Technical analysis of the preliminary phase of CBTC application in Chinese railways

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Abstract

Train control around the world is undergoing a transition period from TBTC to CBTC, which marks a new era of railway signaling technology. Radio based automatic block system has long been proposed in Chinese railway in the beginning of 1960’s, however, it was suspended for various reasons. Now, as a big project in the development of northwest part of China, a railway line running though Qinghai-Tibetan plateau with a total length of 1114 kilometers is under construction. Because 90% of the railway line passes through frozen soil areas, TBTC of any kind cannot be applied. Therefore, CBTC is the only choice. Besides of cold weather, there are many other special environmental issues, such as low population density, bad living conditions, etc, making the construction of the railway line very difficult. There are also many difficulties in implementing CBTC on the railway line. This paper focuses on describing the techniques of implementing the preliminary phase of CBTC in the Qinghai-Tibetan railway. In order to improve the reliability, availability, maintainability and safety (RAMS), many measures have been adopted, especially, the three-dimension theory and technology of combining ‘dedicated address’, ‘time stamp’ and ‘registration number’ has been used. Combining these measures with ARQ methods, a closed-loop control system can be constituted to ensure traffic safety and satisfy the required traffic efficiency.

1 Introduction

With the rapid development of communication, computer, and control technology, traditional track circuit based train control (TBTC) system is challenged. Although the idea of radio based moving block system was proposed by the author of this paper in the early 1960’s[1], it was only a creative
idea and preliminary laboratory experiment because of many reasons, including
the immaturity in techniques and production technology. In the 1980's, several
projects, such as ATCS, ARES, CARAT, have emerged; there were also a
standard in European railway, i.e. ETCS/ERTMS, and several pilot projects have
been established. Although there are various names for train control systems
based on communication technology, for example, there are other names such as
PTC and PTS, a unified name is now been gradually accepted, namely
Communication Based Train Control (CBTC), which symbolizes that train
control has stepped into a new phase.

The development of CBTC has stepped into mass transit system and railway,
with greater development expected in the future[2].

The major issues for the practical application of CBTC include: firstly, the
reliability and safety of CBTC application; secondly, the cost-effectiveness of
CBTC application. For the second issue, there is not a final conclusion, because
CBTC is still in the experimental phase. However, it can be predicted that CBTC
will have a better cost-effectiveness than TBTC.

The Qinhai-Tibet railway of China has encountered many problems in the
application of TBTC, so CBTC is the only choice. However, it is impossible to
realize a perfect CBTC in one step, at present only the first phase of the CBTC
can be implemented. This paper focuses on the major issues of the preliminary
phase of CBTC application in Qinhai-Tibet railway line.

2 Major technical environment of Qinhai-Tibet railway line of
China

The construction of the Qinhai-Tibet railway line is one of the four major
projects of China’s northwest development strategy. The east end of the railway
line is Ge’ermu city of Qinhai province, the west end is Lasha city of Xizang
autonomous region. The total length of the line is 1140km, 965km of which is
the total length of the sections whose altitude height above sea level is 4000m,
up to 84% of the total; 547km of which is the total length of the sections which
pass through frozen soil areas, up to 48% of the total. The big problems
encountered in the construction of the railway line include: high altitude above
sea level, low air pressure, thin air density, permanent frozen soil, complex
geology structure, unpredictable climate, less population density, frequent
ground roll thunder and so on. So large a number of problems has never been
encountered in the history of railway construction around the world. From the
viewpoint of railway signaling engineering, because more than half of the
railway line passes through frozen soil areas, track circuit of any
kind cannot be
installed, not to speak of the routine maintenance and adjustment because of less
population density and harsh living standard, so it is very natural to adopt CBTC
instead of TBTC. However, at present mobile communication network in the
area is not available, and the building of a new mobile communication network
cannot be finished in a short time because of many limitations, such as power
supply, maintenance, manpower and investment cost. Therefore, the application of CBTC in Qinhai-Tibet railway line can only be in the preliminary phase. Nevertheless, it shows that Chinese railway signaling has stepped into CBTC from TBTC, because many experiences and lessons related to CBTC application, such as design, construction, management and maintenance can be drawn during the construction.

3 The CBTC scheme for Qinhai-Tibet railway line

The implementation of CBTC for Qinhai-Tibet railway can be divided into two phases, according to the wireless communication method adopted. The first phase: using half duplex radio station; the second phase: using mobile wireless communication network.

In the first phase, radio based cab signaling is used to replace the signal for traditional semi-automatic block system. The effective range for radio based cab signal is 3-4 kilometers around a station. Each train has a train radio in its train-borne equipment, each station has a radio in its station control equipment. Each radio station, no matter train-borne or trackside, is assigned a unique address so as to form a communication network, as shown in figure 1. Therefore, the operation of the communication network is orderly and reliable, and detectable.

In this phase, in order to realize train integrity inspection, axle counters are installed at both ends of the station, ensuring that there is only one train in the section. This is also the basic condition for the radio based cab signaling to indicate permissive signal.

In order to guarantee that the radio based cab signaling begin to work at a point with a fix distance from the home signal of a station, a passive transponder is installed at that fixed point, to notify the train-borne equipment that the radio based cab signaling should be activated.

In the first phase, computer interlocking of various scale are installed at all stations, they work separately, however, their proper operation and correct route setting is one of the basic conditions for radio based cab signaling.
In the last period of the first phase, a ‘C’ device will be added in the train-borne equipment, which will be discussed later.

The second phase will make some modifications on the basis of the first phase. The prerequisite condition is that mobile communication network similar to GSM-R or TETRA is available. CBTC in this phase will be fully automatic, intelligent and highly efficient, because train following operation in the section can be realized to make the headway to reach a minimum. This is the so-called moving automatic blocking system. Remote control of the computer interlocking system at small stations can be realized. Of course, in order to implement the second phase of CBTC, apart from wireless communication network, the building of power network, weather forecasting network and various wireless forecasting networks are all necessary.

4 Analysis to the reliability and safety of radio based cab signaling

When changing from the cab signaling under TBTC to the cab signaling under CBTC, the most important issue to railway signaling workers is the reliability and safety, because traffic safety is directly involved. So the starting point in the design and experiment of the system is to guarantee the reliability and safety when system functionality is satisfied. The concrete measures are described as following.

In TBTC, when any home/exit signal or speed signal is transmitted in the track circuit, although fixed information can be continuously transmitted through track circuit, the duty man in the station can only know whether the information has been correctly transmitted, while doesn’t know whether the information has correctly reached the driver, in other words, the transmission process of the information is a open loop. However, in the radio based cab signaling, a closed-loop transmission is realized, as shown in figure 2, so it is essentially different with TBTC in terms of reliability and safety.

Secondly, the information transmitted in the track circuit are continuous analog values, the transmission can be interrupted or distorted by some interferences, which may result in flash or fault indication in the cab signaling, that is to say, the anti-interference ability of transmitting information by track
circuit is poor. In the radio based cab signaling, digital coding method is adopted for information transmission, while judgment according to the law of large numbers is adopted for information reception. Therefore, only continuous interference or long time information interruption can cause indication interruption in the radio based cab signaling. In other words, the difference between TBTC and CBTC lie firstly in the difference between analog and digital method, secondly the simple and continuous way of information processing vs. processing according to law of large numbers.

The information transmitted in the radio based cab signaling is digitally coded, and the addresses for transmitting and receiving are independent. Therefore, even if the radio based cab signaling use open space, there will be no disorder in the receiving of information. These addresses are uniformly planned by the dispatcher of each section and allocated to each station and train. The address is unique, just like each family has only one mailbox, and cannot be modified by any other unit.

Each piece of information transmitted in the radio based cab signaling has a time stamp, namely the information transmitter has its own time, according to the valid time of the information specified by the system designer and customer. If the time stamp received by the receiver has expired, the receiver will regard the information as invalid, and will not acknowledge and execute the corresponding information. Only during the valid time window, will the information been executed, as shown in figure 3. The refreshing and time limit function is more reliable than transmitting fixed information in the track circuit in TBTC because once the information transmitted in the track circuit are interfered for a long time and causing severe distortion, the receiving end of the track circuit will be not able to decode the information correctly.

In the radio based cab signaling system, apart from that each station and each train has a unique address, a unique registration number is also assigned to each station and each train. So when retrieving information from the 'mailbox', the information will be further checked by 'registration number', just like checking the name of the receiver of the letter in the mailbox. The registration number will be refreshed and confirmed every 24 hours, to avoid the train splitting or composition operation in the district.

![Figure 3](image-url)
Therefore, time stamp, registration number and network address constitute a strong constraint for the information transmitted in the open space, which in fact forms a three dimensional control, as shown in figure 4. If using \( x, y, z \) to represent axis for time stamp, network address and registration number respectively, while \( \Delta x, \Delta y, \Delta z \) represents the increment of \( x, y, z \) respectively, the actual range for the information is:

\[
A = f[(x + \Delta x),(y + \Delta y),(z + \Delta z) - (\Delta x, \Delta y, \Delta z)]
\]  

Therefore, the constraint for the information in the radio based cab signaling is stricter than that in TBTC, hence the reliability is enhanced in CBTC.

In order to enhance the anti-interference ability of transmitting information of radio based cab signaling in radio channel, multiple error detecting and correcting process are adopted. The first process is the information of radio based cab signaling plus error detecting and error correcting method; the second process is the radio transmitter and receiver plus error detecting and correcting methods, as shown in figure 5. These measures are stricter than that for the information transmitted in TBTC.

In view that the information transmitted in the open space is influence by each media in the space and the transmitting power, the frequency and transmitting power are limited in the radio based cab signaling system, namely the trains
running in up or down directions use different frequencies, and adjacent stations use different frequencies, too. The transmitting power of each radio station is limited to restrict the effective range of electronic wave be within the range of about 4km, namely, only when a train is within 4km of a station, can it receive/transmit information. Common frequency interference can be avoided by these methods.

Apart from above measures, redundancy measures are also adopted in the radio based cab signaling system.

1. The hardware of station equipment and train-born equipment are both hot standby, the reliability degree $R_s$ of the system is [3]

$$R_s = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} - \frac{1}{\lambda_1 + \lambda_2}$$

(2)

where $\lambda_1, \lambda_2$ are the failure rates of the working equipment and the redundant equipment respectively.

2. In radio based cab signaling system, the method of judging by law of large numbers for information processing is adopted. Its reliability is

$$R_s(t) = \sum_{k=r}^{n} C_n^k e^{-kn\lambda_0} (1 - e^{-\lambda_0 t})^{n-k}$$

(3)

where $n$ is total number of information for larger numbers, $k$ is the number of voting information, $\lambda_0$ is the failure rate of single information.

Therefore, the reliability of the whole system is greatly enhanced.

5 Application of transponders

In order to ensure traffic safety in the radio based cab signaling system, both active and passive transponders are used, mainly for:

1. To activate the train-born equipment of the radio based cab signaling at a fixed point. As mentioned before, a passive transponder is placed at certain point with a fixed distance from the station. When a train passes the transponder, the train-born equipment will be activated, and the driver will be alerted at the same time. Another purpose of using the transponder is to calibrate the odometer error of the train-born equipment.

2. An active transponder is placed at the exit point of each track in a station. When a train has passed the transponder, it means two things: firstly a train has left the station, secondly, which train has left the station. The former restores the exit signal to red to protect the train running in the section, the latter makes the station equipment to record the actual train operation time.
6 Application of GPS

GPS is used in the system for the purpose of enhancing train positioning precision. By combining GPS with the existing speed/distance measuring system, a comprehensive train positioning system is formed to obtain very accurate train positioning results.

7 Application of ‘C’ device

In view of the special environment of Qinhai-Tibet railway line, namely it passes through plateau with thin air density, any railway worker may feel dizzy or even lose his working ability for lacking of oxygen. The driver is the key for driving the train to ensure traffic safety. Therefore, on one hand, adequate medical measures should be adopted to guarantee his safety, on the other hand, from the viewpoint of railway signaling control, measures should be taken to avoid the happening of above situations. A ‘C’ device is added to the radio based cab signaling used for Qinhai-Tibet railway line to achieve this purpose. Its major function is to check whether the train driver can work properly. If something abnormal should happen, the control of the train will be switched to automatic control from manual control, to ensure the safety of the train. The core of this equipment is the corresponding sensors and a highly reliable ATP system.

8 Conclusion

Although the CBTC system used for Qinhai-Tibet railway is a preliminary system, it is both a challenge and a chance for Chinese railway because it symbolizes a turning point for railway signaling. It will have a bright future. Of course, at present the most import issue is the RAMS of CBTC application. Now it can be confirmed that the application of CBTC will bring about incomparable advantages than TBTC, the most important of which is that CBTC can produce large amount of traffic information, which meet the requirement of today’s information society.

References