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Digital automatic train control system for the Shinkansen lines of East Japan Railway Company

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Abstract

The Automatic Train Control (ATC) system was originally developed to support safe, super-high speed railway transportation utilizing Japan's Shinkansen (super express) network. East Japan Railway Company, commonly referred to as JR East, has developed a new Shinkansen ATC that utilizes digital communications and control. Officially named "DS-ATC," this system controls train speed mainly relying on the on-board equipment, allowing a reduction in rail-side devices. Since the braking system is transformed from stepwise to one-time command control, passenger riding comfort is enhanced. Reductions in arrival times and intervals between trains can be realized as well. The DS-ATC incorporates various new information technology such as the latest microcomputers, digital radio communications and database compilation/utilization techniques. Consequently, the volume of communications between the on-board computer and rail-side computer is increased, system reliability is enhanced, and the cost and construction processes are reduced as the result of requiring fewer system components. DS-ATC is expected to contribute to safer, smother Shinkansen transportation . The system architecture, functions, train braking control process, merits of the digital ATC, and DS-ATC implementation schedule are described in this paper.

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1 Introduction

Concurrent with the opening of the Tokyo Olympics, operation of the Tokaido Shinkansen Line commenced between Tokyo and Osaka in October 1964. At present, seven Shinkansen lines are in operation, including the Tokaido, Sanyo, Tohoku, Joetsu, Hokuriku, Yamagata, and Akita Shinkansen lines.

As Shinkansens run at super-high speeds, the cab signal system that sends speed signals to the driving cab has been used since operation of the Tokaido Shinkansen Line commenced. The Automatic Train Control (ATC) system is used to automatically control train speeds in accordance with those speed signals.

The ATC is positioned as an important piece of equipment that ensures safe, stable high-speed transportation. It involves advanced operational parameters such as a maximum speed of 275km/h, annual transportation of 17.7 billion passenger-kilometers, and per-train average delay time of one minute or less per day for the JR East Japan Shinkansen lines. In addition, the revenues from the Shinkansen lines occupy nearly 30% of the entire revenues of JR East Japan. Therefore, it can be said that the ATC is also important for ensuring stable revenues.

JR East decided to develop and introduce a new digitally operated ATC (DS-ATC: Digital Communication & Control for Shinkansen-ATC) taking into account the facts that the present ATC needs to be renewed in the near future and the Tohoku Shinkansen Line is scheduled to be extended further to the north.

2 Outline of Shinkansen ATC

Before discussing the DS-ATC further, I will briefly explain the present analog ATC.

2.1 Reason for Introducing ATC [1]

In the case of super-high-speed trains like Shinkansens, it is difficult to fully ensure safety with a conventional operation system; that is one where the driver applies the brakes while watching signals installed along the tracks. Therefore, ATC was introduced as a system that always transmits signal information to indicate permissive speeds to the driving cab and controls train speed automatically in accordance with the permissive speeds indicated.

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What the ATC performs is only speed reduction control that is directly concerned with safety. The driver performs the operations of starting the train, increasing its speed and stopping it at the designated position along the platform.

2.2 System of Speed Control [2]

While applying a permissive speed signal current to each rail section (track circuit) divided into a certain length, speed signals are transmitted to trains utilizing the mutual electromagnetic induction reaction between the current and pick-up coil of the train. An on-board ATC device outputs a braking command to reduce the speed of the train to lower than the permissive speed. Permissive speed information is transmitted in discrete signals, making it possible to perform train stopping control using multi-level braking control as shown in Fig. 1.

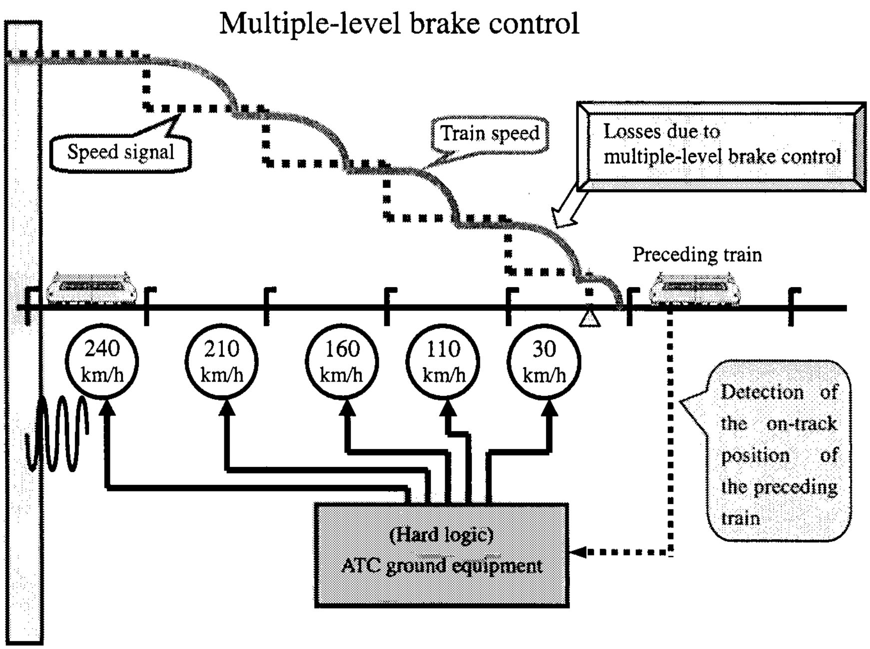

Figure 1:Present ATC, the ground equipment transmits speed signals according to the position of the preceding train to each track circuit. If the actual speed is faster than the speed signal, the brakes are applied by the on-board equipment.

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2.3 Evaluation of the Present ATC

The present ATC is carefully designed and structured from the viewpoint of safety and reliability. It is an excellent system that has supported high-speed, safe train operation for many years since the commissioning of the Tokaido Shinkansen Line. However, its service life is to end in the near future; it is designed and structured utilizing technologies of the 1970s that focused on the use of electromagnetic relays, and the multi-level braking control system is rather unsatisfactory in terms of riding comfort and train operation efficiency. Therefore, it has become necessary to improve the present ATC drastically.

3 Development of DS-ATC

This section describes the newly developed DS-ATC.

3.1 Reason for Development

Taking into consideration that the present ATC is aging, in 1998 it was decided to develop a new ATC that can make up for the shortcomings of the present ATC described in Section 2.3, form an in-house project team and introduce the latest IT technologies.
Through 1999 and into 2000, an investigation committee consisting of knowledgeable people inside and outside of the company carried out investigations to verify the safety of the DS-ATC under development. In July 2000, the investigation committee reported that the DS-ATC had no trouble in terms of safety and reliability. Accordingly, it was decided to manufacture the DS-ATC and initially use it in the northern extension of the Tohoku Shinkansen Line.

3.2 Operating System using the DS-ATC

Figure 2 shows the operating system using the DS-ATC.

The ground equipment detects track circuits (called a stopping track circuit) accessible according to the present positions of preceding trains and signal conditions and transmits pertinent information to onboard equipment. From the database, the on-board equipment detects a braking pattern for single-level brake

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control that enables the train to stop at the stopping track circuit detected, and simultaneously verifies the permissive speed indicated for the present position of the train and the present speed. If the train's speed exceeds the permissive speed, the on-board equipment outputs a braking command to enable the train to stop before it reaches the stopping position. On the other hand, it outputs a command to release brakes as soon as the train's speed becomes slower than the permissive speed.

Drivers use manual operations to position the trains at stations.

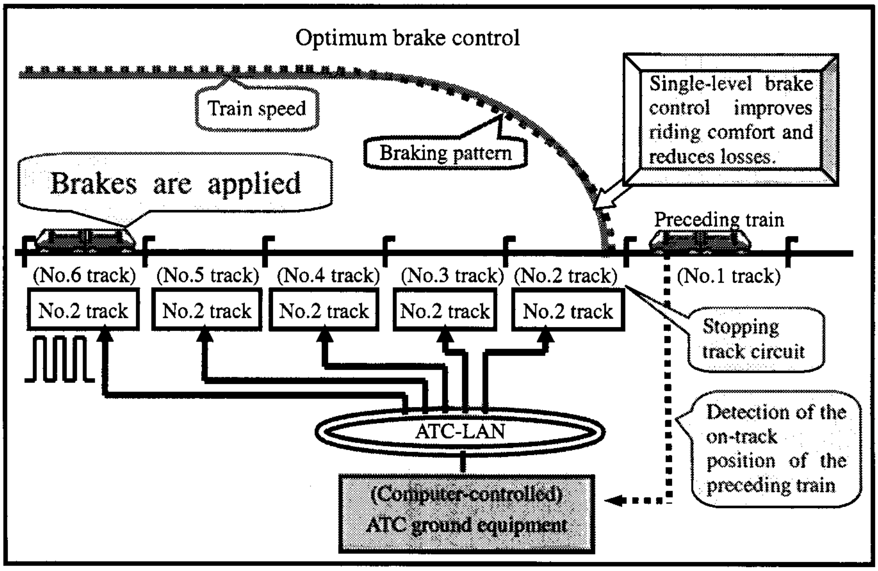

Figure 2: New ATC (DS-ATC), the ground equipment transmits the stopping track circuit determined according to the position of the preceding train to each track circuit. Brakes are applied after comparing the actual speed and braking patterns by the on-board equipment, if it's necessary.

3.3 System Functions and Equipment Composition

Figure 3 shows the principal equipment composition. The outline of each function is as described in the following.

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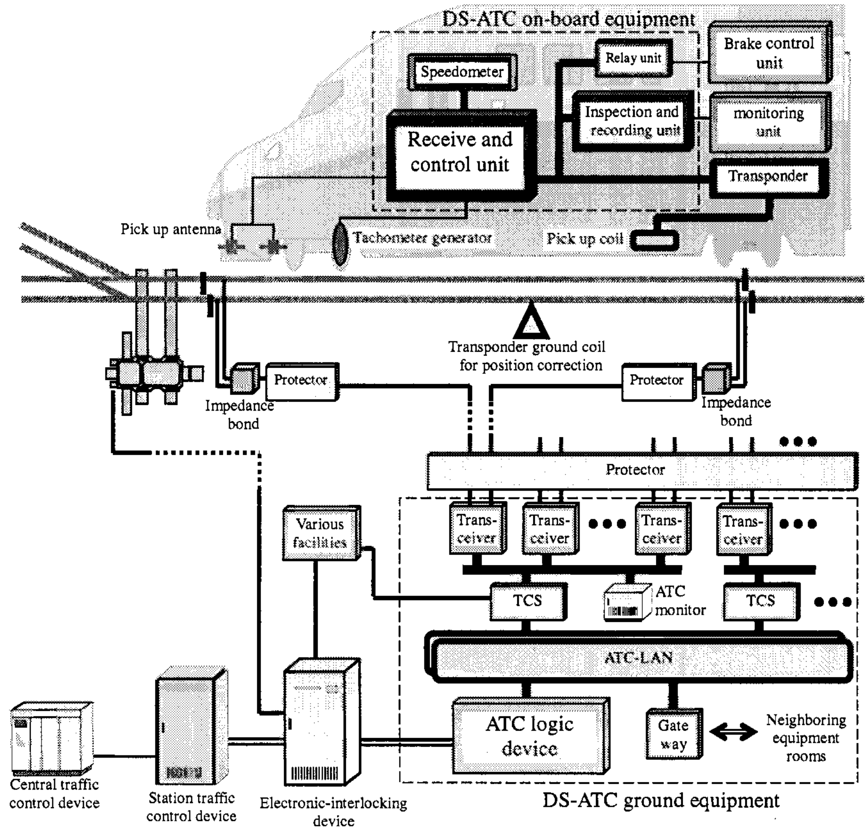

Figure 3: DS-ATC entire composition

3.3.1 Ground Equipment

The ground equipment is composed of the following devices.

3.3.1.1 ATC Logic Device

The ATC logic device receives information pertinent to trains on the line, train routes and site equipment, monitors the trains using this information and prepares ATC telegraphs to be transmitted to each track circuit.

3.3.1.2 Transmission Control System (TCS)

The TCS deciphers ATC telegraphs received from the ATC logic device and

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transmits the deciphered telegraphs to each transceiver. Vice versa, it performs train detection based on information received from each transceiver.

3.3.1.3 Transceivers

One transceiver responds to a track circuit. Each transceiver transmits ATC telegraphs to a track circuit after modulating them into MSK (Minimum Shift Keying). Vice versa, it demodulates signals received from a track circuit, and transmits train detection information to the TCS.

3.3.1.4 ATC Monitor

The ATC monitor records the conditions of signal currents flowing through track circuits and the contents of telegraphs as maintenance information.

3.3.1.5 Gateway

The Gateway performs mutual information transmission with the ATC devices installed in adjacent equipment rooms.

3.3.2 On-board Equipment

The on-board equipment is composed of the following devices.

3.3.2.1 Receive and Control Unit

Based on the stopping position information transmitted from ground equipment, this unit searches for braking patterns stored in the database. Next, it verifies the present position of the running train concerned and the proper braking pattern and outputs a braking command. Then, it outputs a permissive speed signal to the speedometer.

3.3.2.2 Inspection and Recording Unit

This unit records histories of performance and inspections, and outputs performance conditions to the monitoring device.

3.3.2.3 Transponder

This unit receives position information from wayside coils installed approximately every three kilometers and outputs it to the receive and control unit.

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3.3.2.4 Speedometer

As shown in Fig. 4, this indicates permissive speed signal and train speed.

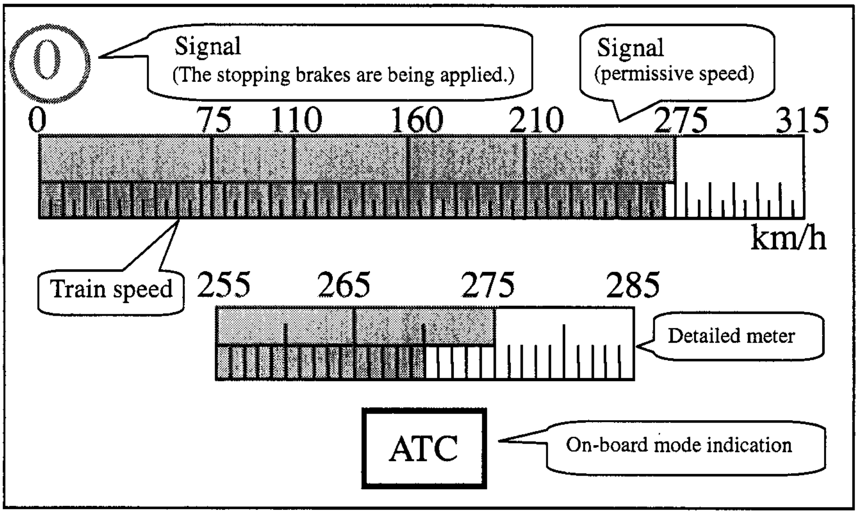

Figure 4: Cab signals of DS-ATC

3.4 Ensuring Safety and Reliability [3]

In the case of the DS-ATC, both the ground and the on-board equipment are made failsafe, and to ensure the safety of the entire system, communication between them is performed by control with consecutive numbers and conducting transmission error verification. The ground equipment ensures safety and reliability using two-out-of-three voting system verification. On the other hand, the on-board equipment ensures safety and reliability by incorporating dual processors for comparison and verification.

All of the communications that the ground equipment transmits to the on-board equipment are given CRC-approved codes and consecutive numbers respectively. The on-board equipment confirms the codes and numbers received, and annuls incorrect communications. Thus, the safety of communications between the ground and the on-board equipment is ensured.

Trains are detected by verifying the receiving signal level and the correctness of the communications received. The correctness of the communications received is judged by verifying the consecutive numbers of the communications transmitted and received, the track circuit numbers and the CRC-codes.

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4. Effects of DS-ATC introduction

The effects expected from the introduction of the DS-ATC are described in the following.

4.1 Improved Riding Comfort

Compared with the multi-level braking control ATC shown in Fig. 1, the single-level braking control DS-ATC enables smooth speed control by virtue of variable braking forces, thus improving riding comfort.

4.2 Shorter Time Intervals

In the case of the multi-level braking control, the frequency of low-speed travel tends to increase because applied brakes are released in stages. In the case of trains with a quick deceleration system, train speed decreases quicker than in the case of trains with other type of deceleration systems. Therefore, the length of the low-speed traveling section is longer.

On the other hand, in the case of the DS-ATC, such losses in train operation can be decreased because single-level braking control is employed. In addition, it is possible to perform optimum train control by train type because the on-board database has braking patterns designed to the deceleration performance of each type of train.

4.3 Future Possibility

It will become possible to respond to increases in train speed in the future only by changing the database, and not by changing the hardware as hitherto required.

5. Introduction of the DS-ATC

This section describes the DS-ATC introduction plan that is being implemented at present.

5.1 Northward Extension of the Tohoku Shinkansen Line

It was decided to introduce the DS-ATC into new lines constructed concurrently

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with the implementation of the northward extension of the Tohoku Shinkansen Line scheduled in December of this year (2002). After a trial run of trains mounted with the DS-ATC, scheduled for this autumn, JR East will start operating its Shinkansen trains with the DS-ATC in limited sections after December of this year. This will be the debut of world's first fully digital ATC.

5.2 Renewal of Tohoku-Joetsu Shinkansen ATC

The present ATC used on the entire Tohoku-Joetsu Shinkansen Line (approximately 840km, with 26 stations) is aging and needs to be replaced in a few years, so its renewal plan is being drafted. JR East is planning to replace the system for the entire line with the new ATC discussed here.

This renewal project is expected to be of an unprecedented large scale because it involves the installation of optical fiber lines for information exchange, the implementation of automated shunting operations at large-scale rolling stock depots, and the realization of wireless train control. At present, it is planned to complete the entire project by 2008.

6. Conclusion

JR East has developed a digital ATC for its Shinkansen lines applying the latest computer and network technologies, and is moving forward with the introduction of the system. Shinkansens operating with this digital ATC will provide passengers safer, more comfortable travel. Moreover, since the new ATC is of an on-board control type, its entire composition is more compact, which allows for reductions in construction and maintenance costs.

We, at JR East, are confident that the DS-ATC will become a standard ATC for railway systems and intend to recommend its introduction in various fields.

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