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Automatic train control with on-board computers

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Abstract

Since 1981, the Automatic Train Control (ATC) devices have been used to maintain a safe distance between trains on the Yamanote and Keihin-Tohoku lines in Tokyo. Although shorter train headways have been desired for years to increase the line capacities, this has been impossible with the conventional ATC. The authors have developed a new ATC system, the Digital ATC system, to replace the conventional ATC. With digital transmission and on-board intelligence, the Digital ATC system enables a reduction in train headways in peak hours at a lower cost than the existing system. In the Digital ATC system, the ground equipment calculates the furthest block to which the train can travel safely (the stopping point) and transmits it to the train as a digital signal. Based on the stopping point information sent from the ground, the on-board equipment retrieves the appropriate permitted speed profile (the braking pattern) from the on-board database. The actual speed and position of the train are compared with the permitted speed profile and brakes are applied automatically when necessary. The new system will be put into use between Minami-Urawa and Tsurumi on the Keihin-Tohoku line in 2003.

1 Introduction

The Yamanote and Keihin-Tohoku lines are the most crowded commuter routes in Tokyo. On these lines, trains run at 2'30" headways in peak hours. Although a greater line capacity of these lines has been long hoped for, reduction in train headways has been impossible with the conventional ATC. Reviewing the

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fundamental requirements for train interval control, the authors have developed a new ATC system, the Digital ATC system, based on digital transmission and on-board intelligence.

2 Conventional ATC

The conventional ATC was developed originally for the Tokaido Shinkansen and later introduced to some heavily-used commuter routes in Tokyo, including the Yamanote and Keihin-Tohoku lines.

In the conventional ATC, the lineside device continuously sends signals describing the permitted speed, to which the train speed is automatically reduced. The permitted speed is determined for each block and sent in frequency-coded signals through track circuits. On the train, the permitted speed is displayed in the driving cab and is compared with its current speed. If the train is traveling too fast, the brakes are automatically applied until the train has slowed down to the permitted speed.

Although the introduction of the conventional ATC has eliminated lineside signals and achieved a higher degree of safety, the existing system still presents the drawbacks described below.

2.1 Waste in line capacity and train running time

In the conventional ATC, the permitted speed for each block is specified in a finite number of speed steps, such as 90 - 65 - 45 - 25 - 0km/h. Therefore, brakes are applied and released repeatedly when a train is traveling close to the preceding train. This makes the train headway and the train running time considerably longer than the theoretical limit.

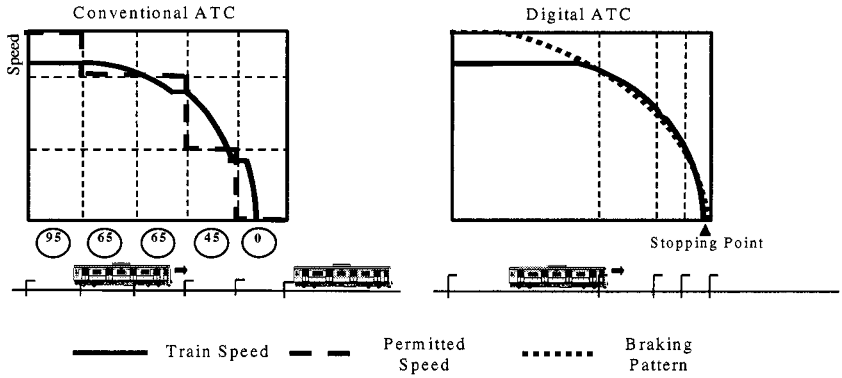

Figure 1: Conventional ATC and Digital ATC

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2.2 Deterioration of riding comfort and driver-friendliness

The conventional ATC gives the driver no indication of the permitted speed for the block ahead of him. If the train speed is higher than that, brakes are applied unexpectedly when the train enters the new block. This may cause a sudden change from acceleration to deceleration, thereby deteriorating riding comfort and driver-friendliness.

2.3 Costly ground equipment

Construction and maintenance of the conventional ATC are costly. In the lineside devices, many relay circuits are used and require large space. In addition, numerous long cables are laid between each track circuit and centrally- placed components.

2.4 Difficulty in full utilization of improved rolling stock performance

With the conventional ATC, it is difficult to fully utilize the improved braking capabilities of modern rolling stock in order to achieve shorter headways. Since the ground equipment determines the permitted speed irrespective of the rolling stock performance, the ground equipment needs to be adjusted to the rolling stock with the worst braking performance on the route. When the braking performance of all the rolling stock has been improved, a large-scale alteration to the ground equipment is inevitable.

3 Principles of Digital ATC

To solve the problems mentioned above, the Digital ATC system has been developed based on principles which are completely different from those of the conventional ATC.

3.1 Train interval control based on stopping point information

In order to guarantee that the train can stop clear of the preceding train, the transmission of the permitted speed is not necessarily required. The following three sorts of information will suffice instead: (1) the point where the train should stop (stopping point), (2) the current train speed, and (3) the current train position. In the Digital ATC system, not the permitted speed for each block but the stopping point is transmitted from the ground equipment to the train. The current speed and position of the train are monitored on-board.

3.2 Digital transmission

The stopping point information is digitally transmitted through track circuits,

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whereas analogue transmission is used in the conventional ATC to send the permitted speed. Digitization enabled the transmission of the stopping point, which consists of a far greater amount of information than that of the permitted speed.

3.3 On-board intelligence

In the Digital ATC system, more intelligence is vested in the on-board equipment. The on-board equipment continuously monitors the speed and position of the train. The on-board equipment stores braking patterns in its database and retrieves the appropriate braking pattern when the stopping point information is received.

3.4 Autonomous decentralized system

Both the ground equipment and the on-board equipment of the Digital ATC system are autonomous decentralized systems. The ground equipment is a network of logic controllers which are decentralized and independent. This composition prevents a fault in one part of the system from affecting another. Also, it enables the system to be built up step by step. The on-board equipment of each train autonomously controls the train speed based on the stopping point information it receives. The ground equipment no longer needs to be altered in order to make the best use of the braking performance of the train.

4 Configuration of Digital ATC system

4.1 Ground equipment

The ground equipment is composed of logic controllers, transmitter/receiver units, and interfaces with interlocking systems. A logic controller is placed at each station with an interlocking system and it covers the area including that station and adjacent stations without interlocking systems. Transmitter/receiver units are distributed to all stations and connected to the track circuits. Logic controllers and transmitter/receiver units are connected by a 10Mbps optical network called ATC-LAN.

The logic controller, crucial for the safety level of the whole system, is a fail-safe two-out-of-three voting system. The rest of the ground equipment, including the network, constitutes a duplex system to ensure higher reliability. As the logic controller solely processes the data vital for safety, a simplified system has been realized.

4.2 On-board equipment

On trains, every car with a driving cab is fitted with a reception/control unit, a

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transponder signal processing unit, and an inspection/record unit. The reception/control unit receives the ATC signal sent through the rails and controls the train speed. The transponder signal processing unit receives information from transponders mounted between the rails. The inspection/record unit registers the status of the train itself and the on-board equipment every 300ms for easy diagnosis of failures. In addition, this unit performs an automatic inspection of the on-board equipment.

The reception/control unit is composed of two sets of fail-safe devices to enable normal train operation even when one set has failed. The transponder signal processing unit and the on-board database also have a duplex configuration.

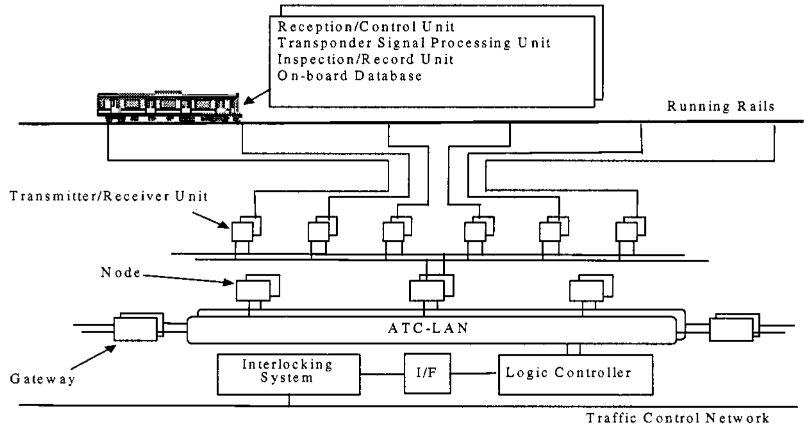

Figure 2: Configuration of Digital ATC system

5 Function of Digital ATC system

In the Digital ATC system, the ground equipment detects train occupancies, calculates the stopping point, and sends it to the trains. Receiving the stopping point, the on-board equipment retrieves the braking pattern and controls the train speed.

5.1 Train detection

Trains are detected using track circuits. From one end of a track circuit, a 16-bit digital signal is fed by a transmitter/receiver at intervals of 160ms. This signal is received at the far end by another transmitter/receiver unit and its level is measured. By the variation in the received signal level, the logic controller

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judges whether the block is occupied by a train.

5.2 Calculation of stopping point and transmission of ATC signal

The logic controller calculates the stopping point and creates an ATC signal message, which is transmitted to the track circuit by the transmitter/receiver unit.

The stopping point is calculated based on the train occupancy information and the route setting information. The route setting information is obtained from the interlocking system. Then, a 64-bit ATC signal message, which contains the description of the stopping point, is created and transmitted from the transmitter/receiver unit to trains through the rails at intervals of 320ms as a minimum shift keying (MSK)-modulated signal in the high-level data link control (HDLC) format.

5.3 Recognition of train position

The position of the train is continuously located by the on-board equipment, based on the route information in its database and the pulse count of the tachometer-generators. The train position, described by the block code and the distance to the far end of the block, is initialized and corrected by the message from a transponder placed between the rails at approximately 1 km intervals.

5.4 Reception of stopping point information and pattern retrieval

The ATC signal transmitted through the rails is received by the pick-up antennae mounted on the front bogie. The on-board equipment performs a cyclic redundancy check (CRC) of the received message and checks the serial number and contents of the message for integrity. After that, based on the stopping point in the received message and the actual train position, the reception/control unit retrieves the braking pattern from the on-board database. The braking pattern has been drawn with consideration of track characteristics such as the curve radii and gradients as well as the braking capabilities of the train.

5.5 Speed check and brake control

The on-board device compares the train speed with the retrieved braking pattern and applies brakes if the train speed is over the braking pattern. While the brakes are being applied, the on-board device performs feedback control to make the train decelerate closely following the braking pattern. In order to improve riding comfort, the brake force is increased step by step up to the maximum service braking and decreased just before the train comes to a stand.

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5.6 Display in the driving cab

Around the periphery of the speedometer in the driving cab, triangular light-emitting diodes (LEDs) are placed at 5km/h intervals up to 110km/h, with 0km/h in red and others in green. The 0km/h LED is turned on when brakes to a stand are applied by the Digital ATC system, and the LED corresponding to the restricted speed lights up when the train is on a curve or a turnout. In other cases, the LED corresponding to the permitted speed is illuminated.

The monitor display on the driver's desk indicates the distance to the stopping point, the type of the ATC braking initiated, and the reason for brake application. The driver can expect the position of the preceding train based on the distance to the stopping point.

A few seconds before the brakes are applied by the Digital ATC system, the "pattern approached" lamp warns the driver of the imminent brake application. Thus the driver can avoid a sudden brake application during acceleration.

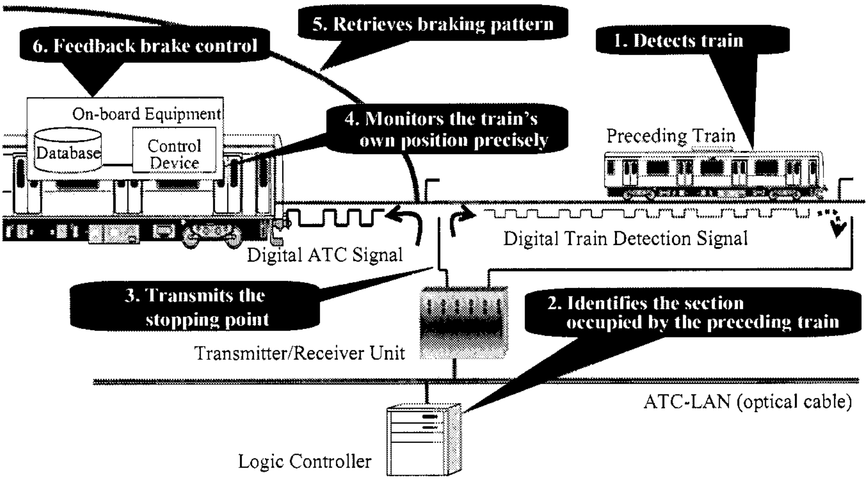

Figure 3: Operation of Digital ATC

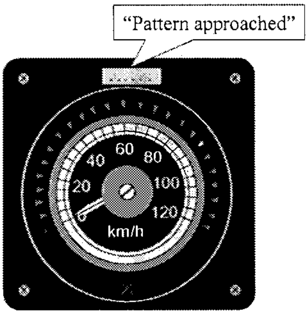

Figure 4: Speedometer on driver's desk

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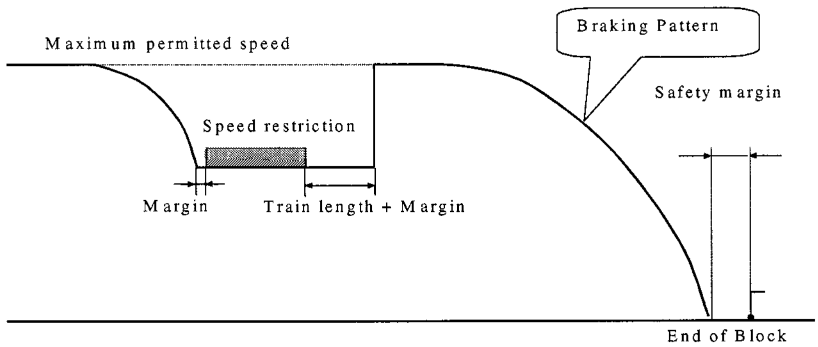

Figure 5: Braking pattern

6 Preparation of on-board database

In the Digital ATC system, braking patterns are prepared beforehand and stored in the on-board database rather than being computed by the on-board equipment every time when a new stopping point is given. For the Yamanote and Keihin-Tohoku Lines, approximately 3,200 braking patterns are required. Although this method requires a greater storage capacity, it enables advance verification of the braking patterns and it gives smaller processing load to the on-board equipment.

The data required to produce braking patterns include the following: (1) description of blocks and track circuits (location, length, etc.), (2) description of curves, slopes, turnouts (location, length, radius of curve, gradient of slope, turnout number, etc.), and (3) description of train characteristics (length, maximum speed, brake performance, etc.). Based on these data, braking patterns are generated automatically and stored in read-only memories (ROMs), which are mounted on the train. The patterns are also printed for visual inspection. Figure 5 shows a braking pattern.

7 Benefits of Digital ATC system

The Digital ATC system enables shorter train headways, better riding comfort and more flexible utilization of rolling stock performance at a smaller cost.

7.1 Increased line capacities

The Digital ATC system enables reduction in train headways. On the Yamanote and Keihin-Tohoku lines, it is now possible to reduce the minimum headway, which has been 2 minutes and 30 seconds (including the dwell time of 50 seconds), to 2 minutes and 10 seconds, in other words, to increase the line capacity from 24 to 28 trains per hour.

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7.2 Improved riding comfort and driver-friendliness

The digital ATC system decelerates trains by continuous brake application, preventing deterioration of riding comfort caused by the intermittent brake application. In addition, the driver is provided with the information on the stopping point and the status of the system.

7.3 Adaptability to improved rolling stock performance

When the braking performance of the rolling stock is improved, the conventional ATC requires alteration of ground equipment on a large scale if the train headway is to be shortened. However, in the case of the Digital ATC system, it is sufficient only to replace the on-board ROM that stores braking patterns. This enables the best use of the improved braking performance without having to alter ground equipment.

7.4 Smaller cost

To cut building cost, components commonly used elsewhere are adopted as much as possible. Use of compact devices has reduced installation space and has cut the cost for housing. Since the housing rooms are distributed and connected with optical local area network (LAN), costs for cable laying and trough construction have also been reduced. Adoption of non-insulated track circuits has also decreased the quantity of transmitter/receiver units and their maintenance costs.

Figure 6: Keihin-Tohoku line trains fitted with Digital ATC equipment

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8 Installation

Installation of trackside equipment between Minami-Urawa and Tsurumi on the Keihin-Tohoku Line began in June 2000 and will be completed in the spring of 2003. Also, retrofitting of the on-board equipment to the 83 trainsets, each consisting of ten cars, is under way since November 2000. During the installation work, train operation is continued using the conventional ATC.

9 Conclusions

In order to allow trains to operate at shorter headways on the Yamanote and Keihin-Tohoku lines, the Digital ATC system has been developed to replace the conventional ATC. The Digital ATC system achieves shorter train headways at a smaller cost. It also improves riding comfort and driver friendliness. In addition, the Digital ATC system can easily exploit the improved rolling stock performance.

The outcome from the development of the Digital ATC system is also utilized for the Shinkansen. When the Tohoku Shinkansen is extended northward from Morioka to Hachinohe in December 2002, a system called the "Digital Communication and Control for Shinkansen-ATC" (DS-ATC), which was developed based on the Digital ATC, will be put into use in the extended section.

As a future train control system, the East Japan Railway Company is developing the "Advanced Train Administration and Communication System" (ATACS) based on radio communication and on-board intelligence. Technologies acquired through the development of the digital ATC system have also been applied to this system.

References

[1] Matsumoto, M., On-Board Autonomous Decentralized Train Control System, *J. IEE Japan*, **121(2)**, pp. 110-114, 2001

[2] Matsumoto, M., Hosokawa, A., Kitamura, S., Watanabe, D. & Kawabata, A., Development of the Autonomous Decentralized Train Control System, *IEICE TRANS INFO. & SYST.*, **E84D(10)**, pp.1333-1340, 2001

[3] Matsumoto, M. & Mizukami, Y., New ATC System for Yamanote and Keihin-Tohoku Lines, *Japanese Railway Engineering*, **41(2)**, pp. 6-10, 2001