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Radio Train Control System (ATACS)

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Since the first railroad began operations in 1830, various schemes for ensuring safety have been developed and these schemes have contributed significantly to the safety and efficiency of railroad operations. However, issues still remain from such perspectives as control from wayside equipment, reduction of cost, achieving even greater safety, and provision of new services. With the full model change of the railway control system as the objective, the safe and simple train control system ATACS (Advanced Train Administration and Communications System) is currently being developed. This system replaces the method of control from wayside equipment with a system that deploys a division of control between wayside equipment and on-board equipment from the functional perspective based on information technology. This paper reports on the scheme of ATACS, overview of tests to date using actual train cars, and overview of the ATACS prototype test using actual train cars that will begin in autumn 2003.

● Keyword : Train control, on-board position detection, digital radio, moving block

I Introduction

The world's first railroad that provided commercial services is said to have been the Liverpool & Manchester Railway (UK) that began operations in 1830. By placing guards at level railway crossings, three types of messages using hand signals -- representing danger, caution, and proceed -- were used. But with the increasing number of train services, accidents occurred and in order to prevent this, various safety devices were invented and deployed. Following the introduction in 1834 of a signal tower to indicate danger or safety, Morse code which was announced in 1837 was used to make contact with neighboring stations and a "Space Interval Directive" was enforced in 1858 forming the basis for train safety devices of the present day. The "track circuit" for detecting the position of a train was invented by the American William Robinson in 1872 and in 1873, the following year, this was adopted by the Pennsylvania Railroad.

On the other hand, in order to ensure safety and efficiency in the track composition of trains in stations, in 1856 John Saxby invented an interlocking machine that formed the basis for the mechanical interlocking machines of today. Moreover, the interlocking relay was born in the United States through the success of CTC in the 1920s which was used as the model and use of this relay began in the United States in 1927.

These technologies were epoch making at the time and contributed significantly to the safety of railways and efficiency of transport to achieve the position currently enjoyed by the railroad as the safest and most dependable means of transportation. Needless to say, the railway signal system of today is the result of accumulated technology through constant improvements made to the above equipment.

Through such "schemes for safety," a certain level of safety and transport efficiency has been achieved but since control is from wayside equipment, such issues as reduction in cost, further improvement of safety, and provision of new services have been left unattended. With an eye on current and future technological trends, the development of the new train control system ATACS that is appropriate for the 21st century is currently being undertaken. The development work involves fundamental review of railroad control systems and the perspective of what form the control system to be newly developed should take.

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2 New Train Control System

In recent years, the development of information communication technology such as mobile communication and computers has been significant. Moreover, it could be said that these technologies are suitable for the control of trains which are mobile in character. ATACS is a safe and simple railway control system that utilizes information communication technology as base and deploys a division of control between the wayside and on-board equipment from a functional perspective to replace the past method of control that relied principally on wayside equipment.

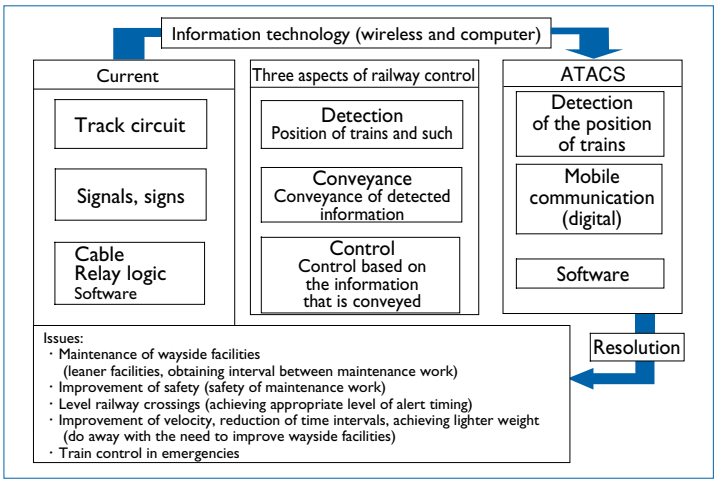


Fig.1: The Three Aspects of Train Control

3 Train Control Based on Information Technology

When one returns to the basics in considering a train control system, from the time of immediately after the development of the railroad, the control system embodied the following three aspects and this has not changed in the ensuing years. Moreover, as long as there is no change in the fundamental character of the railroad that involves trains moving on tracks, these aspects cannot be expected to change in the future.

(1) Detection: Detection of position of trains and such

(2) Transmission: Transmission and receipt of information on this position (transmission to other trains, to track composition equipment at stations, to maintenance personnel, etc.)

(3) Control: Control based on the position information that is received (control of velocity, control of route, control of alerts at level railway crossings, etc.)

In the following sections, the status of these three aspects, detection, conveyance, and control, in the current system will be analyzed and the direction of improvement in the development of ATACS will be indicated. This figure compiles the results of such analysis.

4 Development Objectives, Expected Results

The objective of developing ATACS is to undertake a "full model change of the railway system." The expected results of this are the following.

(1) Reduced cost

By changing the current system which is based on heavy equipment and high cost to a scheme with little equipment and less reliance on manual work, a low cost system may be created.

(2) Increased safety

The pipe for transmitting information to the train in the current system that is based on the track circuit is weak. The development initiative aims to include maintenance work into the control system that currently remains as an issue and resolution of train control in emergencies during natural disasters through enhanced capability in information transmission and through these results, improvement of the safety of the railroad system as a whole may be expected.

(3) Enhanced efficiency of transport

With the current system, control is uniformly undertaken using the block system so that even were high performance vehicles to be introduced, control will conform with the performance of legacy vehicles. Moreover, in order to achieve enhanced efficiency of transport such as through increased train velocity or reduced time interval, major improvements are required in the wayside equipment thus necessitating work over a long period, numerous man-days of labor, and high cost. With ATACS, trains have autonomous control based on performance level and through the adoption of the moving block method, enhanced efficiency of transport will be targeted.

Fig. 2 shows an overview of the ATACS system.

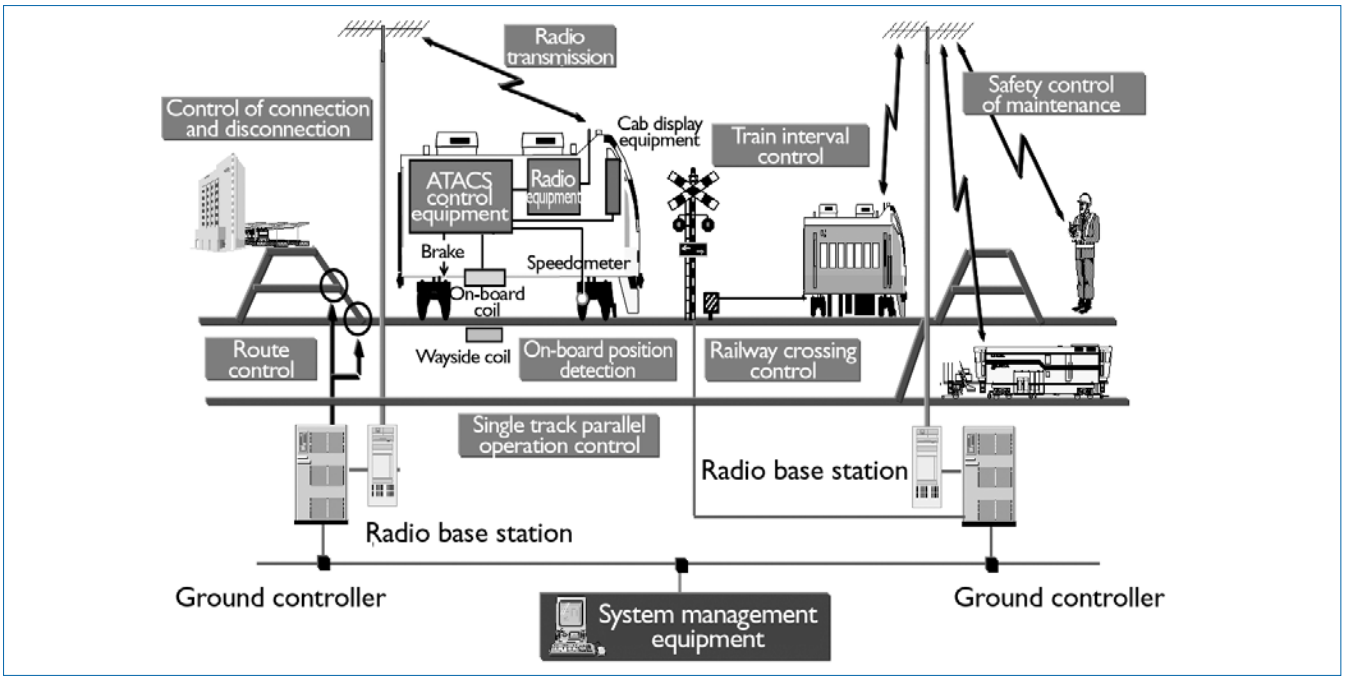


Fig.2: Overview of the ATACS System

5 System Configuration

5.1 Equipment Configuration

ATACS is comprised of the on-board ID management equipment, system management equipment, ground controller, radio base station and transmission circuit that connects the various equipment, on-board radio station deployed on trains, on-board control equipment, display equipment in the cab deployed at the cabs at the front and rear of a train, and transmission equipment that connects the on-board control equipment with the display equipment in the cab.

5.2 Wayside Equipment

5.2.1 On-board ID management Equipment

On-board ID management equipment manages ID of the on-board control equipment of all trains that exist within the ATACS system and is used when ground controller breaks down and is started up again. The on-board ID management equipment is comprised of fail-safe hardware.

5.2.2 System Management Equipment

System management equipment has such functions as setting the track kilometer posts between stations, setting track closure information that is input in units of track blocks that corresponds to the legacy track circuit with the turnout in the station compound as the main constituent, setting the route of maintenance vehicles that have position information as do trains, setting provisional speed limits in units of 5 km/h with track kilometer posts between stations and track blocks in the station compound as in the case of track closure, control of setting parallel operation of single tracks in order to obtain interval between train operations for carrying out required maintenance work, changing the system mode setting upon impairment of the system, and monitoring the status of operation of the system as a whole.

5.2.3 Ground Controller

Ground controller has such functions as tracking trains based on the position information received from the on-board equipment, interlocking control that safely configures the requested route, controlling the interval between trains based on the route and train position, controlling the system boundary that enables automatic control of ATS and ATACS based on line open condition at the system boundary, and controlling the level railway crossings based on the train position and velocity.

5.2.4 Radio Equipment

The radio station is comprised of the base radio station that is connected to the ground controller and communicates with the train and the on-board radio station that is connected to the on-board control equipment and communicates with the wayside.

Digital radio operates in the 400 MHz bandwidth, configures a zone through the repetition of 4 frequencies, and has a transmission speed of 9,600 bps. Based on the volume of information required for controlling a train and displaying the status of a train, a single cycle (960 ms) from the wayside to the train is divided into 16 slots with 12 slots used for controlling the train and the remaining 4 slots used to transmit such information as the version of the route database. Through this scheme, one radio base station is capable of controlling a total of 12 trains on the up and down line.

Since ATACS controls trains using radio communication instead of track circuit, radio transmission must always be stable with respect to all trains in the system. For this reason, radio base stations are installed at intervals of approximately 3 kilometers to satisfy the required quality of transmission. Moreover, an error correction code is attached to the control information or the accuracy or otherwise of data is determined using an error detection code towards ensuring stable transmission quality. Security is also enhanced through encryption. Fig. 3 shows the overview of the radio system.

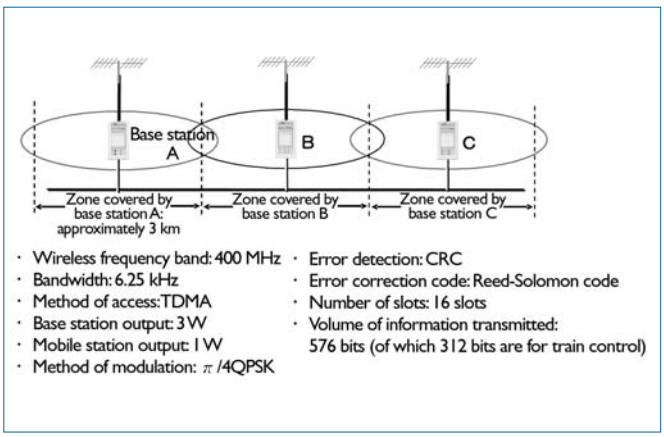


Fig.3: Overview of the radio System

5.3 On-board Equipment

5.3.1 On-board Control Equipment

On-board control equipment obtains the train's own position and determines and transmits this position by appending information on the length of the train. A brake intervention curve is produced from this position information and the Limit of Movement Authorized (LMA) that is sent from the key facility to enable travel within this scope. In the event the speed of the train exceeds brake intervention curve, the system automatically outputs brake control.

Transmission equipment is mounted on the train to connect the display equipment in the engineer's cab at the front and rear of the train and the on-board control equipment and a single train make-up is comprised of one control device. Fig. 4 shows the configuration of the on-board equipment.

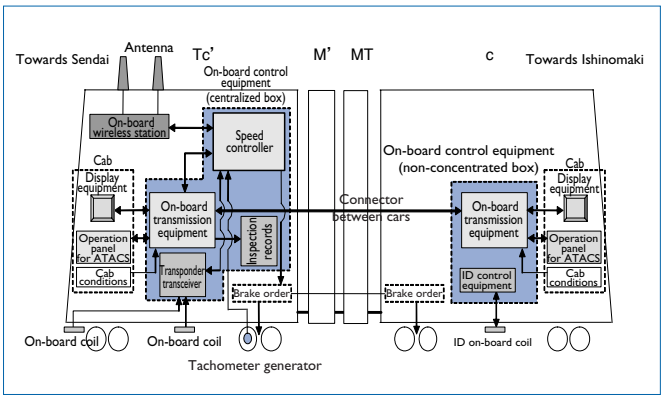


Fig.4: Configuration of the On-board Equipment

6 Functions

The functions of ATACS are the function for tracking trains, function for controlling the train intervals, function for setting routes in the railroad compound, function for controlling level railway crossings, function for setting provisional speed limits, function for controlling parallel operation on a single track, function for controlling system entry and departure, function for ensuring maintenance safety, and function for controlling train protection control. The following sections provide an overview of each function.

6.1 Function for Tracking Trains

Ground controller continuously tracks the train's position using the position information that is transmitted from the on-board control equipment in cycles of approximately one-second.

In tracking a train, both the ground controller and the on-board control equipment have a common route database and the ground controller tracks the train by laying out the position information received from the on-board equipment on the track block.

Moreover, on-board recognition of the train position in branching sections in the railroad compound is undertaken by the ground controller transmitting route information that corresponds to the route conditions to the train. The on-board control equipment plots the train's position calculated from the distance traveled on a track block that is based on the route information sent by the ground controller to

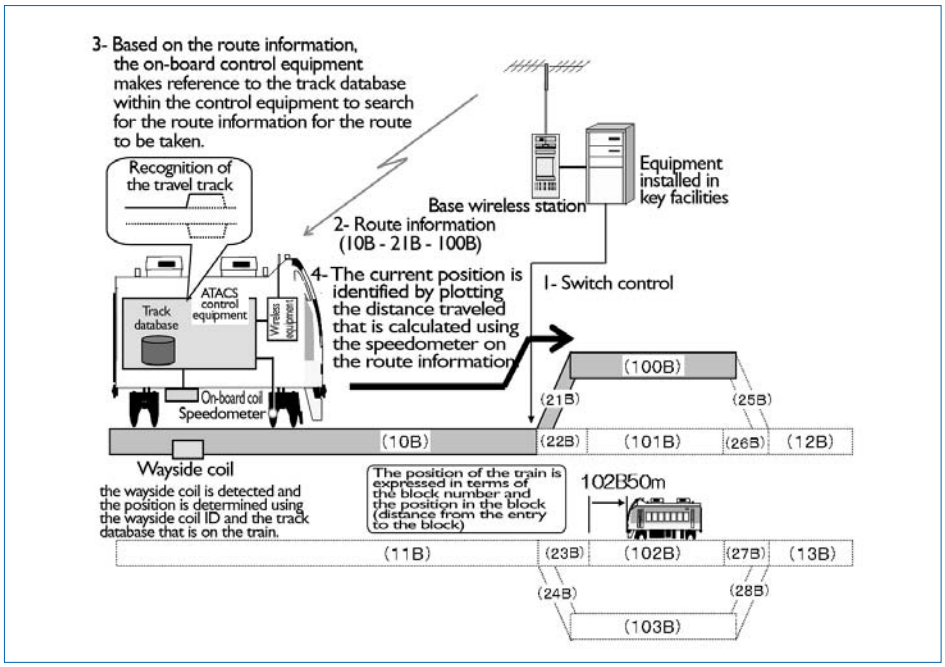


Fig.5: Example of Composition of a Track Block

identify the current position. Fig. 5 shows the scheme for identifying position in ATACS.

6.2 Function for Controlling the Train Interval

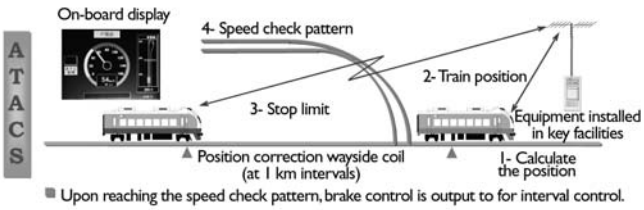
6.2.1 On-board Position Detection

The initial position of a train upon turning the electric power on is obtained by the on-board transponder reading the specific data of the wayside transponder that is installed at the rest position of the train and collating this to the track data held on the train. Movement of position as a result of the train traveling is calculated by totaling the travel distance using the tachometer generator and the position after travel is transmitted in each cycle to the ground controller.

Some degree of error is generated in the tachometer generator due to travel and a transponder is installed as required and specific data is read upon passing this transponder to correct position information and reduce the error.

6.2.2 Control of the Train Intervals

The train position information that the train itself detects is transmitted using digital radio to the ground controller that controls the train. The ground controller configures the route required for train operation based on the train position information that it receives. The equipment then searches for conditions that would act as impairment in the section to the end of the route (train traveling ahead, system boundary, radio area boundary, etc.). The equipment then calculates the furthermost point to which the train may travel (stop limit) and resends this information using digital radio to the train. The on-board equipment that receives the stop limit from the ground controller produces a brake intervention curve from the stop limit position to the current position of the train and the train travels within this range. If the speed of the train exceeds the brake intervention curve, the on-board control equipment outputs brake control to cause the train to stop prior to the stop limit. Fig. 6 shows the overview of train control in ATACS.



①The train position is calculated by the number of revolutions of the wheel (corrected by the wayside coil for position correction).
②The train position is transmitted to the wayside equipment using radio equipment.
③The wayside equipment produces a stop limit based on the position of the train traveling ahead and transmits this information to the train that follows.
④The train that follows produces a brake intervention curve from the stop limit.

Fig.6: Overview of Train Control in ATACS

6.3 Function for Controlling the Setting of Routes in the Railroad Compound

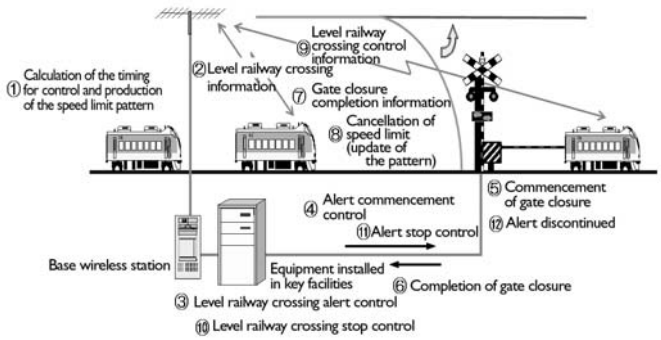
The function for controlling the setting of routes in the railroad compound controls the route by dividing the rails into certain track blocks principally based on turnouts and clarifying the relationship between the blocks and the turnouts in order to control the route. This configuration achieves the fundamental functions that are linked with route competition, approach lock, route lock, and point lock as in the past.

6.4 Function for Controlling Level Railway Crossings

In place of the current system of alert control using the track circuit and electronic train detector, control of level railway crossings in

ATACS is undertaken by the on-board control equipment that calculates the time to each level crossing and requests the ground controller to sound an alert at the relevant level crossing when the time to that crossing becomes less than the required alert time. Moreover, the alert is discontinued when the system recognizes that the rear of the train has completely passed through the level railway crossing based on the train position information.

Fig. 7 shows the railway crossing control system and its characteristics in ATACS.



	ATACS	Current system	
Alert control	Train speed, position	Fixed point control	More appropriate alert time Greater flexibility with respect to changes in transportation
Alert status	Pattern control	Not acquired	Enhanced safety
Railway crossing failure	Pattern control	Obstruction warning indicator (visual observation)	Enhanced safety
Railroad compound crossing	Prevention of overrun: not required	Prevention of overrun: required	More appropriate alert time

Fig.7: Function for Controlling Level Railway Crossing

6.5 Function for Setting Temporary Speed Restriction

When the traffic controller sets a temporary speed restriction for a certain section, the system management equipment transmits this information via the ground controller to the on-board control equipment.

When the on-board control equipment receives the temporary speed restriction information from the ground controller, it reflects this temporary speed restriction in the track data and produces a brake intervention curve that incorporates this temporary speed lrestriction.

When the speed of the train exceeds this brake intervention curve, brake control is output as in normal operations and the brake control is released when the speed of the train is reduced to less than the temporary speed restriction. Fig. 8 shows the method temporary speed restriction control.

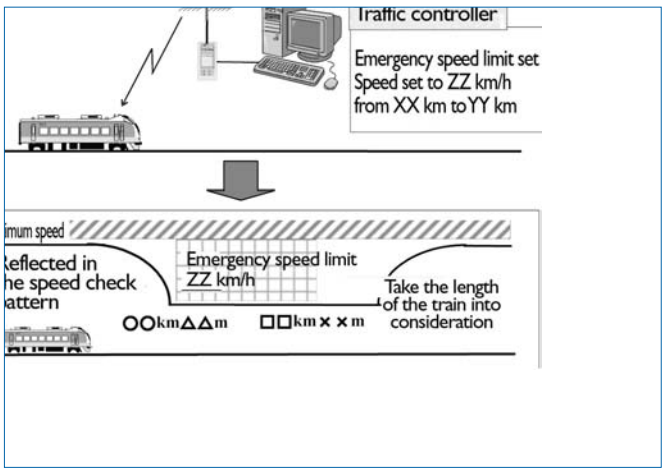


Fig.8: Temporary Speed Restriction Control Function

6.6 Function for Controlling Parallel Operation on a Single Track

The function for controlling parallel operation on a single track is a function for continuing operation of trains when one set of tracks in a double track section is unusable due to maintenance work or other reasons by designating the usable track for single track operation.

In ATACS, since control of train interval and control of level railway crossings are effected using data, it is easy to implement single-track parallel operation without the need to increase wayside equipment.

6.7 Function for Controlling System Entry and Departure

Entry into and departure from the ATACS section is undertaken by installing a switching track block in the section that comprises the boundary and automatically switching the control method when traveling through this section.

Entry into the ATACS section involves determining the position of the train when passing the transponder that is installed prior to entry into the ATACS section and beginning radio connectivity with the ground controller. While traveling in the switching track block, the on-board control equipment switches the method of control from ATS to ATACS based on receipt of a line-clear signal for the boundary track used to enter the system and the stop limit in the system.

In departing from the ATACS section, a switching track block is installed as in the case of entry and if the status of the boundary track for departing from the system turns to line-clear as the train travels in this block, the on-board control equipment switches the method of control from ATACS to ATS and after traveling for a certain distance, discontinues radio transmission.

6.8 Function for Ensuring Maintenance Safety

Currently maintenance work is separate from the control system and relies entirely on the care exercised by the workers. In ATACS, concurrence between maintenance work and train operation is obtained for management and control. Maintenance vehicles are also controlled as is the route of maintenance vehicles in a railroad compound. Fig. 9 shows safety control with respect to maintenance work.

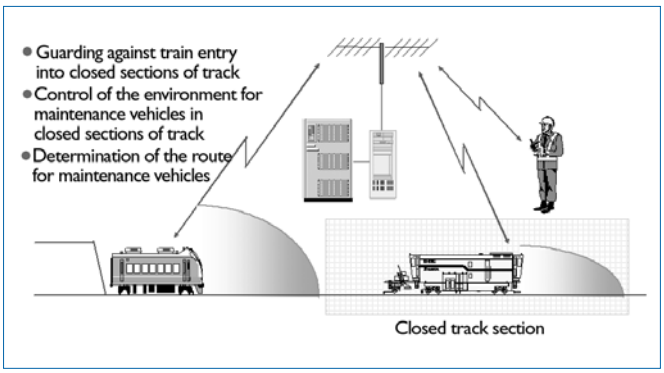


Fig.9: Safety Control of Maintenance Work

6.9 Function for Controlling Train Protection

When a train needs to be stopped in an emergency through the use of the emergency button at platforms, obstacle notification equipment or obstacle detection equipment of level railway crossings (currently operated by the obstruction warning indicator), train protection control is activated in ATACS.

7 Development Process

Since the content of development is extremely diverse, the development process is being carried out in several stages.

- Phase 1: This phase covered the period from September 1997 to February 1998 during which train operation tests were conducted on the approximately 16 kilometer section between Nigatake Station and Higashi Shiogama Station on the Senseki Line using four actual trains. The proper functioning of on-board position detection, radio transmission, and train interval control that are fundamental to this system has been verified.
- Phase 2: This phase covered the period from October 2000 to February 2001 during which train operation tests were conducted on the approximately 7 kilometer section between Nigatake Station and Tagajo Station on the Senseki Line. Through verifying applied technology required for application of this system, technical feasibility of practical use of the ATACS system was verified.
- Prototype Test: Based on the results of development to date, tests will be undertaken on long-term reliability and durability.

Fig. 10 shows the development process.

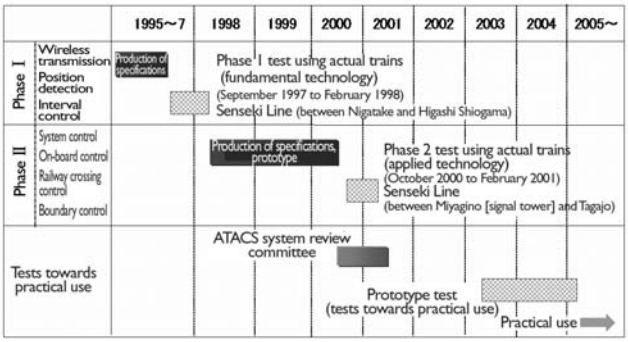


Fig.10: ATACS Development Process

8 Phase 2 Tests using Actual Trains

8.1 Overview of the Test

The Phase 2 tests using actual trains were conducted between October 3, 2000 and February 21, 2001 between Nigatake Station and Tagajo Station on the Senseki Line in Miyagi Prefecture using two test trains.

The train operation tests were comprised of a monitor run test for testing functions without brake output during the daytime and a control run test for confirming functions with brake output on the main line at night after regular services had ended. Fig. 11 shows the composition of the tests involving actual trains.

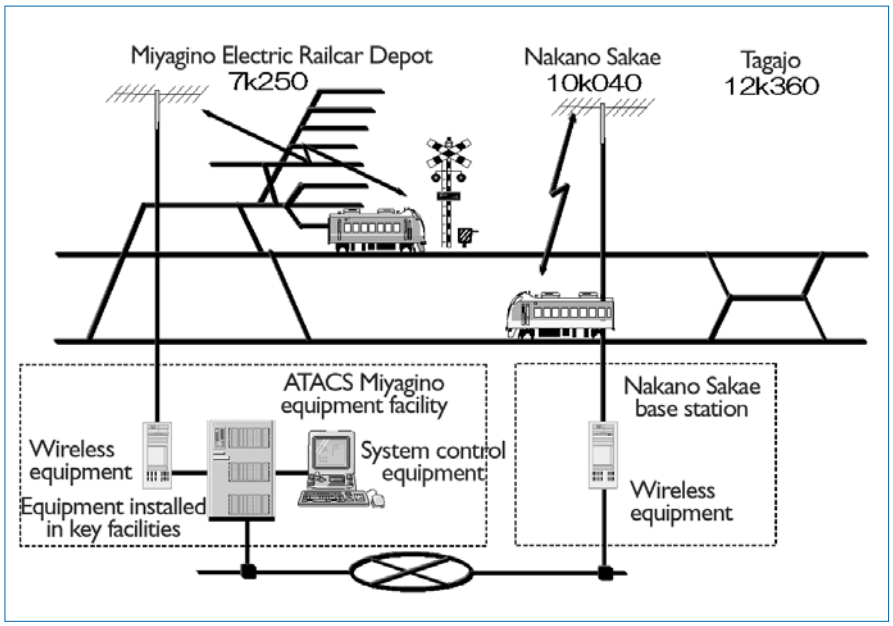


Fig.11: Phase 2 Tests using Actual Trains

8.2 Results of the Test

8.2.1 Ground Equipment

With respect to the system control equipment, it was confirmed through tests that train tracking, temporary speed restriction, track closure, and request for route for maintenance vehicles based on information from the ground controller function properly.

The ground controller was tested with respect to train tracking based on the position information from the train, course control not based on track circuit, train interval control, level railway crossing control based on position information, automatic switching of the method of control upon entry into the system or departure from the system, and determination of position upon start up and these were found to function properly.

8.2.2 Radio Station

With respect to the radio station, the bit error rate, reception level, and frame reception rate were measured between the radio base station and on-board radio station.

The average bit error rate was 6.0×10^{-5} thus satisfying the design level.

The reception level also satisfied the design level. The frame reception rate was 99.9% from the radio base station to the on-board radio station and 99.5% from the on-board radio station to the radio base station thus satisfying the design values.

8.2.3 On-board Control Equipment

The on-board equipment was tested with respect to determination of train position through reception from transponders, calculation of distance traveled through distance totaling by the tachometer generator, production of brake intervention curve upon reception of stop limit information, brake control output upon the train exceeding the brake intervention curve, reflecting the temporary speed restriction in the brake intervention curve upon receipt of such limit, pattern approach time calculation for control of level railway crossings, and prediction of position to be reached in a given time, and these were found to function properly.

The precision of train position detection that is fundamental to this system had a maximum error value of 0.26% (average 0.18%) thus satisfying the 0.3% that was the targeted value.

In the interval control test, two trains were used for the test and a stop limit assuming the minimum interval to be 80 meters was produced using the position information of the forward train and this was transmitted to the rear train. The rear train produced the brake intervention curve based on this information and the method of applying the brake intervention curve at speeds of 25 km/h, 45 km/h and 65 km/h (only for an interval of 150 meters) was put into effect. As a result, the rear train stopped before reaching the stop limit in every case, thus confirming that interval control was functioning properly.

9 Prototype Test

Using the results of the Phase 1 and Phase 2 tests, and with the cooperation of researchers from outside the company, discussion were held on the system. Based on the results of this deliberation, the long-term durability of the system will be tested on the Senseki Line with the aim towards putting the system to practical use.

9.1 Objectives of the Tests

The objectives of the tests may be roughly categorized into "verification of the safety and reliability of the system through tests on

long-term durability," "test of the various functions and verification of train operation with the aim towards putting the system to practical use," and "confirmation of points noted in the system review meeting."

(1) Verification of the safety and reliability of the system through tests on long-term durability
Through collecting large volumes of data over a long period, the safety of such functions as on-board position detection, route control, and level railway crossing control will be confirmed and the reliability of the wayside and on-board equipment will be verified.

(2) Test of the various functions and verification of train operation with the aim towards putting the system to practical use
The various functions required for practical use and functions that have been subject to improvement based on the results of tests up to Phase 2 and handling of abnormalities will be confirmed and verified together with review of train operation.

(3) Confirmation of points noted in the system review meeting
Functions for restoration of the system that take into consideration system maintenance and system breakdowns will be verified.

9.2 Test Composition

The tests will be conducted between Aoba Dori Station and Higashi Shiogama Station (about 18 km) on the Senseki Line installing key station equipment at four locations and radio base stations at eight locations. The on-board equipment will be close to the type that will be used in practical application. In order for large volumes of data to be collected and the functions to be efficiently confirmed, the equipment will be installed on all trains used on the Senseki line (18 trains).

9.3 Test Schedule

The test is scheduled to be carried out in the approximately two years starting from October 2003. During the tests, a combination of monitor run tests and control run tests will be carried out to confirm the status of operation of the various devices. The monitor run tests will take place during service hours and involve the collection of such data as precision of train position detection while the control run tests will take place after service hours and involve various comprehensive functional verification including brake control. The tests will be conducted over a long period of time in order to ensure efficiency in the verification.

10 Conclusions

Development of ATACS began in 1995 and starting from the current fiscal year, prototype tests that represent the final stage of development will begin.

Similar train control systems using radio equipment are being developed overseas and this is believed to be the main direction for the future of train control systems.

In the future, verification of performance will be undertaken through the prototype tests while adjustments in train operation including during abnormal conditions will be made towards development for putting the system into practical use as soon as possible.