECHNIQUES CONCERNING THE SPEED RAISING ON TRUNK LINES OF CHINESE RAILWAY

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ABSTRACT:
A new Automatic Train Protection (ATP) system, which is suitable for the speed raising on the major trunk lines of Chinese railway is analyzed in this paper. This ATP system is based on distance to go curve and applies continuous over-speed control for both passenger and freight trains. This advanced ATP system consists of three parts, namely the universal cab signal based on DSP techniques, the intermittent information system which is added on the existing track circuits of autoblock system and the ATP equipment. All these parts can interface with not only diesel locomotive, but also electric locomotive. Based on static and dynamic parameters of train and environmental conditions, the ATP system automatically calculates what kind of braking is required. This system has a very useful display screen in front of the driver. This system has been put into application on more than 300 kilometers of railway lines.

1.BACKGROUND OF RAISING TRAIN SPEED ON TRUNK LINES

Chinese railway, totaling more than 50,000 kilometers, plays a very important role in the construction of national economy. With the development of economy and science, on one hand, the railway is required to operate faster by passengers and goods owners; on the other hand, railway is now facing fierce competition from other transportation means. So, it is very urgent to raise train speed. Especially, on the five major trunk lines of Chinese railway with a total length of 10,000 kilometers, train speed should be raised, to 160-180km/h for passenger trains, and 80-100 km/h for freight trains.

To raise train speed on the trunk lines, there are many engineering works to do, such as reinforcing track bed and bridges, changing locomotive types, upgrading or reinforcing cars, replacing switches. A tremendous investment is needed to finish all these works. This paper focuses on the measures of securing traffic safety.

2 MEASURES OF SECURING TRAFFIC SAFETY ON SPEED RAISED LINES

On the five major trunk lines, several kinds of three-aspect fixed block systems have been installed, including the AC counting track circuit introduced in the earlier period, the 4-information frequency shift track circuit, the 18-information frequency shift track circuit, the polar frequency track circuit, and the UM71 track circuit introduced from France. It would be good to have all these block systems changed into a unified one, however, a tremendous investment is needed. For example, if the cost of replacing one kilometer is 500,000 Yuan RMB, the total cost of replacing 10,000 kilometers of railway will be 500,000,000 Yuan RMB. Furthermore, the long construction period will have influence on normal transportation operation. Therefore, the measures of ensuring traffic safety on speed raised lines should be implemented on the existing block systems. Based on thorough analyses, following steps are proposed:

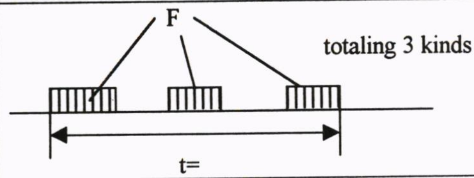
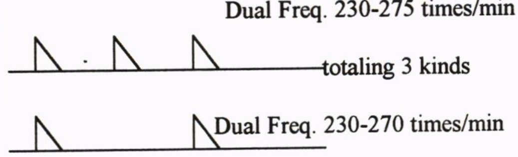
(1) To research and develop a cab signal which is suitable for all exiting block systems.
(2) To research and develop a ATP system which is suitable for both three-aspect block system and cab signal;
(3) To research and develop an auxiliary intermittent information system used by ATP system during the braking process.

All these steps are proposed according to the concrete condition of China and Chinese railway, because any imported technique without modification is not applicable. Through the effort of five years, all these three steps have been finished, and the corresponding products have been put into application after been appraised by relative authorities.

3. UNIVERAL CAB SIGNAL BASED ON DSP TECHNIQUE

The information of block system is the basic order for train operation. But it is a fact that the block systems used on the five major trunk lines are different. Table 1 lists the forms of information transmitted in the track circuit, only considering the case of displaying green light.

Table1 Different Block Systems used on Major Trunk Lines of Chinese Railway

No.	Name of the Block System	Information in the case of green light indication
1	AC counting Carrier Freq. F=25Hz F=50Hz F=75Hz	
2	Polar Frequency	
3.	4-Information Frequency	Carrier Frequency: 550, 650, 750, 850 Hz

	Shift	Modulating Frequency: 11Hz, Frequency Deviation: $\Delta f = \pm 55$Hz
4	18- Information Frequency Shift	Carrier Frequency: Same as above Modulating Frequency: 8, 8.5 Hz Frequency Deviation: $\Delta f = \pm 55$Hz
5	UM71	Carrier Frequency: 1700,2000,2300,2600Hz Frequency Deviation: $\Delta f = \pm 10$Hz 11.4,12.5,13.6Hz (the first category) 8.1,8.5,9.5 (the second category)

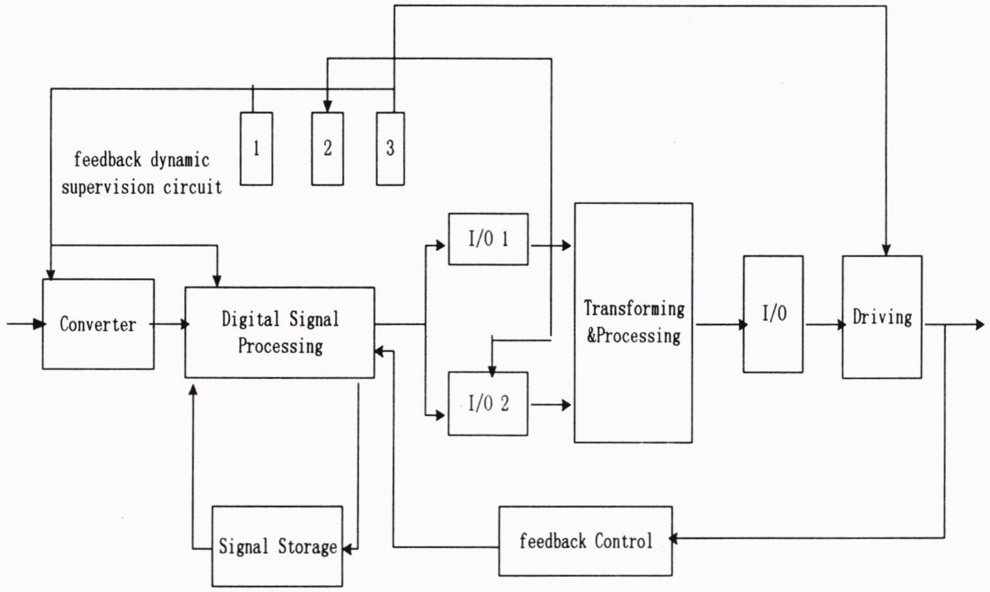


Fig. 1 Block Diagram of Digital Cab Signal Based on DSP Technique

It can be seen that, for a train to being able to operate on every trunk line, there must be a suitable cab signal, which should meet the following requirements:

(1) Universality---suitable for different kinds of existing fixed block systems;

(2) Automatic identification--- automatically identifying different kinds of track circuits correctly, without human manipulation;

(3) Fast responsivity --- automatically identifying the change of block systems, and quickly responding to give corresponding output, for the purpose of securing traffic safety;

(4) Strong anti-interference---having strong anti-interference ability for 50Hz electric traction return current flowing through the track, and the interference from neighboring track;

(5) High fail-safety—being able to lead to safety side when any failure should happen, like all other important railway signaling equipment;

(6) High availability---High availability must be guaranteed because it is used day and night. Necessary redundancy and fault-tolerance techniques should be adopted;

(7) High maintainability and easy to use.

There is no existing universal cab signal which can be adopted, because among the above requirements, the most difficult one to be met is the fast automatic identification ability, because the frequency used by different block systems varies a lot. The second difficult one to be met is the high reliability and high fail-safety. This case is similar to the unification of European railway by the EU, in which EUROCAB must be researched and developed in ETCS under the unified leadership of EU. Because it is impossible for ordinary real-time microprocessor to meet all these requirements, modern digital signal processing techniques and the corresponding processor chips should be adopted. As shown in fig.1, the multi-channel dynamic supervision is used to achieve high reliability and fail-safety. The universal cab signal named as SJ Type has been installed on more than 8000 locomotives after going through the field test and being appraised by relative authorities [1].

4. ATP SYSTEM BASED ON DISTANCE TO GO CURVE

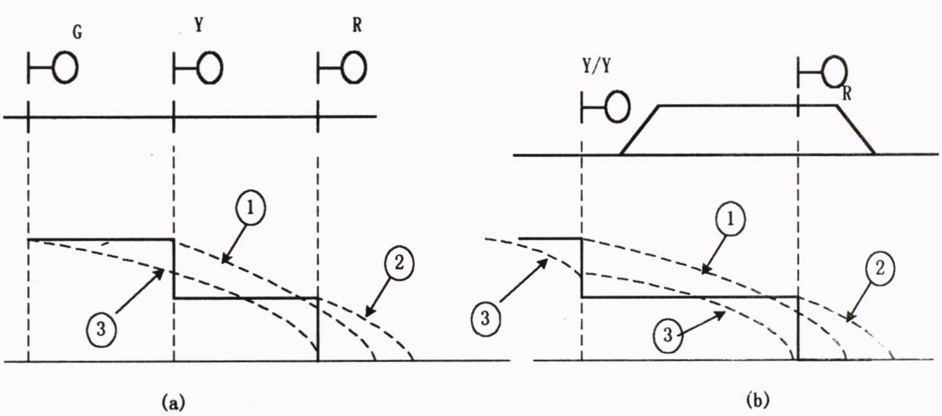


Fig. 2 Two Kinds of ATP Braking Curve

At the speed of 180 km/h, a train can travel 50m per second. Under this condition, train operation safety can't be guaranteed to totally rely on the driver to look at the wayside signal or cab signal and take corresponding braking measures. So, there must be an ATP system. Most of the ATP systems used in the railways all over the world, including high-speed railways, are based on stepped curve. So far as three-aspect block system is concerned, the braking curve based on stepped curve is shown in fig. 2(a) by a solid line. Clearly, it is impossible to apply ATP brake without changing the location of signals, otherwise, the cases indicated by the curves noted as ① and ② will happen, which mean that the train will overrun the red signal, because the service braking distance of train at 180km/h is approx.

1500-2500m depending on the gradient of line, but the length of block section in 3-aspect system is in the range of 1200-1800m. Similarly, fig. 2(b) shows the case of train entering the station and coming to stop at the side track, in which the train will also overrun the red signal if stepped curve is adopted. So, ATP braking mode based on distance to go curve should be adopted, indicated by the curve noted as ③ in fig. 2(a), (b). This mode is the goal for many countries in developing ATP system. It should also be adopted in Chinese railway for realizing ATP on speed raised lines. Fig. 3 is the hardware structure of LCF Type ATP system researched and developed.

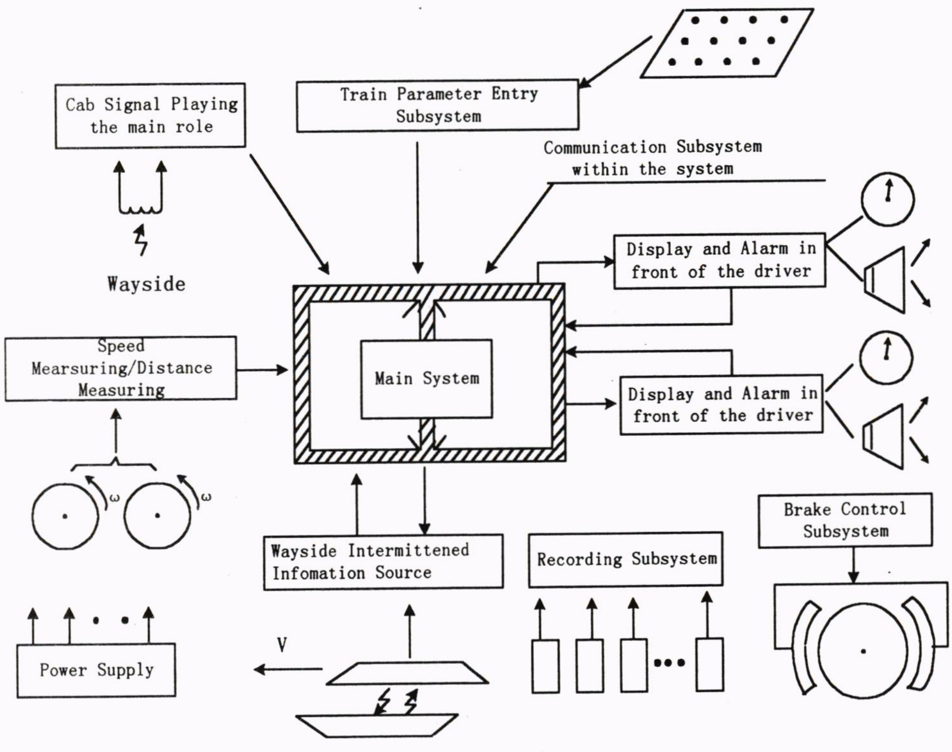


Fig. 3 Hardware Block Diagram of LCF/ATP

From the viewpoint of hardware, there are 8 subsystems in the ATP system, namely:

(1) Universal Cab Signal Subsystem, which receives the main orders of train operation from the block system.

(2) Speed/Distance Measuring Subsystem, which measures the real speed of train by means of vehicle-mounted sensors and on the basis of this the actual distance of the train must be given. Of course, any take-off distance and any kind of virtual distance must be excluded in this subsystem.

(3) Intermittent Information Subsystem, which will be described later.

(4) Recording Subsystem, which records the actual parameters of train during its operation.

The items for recording are determined by railway management organization.

(5) Brake Control Subsystem, which is the input/output equipment between the main system and the braking mechanism. This means that, by the orders from main system, it becomes the real applied force either in service brake or emergency brake.

(6) Display and Alarm subsystem. This subsystem gives the evident display in front of the driver, such as the distance of block section, real speed of train, instance braking performance and distance measurement. Meantime, this subsystem gives alarms which alert the driver at critical moment.

(7) Parameter Entry Subsystem. In this subsystem, by usage of IC card or manual operation, some static parameters, such as train weight, train length, braking efficiency of train are input into the ATP system. The driver can not only manipulate the keyboard but also check the correctness of the input parameters.

All these subsystems have their chip microprocessors. And they change the necessary data with the main ATP system, according to the protocol of HDLC.

All the subsystems are duplicated in order to increase the reliability and availability [2]. Furthermore, the circuits of each subsystem are designed according to the principle of fail-safety which is widely adopted in railway signaling techniques.

Fig.4 is the corresponding software structure.

The ATP system is based on the following mathematical model [3].

$$S_b = S_k + S_e = \frac{v_0 t_k}{3.6} + \sum \frac{4.17\left(v_1^2 - v_2^2\right)}{1000\varphi_h \theta_h + w_{0d} + i_j} \tag{1}$$

Where S_b, S_k, S_e stands for the full braking distance, the idle running distance and the effective braking distance respectively; t_k for the non-effective time after brake is applied. v_1, v_2 for the initial and final speed of the speed interval; i_j for the conversion gradient of the line; φ_h for the conversion friction coefficient; θ_h for the conversion braking rate of the train; w_{od} for the unit basic running resistance when the locomotive is working in coasting mode.

Each subsystem and the main system have their own diagnosis software, which can be divided into two parts: initial and dynamic. The initial diagnosis software is the full one, which can diagnose the whole system except the hard core part. The dynamic diagnosis software is called during the operation of the system. All the diagnosing results will be displayed in front of the driver.

LCF/ATP has proven to be a success by the experiments on 10 locomotives. Now, it has been put into wide application after been appraised by relative authorities.

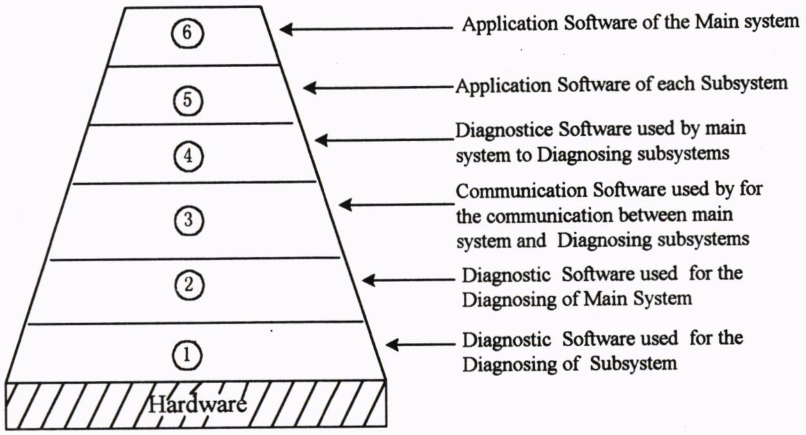


Fig. 4 Software Structure of LCF/ATP

5. THE INTERMITTENT INFORMATION SYSTEM ADDED ON EXISTING TRACK CIRCUIT

It has been pointed out in Section 4 that LCF/ATP is a train over-speed protection system based on distance to go curve. In order to supply speed-distance information, a lot of parameters should be supplied to ATP system, such as:

- The current position of the train;
- The distance from the train to the signal ahead;
- The information about the gradients and curves ahead of the train;
- The current speed of the train;
- Whether the signal ahead is a block signal in the block section or home/exit signal at the station;
- The length of the train;
- The weight of the train;
- The braking rate of the train, etc.

It can be seen that these parameters can be categorized into two types, namely the static ones and dynamic ones. As to static parameters, they can be recognized once being entered into the system through the Parameter Entry Subsystem which has been mentioned in the previous section. However, as to dynamic parameters, they can not be supplied by the existing three-aspect automatic block systems. Instead, they must be supplied by auxiliary means. In this sense, these dynamic parameters are briefly called intermittent information. Up to now, there are two methods to supply intermittent information in the world, one is to store the information in the on-board computer, the other is to use transponders.

The first method is characteristic of simplicity. It stores all the information in the on-board computer, which will be accessed with the advance of the train. The major drawback of this method is the poor reliability, because there is no way to check the correctness of the information. Once there are errors in the information, traffic safety will be endangered. Furthermore, the availability of this method is also very poor, because the contents of the database should be changed when the train moves to another line.

The second method is most widely used in the world, which is classified into many kinds. The main problem is that it is an intermittent information in the real sense, and to active transponders, there must be cables linking each information point with the station. The possibilities are also there that the transponders may be stolen or damaged. If this happens, the traffic safety will also be endangered.

At the same time of implementing LCF/ATP in Chinese railway, a new digital intermittent information system added on existing track circuits is also developed, which is named DDX [4], whose principle is shown in fig.5. The key issues to realize this scheme include:

- The frequency band used by the intermittent information
- The reliable modulating methods used to transmit intermittent information
- The contents of the intermittent information, the response time, and the reliability in receiving the information

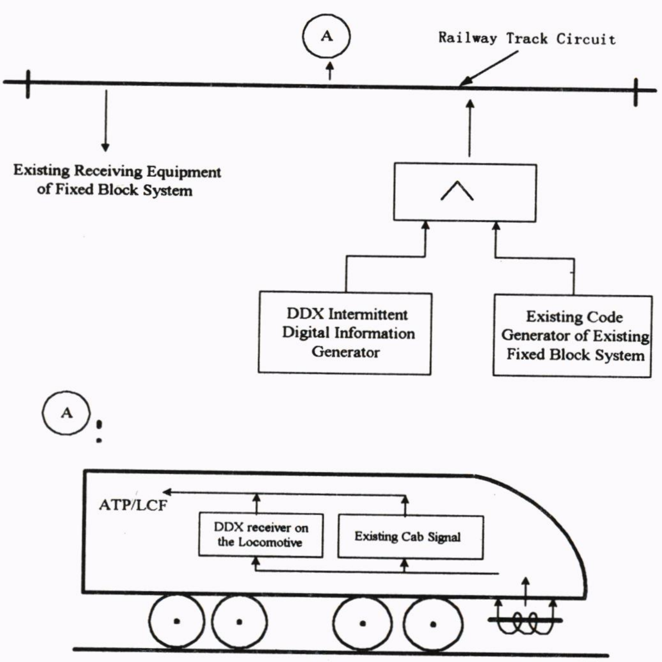


Fig. 5 Schematic diagram of DDX Type Intermittent Information System

In view that DDX type is added on various existing track circuits, the frequency band above 1000Hz is selected, and is different from that used by UM71 type track circuit. Because DDX shares the transmission channel with existing track circuits, the frequency band above audio frequency band are not used for the purpose of avoiding severe attenuation. Furthermore, because DDX shares the inductive coil with the existing cab signal, its modulating method should be different from those of other systems. Based on thorough analyses, The Differential Phase Shift Keying (DPSK) method is finally adopted, namely, the information is transmitted by the phase change of neighboring code, to realize relative modulation; then the absolute phase modulation is realized. This method is characteristic of wide frequency band, high anti-interference, and having no carrier wave component in the power spectrum.

The intermittent information added on the existing track circuit contains at least 20 items needed by LCF/ATP system, such as the code of the signal, the code of the station, the length of the train receiving route, the length of the switch area, the type of the signal ahead, the running direction, the speed limit, the length of each block section. The total length of these items is more than 80 bits.

The contents of code for DDX are determined by hardware, i.e., by the method of connecting terminals on the board. This method can be called as external coding, which can enhance reliability and the easiness for change. It enables every locomotive to realize the brake mode based on distance to go curve as long as the LCF/ATP system is installed on the locomotive.

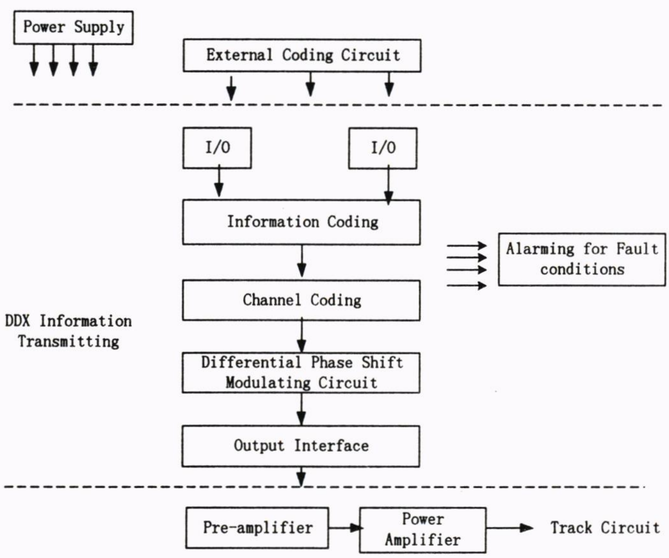


Fig. 6 Diagram of Sending Information from the Trackside in DDX

Fig. 6 is the diagram of transmitting information from the trackside in DDX system. The information transmitted in DDX system is added on the existing track circuit, no additional equipment is needed in the block sections. It is evident that in the method of DDX, the intermittent information is sent at the same cable and channel with the main block information, and there is no additional equipment at trackside which may be stolen. And the intermittent information is sent along the track circuit. The ATP system can receive them many times. Hence the reliability and availability is enhanced.

By the way, the characteristics of DDX Type system are low investment, high reliability, and large information volume. This system has proven to have excellent performance by the trial operation of many years in 10 stations and block sections.

6. CONCLUSIONS

To meet the requirement of raising train speed on the trunk lines of Chinese railway, centering on the realization of LCF/ATP system, the universal digital cab signal and the digital intermittent information system added on existing track circuits are researched and developed. They have not only the characteristics of Chinese railway, but also high reliability and availability. Investment is greatly reduced and traffic safety on speed raised trunk lines are guaranteed. These systems have proven to be very effective after many years of application.

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