Recent Research and Development of Signaling and Telecommunications Technologies

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This paper outlines the recent research and development of train control systems, solutions for existing signaling equipment problems and the application of radio communication technology to railways. It describes what has been called the “intelligent train” and a train control system for secondary lines which does not require interlocking devices in stations. It also describes solutions for point machines on secondary lines, lightning-induced voltage in cables and a visibility test for obstruction warning signals. Finally, it describes the application of millimeter wave technology which enables high speed and large capacity communications.

Keywords: train control, point machine, measures against lightning damage, level crossing, millimeter waves

1. Introduction

Railway Technical Research Institute (RTRI) is now engaged in research and development (R&D) for a new control method that can further contribute to improving safety and efficiency in railway operations, based on findings and knowledge RTRI has obtained through its development of a radio based train control. RTRI is also focusing its efforts on solving existing signaling equipment problems. It is expected that telecommunications technology will gain importance not only for train control but also for monitoring facilities and providing services for passengers. Based on this observation, RTRI is already investing its efforts towards the future.

This paper describes recent R&D findings in signaling and telecommunications.

2. Train control method

2.1 Intelligent train

New ATP or radio based train control systems are being increasingly employed in both Japan and around the world. These are control methods which provides trains with information on where they should stop and which follows safety speed profiles, taking track conditions and braking performance of vehicles into account.

Although this kind of control method is part of conventional signaling, there is a further need to consider obstacles, possible disasters, and vehicle conditions as factors that affect the running safety of trains. These requirements have led to the development of a system called the “intelligent train” where sensing information related to such factors is provided for the train, and the train itself can determine its safe speed control based on the information.

The functional structure of the intelligent train is shown in Fig. 1. The collection and processing of various types of sensor inputs is classed as “sub-intelligence”; while the function which actually determines the safest speed control procedure based on sub-intelligence is called “main-intelligence.”

Various types of sub-intelligence can be assumed, however, current development is aiming at monitoring in the forward direction and monitoring of the soundness of bogies. Each type of sub-intelligence handles vastly different contents, therefore a common format has been adopted for feeding the data up to the main-intelligence, about a type of event and associated recommended measures (for example, immediate stop or slowing down, though no need to stop). The main-intelligence integrates data which will allow it to determine the safest traveling mode in reference to the train’s position at the time and relevant circumstances.

Fig. 1 Functional structure of intelligent train

2.2 Train control system for secondary line

It is expected that the introduction of a train control system using radio communications will lead to reduced need for ground facilities such as track circuits and related cables, thus improving efficiency of equipment maintenance. A train control system for secondary lines which can leverage this merit using radio communications in specific areas has been developed [1]. It is currently being adapted for application.

Another method under development and close to completion seeks to remove the need for interlocking device in stations [2].
As shown in Fig. 2, the train detects its position and triggers the route control. The route are controlled through information transfer between the blocking controller installed in the control center. This control system would remove the need for interlocking devices in stations and thereby further reduce the need for ground equipment.

At the same time, RFID tags are being studied as position detection devices. In order to secure safety, on-board unit checks the reception of all IDs used in one block section, reading sequence of these IDs and so on and passing these checks are set as the conditions for releasing the block. Using general-purpose RFID tags however presents the problem that the incidence rate of transmission errors increases when receiving or sending data from/to a fast-moving target like a train. To overcome this problem, the related transmission protocol has been improved, shortening reading time. In addition, changes made to the volume of information to be sent, means that data reception can occur multiple times within one transmission frame, increasing the number of verifications based on redundant codes. Consequently, RTRI is working towards and promoting the idea of applying RFID tags to the railway environment.

This research was conducted with a grant for railway technology development from the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

Fig. 2  Train control system through route control made mainly on board

3. Solutions to issues related to signal equipment

3.1 Point machine for secondary lines

Spring switches which rely on spring power, doing away with the need for an external power sources are used in secondary lines. In the past few years however, there is an increasing use of 50N rails on turnouts equipped with spring switches, since suppliers stopped manufacturing lightweight rails. 50N rails are not a problem in terms of specification, but they add to the operational load, decreasing margins. There are thus growing fears that this will produce more cases of switches being unable to return to their position as the base plate oil wears away. At the same time, if operational power is increased, the resistance force working on each wheelset would grow when trains are running through in the trailing direction. This condition would have a particular influence on the running safety of lightweight vehicles.

Development is ongoing for a point machine designed especially for secondary lines to overcome these problems while keeping installation costs to below those for introducing an electric point machine. Figure 3 shows the adopted method, where there is no direct switching control from interlocking device, which is the same as in the case of spring switches. The device however does require some form of motive energy to secure sufficient operational force. It was therefore decided to introduce a new type of switch with a point machine operated by an approaching train, which functions as a trigger. As this method needs high-speed operation of one second or so, RTRI devised a new technique using air pressure for motive energy and further developed a new mechanism to realize this technique. RTRI is now developing another mechanism to unlock the locking of a tongue rail when a train forces open the point, to ensure running safety even if there is no switch control when a train runs through the point in the trailing direction.

RTRI is now enhancing the system and will conduct trials with a view to applying this technology in practice.

This research was conducted with a grant for railway technology development from MLIT.

![Diagram of point machine and associated equipment](image)

Fig. 3  Point machine to be forced open by trains along secondary lines

3.2 Measures against lightning damage to signaling equipment

Signaling equipment over the years has been enhanced with electronics and more specifically with the introduction of microcomputers. At the same time, these improvements increase vulnerability to overvoltage and excess current
concomitant with lightning strikes. In order to introduce effective protection measures against this risk, it is necessary to evaluate whether such measures achieve the desired effect.

To comprehend the causes of overvoltage caused by lightning, long-term observations were made of lightning-induced overvoltage generated on signal cables and power wires temporarily installed as overhead lines, and rails. Results of these observations led to the derivation of a formula to estimate the value of lightning-induced overvoltage against a ratio \((U/r)\) of a value of lightning current \((I)\) over a distance to the lightning location \((r)\). A statistical approach was used to determine \(I\) and \(r\), following which a method was derived to calculate the occurrence probability of lightning-induced overvoltage that surpasses the thunder resistance of signal equipment. Application of this method made it possible to clarify the thunder resistance performance of signal equipment required for reducing the frequency of occurrence of lightning damage to a target value.

In addition, a finite differential time domain (FDTD) simulation was applied to related phenomena, where consideration is given to cable laying conditions inside a signal equipment room that had not been quantitatively comprehended so far. Based on the results of the simulation, RTRI developed a new method for quantitatively grasping and evaluating separate conditions required for reducing an inductive surge between signal cables as well as differences in thunder resistance performance due to different grounding layouts [3].

### 3.3 Confirmation of visibility of obstruction warning signal

Obstruction warning signals (hereinafter called the “warning signals”) only light up in case of a detected anomaly and transmit information to trains when an obstruction is detected on a level crossing, or if an obstruction warning device on a level crossing has been activated. These signals are checked for visibility by workers on the ground who often conduct visibility checks at night. This raises efficiency problems in terms of actual confirmation and objectivity of results.

A new method is under development therefore to address this problem, using a near-infrared ray LED, which emits invisible light rays, and is embedded in a warning signal; pictures of the LED are taken with a camera mounted on a train to check recognition (Fig. 4) [4].

Visibility is confirmed when emission of light is recognized from a near-infrared ray LED located 800 meters before a warning signal. In order to eliminate the influence of ambient light, a new method was devised using light emissions blinking in a specific pattern. Moreover, by setting a different LED blinking pattern for each level crossing, distinguishing and confirming two or more warning signals becomes possible if they are observed simultaneously from a train. Furthermore, as pictures of them can be taken from trains, continuous confirmation is now possible whereas before this was very difficult.

Basic performance tests have been completed to verify the methods, and RTRI is now working on adapting the system for practical use.

![Fig. 4 Method for confirming visibility of obstruction warning signal](image)

4. Application of telecommunications technology to railways

#### 4.1 Radio transmission quality evaluation

It is expected that radio communications will take on a more important role with increased potential as radio based train control systems are introduced in practice.

When introducing radio transmission, in order to secure necessary transmission quality, it is important to design circuits appropriately, including deployment of radio base stations. Estimating propagation loss of radio waves which are sensitive to train speed and land features is difficult. Although it is possible to make on-site measurements using actual vehicles, this method has some limitations and would incur significant cost in practice. Consequently, RTRI developed a simulator named “RADTRACE” with a function to support efficient designing of wireless circuits by setting various conditions [5].

Using this simulator as a base, RTRI is also developing a new simulation system to evaluate a radio-based train control systems, with trackside networks.

#### 4.2 Application of millimeter-wave communication

##### 4.2.1 Overview

Millimeter waves are considered to be in a frequency band suitable for high-speed and large-capacity communications. Over recent years, devices with high cost-effectiveness have been developed, along with radio over fiber (RoF) technology for transmission of wireless signals to facilities on the ground as well as “millimeter wave and photonic technology” realized by applying high-speed and high-performance optic-electric (O/E) conversion technology. For example, it should be possible to cover a wide area with a minimum number of millimeter-wave devices by taking the system structure shown in Fig. 5.

Currently, as part of research assignment that is subject to a “spectrum user fee system” launched by the Ministry of Internal Affairs and Communications (MIC), RTRI is tackling development of a system to communicate with trains using a 40 GHz band and a system to monitor the inside of permanent ways using the 90 GHz band. The following findings were obtained.
Fig. 5  Example of application of millimeter wave photonics technology

4.2.2 Use of 40 GHz band

Tests so far have been carried out to confirm communication performance by simulation in simplified mode. This test used a road railer equipped with a mobile station running at 15 km/h in a tunnel section on a Shinkansen line in addition to an automobile running at 100 km/h. Results confirmed that communication at about 100 Mbps was possible with a high coverage.

Current development efforts are being invested into a simulation-based method for forecasting radio propagation characteristics on a railway line and data transmission quality and development of a circuit design support technology; a study of specifications of antennas for use on the ground and on board a train that are suitable for the railway environment; and a study of a technique to secure a level of reliability that is necessary for use of this band in safety related communication equipment.

4.2.3 Use of 90 GHz band

The 90 GHz band shows smaller atmospheric attenuation than other millimeter wavebands and has excellent propagation characteristics and bandwidth utilization features. Therefore, it can be used for wide-area sensing and applied to information transmission between sensors along the railway line and between ground equipment and trains.

Now a system to monitor the inside of permanent ways using millimeter wave radars is under construction as part of R&D work to extend use of radio resources following a commend from MIC. RTRI is conducting basic tests using prototype equipment, which has led to the finding that it can detect electrification poles and buildings around permanent ways.

It is expected that in the future it will be possible to build a system using millimeter wave radars and RoF technology (described in 4.2.1) suited to railway use, with a linearly expanding detection area, as shown in Fig. 6.

5. Conclusions

This paper has introduced some recent examples of RTRI signaling and telecommunications R&D, namely new train control methods, solutions to signaling equipment problems, and application of telecommunications technology using mainly millimeter waves.

Technical development will continue to support safer and more reliable train operations, which is the finality of signaling and telecommunications technology.

Actively leveraging information technology, in the field of signaling safety will take R&D to a new level, which can contribute to more adaptable and convenient transport services, including traffic management.

References


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