Train Control System for Secondary Lines Using Radio Communications in Specific Area

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An electronic token based blocking system has been used on secondary lines since the 1980s, and has contributed to more efficient administration of those sections. However, development of an alternative system is now required due to obsolescence and subsequent lack in supply of spare equipment. A new train control system was therefore designed relying on 2.4GHz band radio communication, for which a license is not required. This approach avoids having to replace the entire older system, and has demonstrated excellent performance in system replacement, since conventional equipment is still used as much as possible. The new system not only allows uncomplicated extensions of certain functions, but also overcomes some problems encountered with the conventional system. After performing field tests it was confirmed that the system performed basic functions without any problems.

Keywords: train control, blocking, radio communications, secondary line, level crossing protection

1. Introduction

A computerized blocking system using electronic token was introduced onto secondary lines about 25 years ago. This type of system is generally called ‘electronic blocking’ [1] and contributes to more efficient administration of lines and reducing maintenance work. Nonetheless the system has become difficult to use due to obsolescence and shortage of spare parts. Demand today to find an alternative solution is therefore growing. In response to this we have developed a new system using general purpose radio technology which can in addition solve other problems found in the conventional system.

2. Conventional electronic blocking system

2.1 Basic function

The structure of a conventional electronic blocking system is illustrated in Fig. 1. When a train leaves a station, the driver pushes a button on the on-board unit in order to set the departure route, and the ID of the on-board unit is transmitted to the departure station via radio transmission. The departure station established communication with the adjacent station, and they perform the blocking procedure. As the result, if no train exists and any routes are not set between the stations, the block is locked and a departure route for the train is set and the blocking units of both stations memorize the ID. When the train arrives at the adjacent station, the train’s on-board unit ID is transmitted to the station unit and if the received ID is equivalent to the memorized one, the block is released.

2.2 Problems

The electronic blocking system has made safe train operation possible at low cost. However, there are several problems in managing the system.

As described in Section 2.1, a train driver is required to push a button to trigger the route setting at every station. On many secondary lines, trains are operated without a conductor, increasing the driver’s work load. For example, drivers must check safety on the platform, operate doors and collect tickets. Therefore, many operators would like to see route setting tasks for drivers removed.

Under the conventional system, the on-board unit ID is related to the train path and train numbers in advance...
at a monitoring terminal. This linked data is sent to station units from the monitoring terminal every day. According to this information, station units can set the departure route for a train by simple operation of the on-board unit by the driver. However, this fixed relationship restricts the scope of use of on-board units. In other words, only on-board units with a suitable type of ID for the path of the train can be applied. Consequently when an on-board unit fails, it may take a long time to find a replacement unit if a suitable one is not at hand, near the train.

Another problem is about the timing of route setting. In the conventional system, when the station unit receives the route setting request from the on-board unit, it decides which route should be set based on the linked data sent from the monitoring terminal in advance. Usually, the driver pushes the button just before the departure time defined in a timetable. However, if the driver pushes the button too early, the block is locked and the route is set as according to conditions which can satisfy safety requirements, because the station unit does not have timing data. In other words, the train may depart earlier than the scheduled time. If a train from the opposite direction should actually depart first from an adjacent station, such action may lead to traffic disturbance.

3. Principles underlying development of the system

When considering the introduction of a new train control system, one possible strategy could be to develop a system based on Communication Based Train Control (CBTC). With this approach, a train detects its position itself and the on-board signal is used instead of a wayside signal, and the amount of ground equipment can be reduced. Introduction of such a system however would require replacing most of the equipment along the entire line generating high initial cost, and leading to significant modification of dispatcher and driver operational rules. While making such a large investment at one time on secondary lines may be difficult, there is a demand for a system which does not require such significant change, and for gradual functional improvement.

Considering these conditions, the following principles were drawn up to underpin development of the new system.

1) Easily replaceable, using conventional equipment as much as possible
2) System architecture that enables gradual functional upgrade
3) Solution to problems encountered with the conventional electronic blocking system

4. System configuration

4.1 Ground system

The basic configuration is indicated in Fig. 2. The ground system consists of central unit, station control units and station radios.

The central unit indicates train location and has functions of diagram management, simple reschedule and so on. A general purpose computer such as PC is applied to it.

The station control unit has a safety related function such as blocking and interlocking, and is connected to the station radio. As indicated in Fig. 2, the interlocking function can be realized by the existing relay interlocking device installed exteriorly.

The wayside control unit and wayside radio are installed when optional function such as level crossing protection described later in Section 5.2, is to be realized. Core hardware of the controller is the same as the station control unit.

Conventional metal cable between adjacent station units is applicable, and information for blocking function is exchanged via the cable. The cable is also applicable to transmission between the central unit and station control units in the same way as the conventional electronic blocking system. On the other hand, newly introduced cable such as optical fiber or data network supplied by a common carrier is applicable to the transmission between the central unit and the station control units.

4.2 The on-board system

The on-board system consists of an on-board unit and radio antenna. Its configuration is shown in Fig. 3.

The on-board unit has a radio transmission function and an interface with the ATS unit containing a continuous speed checking function. Connection between the on-board unit and the ATS unit is not a requirement for the basic blocking function. However, optional functions can be added by virtue of a connection. If ATS-X [2] developed by RTRI is installed in particular, only the ATS unit software should be modified.

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4.3 Radio system

The radio system is based on train control technology in which a train’s location is detected by measuring the distance between the ground radio station and the onboard radio station based on radio propagation time [3].

The radio frequency is 2.4 GHz band for which a government license is not required in Japan. Considering robustness to noise or interference, spread spectrum technology is used and TDMA, FDMA and CDMA are jointly applied. Furthermore, addition of a check code to command data and checking by a fail-safe processor, encrypting the data and so on are applied for ensuring safety and security.

In a station, radio equipment should be installed so as to be able to communicate with trains to at least perform the blocking function. As described in Section 5.1, a minimum of two radio sets are required in the station where automatic relating of the onboard unit ID to the train number is performed. This function may in actual fact be performed in the stations where it is possible for a train to change direction, trains are split or coupled, the train number is changed, or at borders between train control systems.

5. System functions

5.1 Blocking

The basic blocking procedure is based on the conventional electronic blocking system. However, the following new functions were developed in order to solve the problems described in Section 2.2.

With the conventional system, the timing of route settings depended on a driver’s decision, and the possibility remained of premature route setting requests in relation to the schedule. In order to overcome this problem, a function was introduced where the central unit checks the time to set the departure route.

Under the previous system the relationship of the onboard unit ID to the train number was fixed in advance. In the new system, however, it is defined dynamically when each train leaves an origin station. This procedure relies on the distance measuring function of the radio system applied to our system. By using this function, the direction of movement of the train can be detected at the origin station, and the ID of the onboard unit which is installed in that train is specified. The specified ID is sent to the central unit, and it relates the ID to the train number. The central unit traces the movement of the ID using a temporary ID. The departure route for the train is locked. In fact, the value of the temporary ID is not generated randomly: sets of them are specifically predefined.

4) The train leaves the station. At this time, the station control unit detects the direction of movement of the train and specifies the ID of the onboard unit. This procedure is based on the distance measuring function of the radio system. The specified ID is transmitted to the central unit, and the central unit replaces the temporary ID with the specified ID.

5) When the train arrives at the adjacent station, the station control unit receives the ID from the train via radio transmission and detects arrival of the train through the track circuit. Both the neighboring station control units perform a procedure to release the block.

The relationship between the onboard unit ID and

Fig. 4 Sequence showing how the onboard unit ID is associated to the train number.
the train number is defined when the train departs from the origin station, and is held until the train arrives at a terminal station. The blocking and route setting procedures at intermediary stations are therefore performed automatically without detecting movement direction of a train by the radio system. The central unit releases the relationship between the ID and the train number when the train reaches the terminal station. When the train then departs in the opposite direction, a new relationship is defined according to the same above mentioned procedure.

In these processes, train operational safety is guaranteed by the station control units. In other words, relating the on-board unit ID to the train number and its management performed by the central unit contributes only to indicate traffic status and check the time of departure route setting. These functions do not contribute directly to safety.

5.2 Level crossing protection

A track circuit or electronic train detector which is a kind of short track circuit is generally used for level crossing alarm control. On secondary lines however train detection performance becomes unstable in some cases due to superposition of unfavorable track shunting conditions such as rail surface rust and short length or light weight trains. The purpose of level crossing protection is to stop the train before the level crossing if the alarm were not activated.

In order to realize this function, the on-board unit is connected to the ATS which has a continuous speed checking function, and a wayside control unit and a radio are installed close to the actual level crossing. The wayside control unit inputs the level crossing alarm status from the existing level crossing controller, and transmits this condition to the train via the radio transmission.

The basic procedure is as follows and is shown in Fig. 5. In this example, it is assumed that ATS-X is used. ATS-X has a functional compatibility with the conventional ATS which is the system employed mainly by JR companies. It detects an absolute position of the train using an on-board database, and can realize continuous speed checking at low costs. As described in Section 4.2, ATS-X can be connected to the on-board unit just by software modification.

1) ATS-X generates a speed profile to stop the train before a level crossing as it approaches it. The level crossing’s position is registered in a database in the on-board ATS-X unit.
2) When the level crossing alarm is activated, the wayside control unit transmits this information indicating that the alarm is activated along with the ID of the level crossing to the train by radio.
3) If the above information is received by the train, the on-board ATS-X unit clears the speed profile under the condition that the train has passed the alarm trigger point and nonexistence of any other speed profiles to stop the train on the near side of the speed profile for level crossing protection.

5.3 Gradual upgrading of system functions

This function can gradually be introduced into the new system as indicated in Fig. 6. Furthermore, this function can be applied in the case of departure signals to prevent erroneous departures, and has the potential to stop the train if a disaster or other warning are to be received by the train.

6. Field tests

6.1 Conditions

Field tests were performed to confirm the system's basic functions. The prototype system installed is shown in Fig. 7 and Fig. 8. Conditions relating to existing field equipment such as track circuits were input to the prototype system. However the system did not output control commands to actual field equipment such as signals or point machines. The performance of the system was however monitored and recorded and it was possible to confirm each function.

6.2 Results

The functions indicated in Table 1 were investigated in the course of 40 test runs. Results confirmed that all functions performed correctly.

A monitor snapshot of ID detection at the origin station and subsequent relating to the train number is indicated in Fig. 9. As shown on the left hand side of the drawing, there are two on-board units in the station. When
the train departs, its ID is detected and related to the train number correctly.

In Fig. 10, the transition of the measured distances between the train and the ground radios is indicated. The distance change is correctly measured along with the train movement. There were some cases where distance was not measured correctly ($L_1=0$). However, this does not affect performance because the number of these cases was very small and they occurred discretely. Furthermore, during train movement detection, the validity of the transition of measured distance is checked in order to avoid detection error.

Figure 11 shows level crossing protection test results. In this case, the speed profile was set so as to prevent erroneous passing of the station on the near side of the speed profile for level crossing protection. When stopping of the train is detected, the former profile is cleared. This being the case conditions described in Section 5.2 are satisfied, and so the profile for level crossing protection is cleared.

<table>
<thead>
<tr>
<th>Function</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train management (Central unit)</td>
<td>• Checking the timing of departure route setting</td>
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<tr>
<td></td>
<td>• Relating the on-board unit's ID to the train number</td>
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<td></td>
<td>• Relating a new ID to the train number in case of failure of the on-board unit</td>
</tr>
<tr>
<td>Blocking (Station control unit)</td>
<td>• Automatic sending of the departure route setting request to the central unit</td>
</tr>
<tr>
<td></td>
<td>• Blocking procedure between adjacent stations</td>
</tr>
<tr>
<td></td>
<td>• Cancelling the set route and resetting</td>
</tr>
<tr>
<td>Level crossing protection</td>
<td>• Generating speed profile for level crossing protection based on on-board database</td>
</tr>
<tr>
<td>(Wayside and on-board)</td>
<td>• Clearing the speed profile when the information indicating that level crossing alarm is activated is received via radio</td>
</tr>
<tr>
<td>Radio communications</td>
<td>• Quality of radio communications</td>
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<tr>
<td>Data communication on the ground</td>
<td>• Data transmission using the existing metal cable</td>
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<tr>
<td></td>
<td>• Data transmission between the central unit and the station control unit using the network provided by common carrier</td>
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7. Conclusions

A new train control system using the general purpose radio technology and the existing signaling equipment was developed. The new system does not require complete replacement of the previous setup, and has an excellent performance in system replacement. At the same time, the new design allows easy extension to train speed control functions such as level crossing protection.

Field tests were carried out and confirmed that basic functions perform correctly. The expectation is that this system will be introduced to actual lines and will contribute to efficient operation of secondary lines.

![Fig. 10 Test result for detecting train movement direction using distance measured by radio](image1)

![Fig. 11 Test result for level crossing protection](image2)

References