Development of integrated automatic train stop with patterns (ATS-P) on-board system

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Abstract

The East Japan Railway Company (JR-East) has been introducing aggressively the ATS-P system, which has a high safety record in train operations in preventing serious train accidents since 1989. As the existing ATS-P on-board system has been used for 10 years, a number of problems for the on-board system are recently increasing. Investigation into the causes of these problems are difficult with the existing system, which has not got appropriate recording devices.

In order to improve the cost-effectiveness, the reliability and the maintenance of the system, the ATS-P on-board system should be completely re-designed.

The authors have developed the integrated ATS-P on-board system. As a result, the system has the benefit of both the reduction in costs and the improvement in the reliability and also a reduction in the number of devices constituting the on-board system. The existing ATS-P on-board system is composed of several devices, but the integrated ATS-P on-board system is composed of only one main device, a smaller relay block and so on. This system shows results with about 70% of the cost and almost 133% of the reliability of the existing newest on-board system. And moreover, the integrated on-board system has the automatic self-testing function and the communication function to outer equipment.

The integrated ATS-P on-board system has been installed in newly-built E 231 series 350 trains since 1999.
1 The ATS-P system and status quo in JR-East

1.1 Structure and behavior of the ATS-P system

ATS-P uses a transponder to enable the wayside-to-train transmission of a large quantity of information. Transponders serve as digital communication devices for sending and receiving information between wayside coils and pickup coils. Some transmission specifications for the transponder are given in Table 1.1.

Table 1.1 Transmission specifications for transponder

<table>
<thead>
<tr>
<th>Transmission</th>
<th>Frequency etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td></td>
</tr>
<tr>
<td>transmission</td>
<td>Wayside . train 1.7MHz (FSK modulation)</td>
</tr>
<tr>
<td></td>
<td>Train . wayside 3.0MHz (FSK modulation)</td>
</tr>
<tr>
<td>Energy transmission</td>
<td>Train . wayside 245kHz</td>
</tr>
</tbody>
</table>

The information is transmitted by electromagnetic waves between a pickup coil and a wayside coil.

As shown in Fig.1.1, the ATS-P system is divided into a wayside system and an on-board system. The wayside system in each block consists of one encoder and several repeaters with each wayside coil. The encoder transmits the telegraphic messages about the present aspect of the signal to each repeater through the information cable. The repeater then sends, at 64kbit/s,
these telegraphic messages to a train through a wayside coil by means of a FSK modulated signal.

The pair of wayside coils, powered by energy transmitted from an pickup coil, sends to the pickup coil the fixed information such as the speed limit of a curve.

The primary objective of the ATS-P system is the prevention of accidents due to either a stop signal violation or speeding at places such as turnouts or curves. Fig. 1.1 shows the system setup. When a signal is indicating 'stop', wayside coils send to the train the 'distance to the signal' information. The ATS-P on-board system then decodes this telegraphic information and then automatically generates a speed verification pattern for the forward signal indicating 'stop'.

Once the pattern is generated, the train speed is continuously compared with the pattern speed. And when the actual train speed read by a tachometer-generator (TG) exceeds the speed verification pattern, the on-board ATS-P system activates the brake. This speed check mechanism assures that the train stops short of the stop signal. Fig. 1.1 shows the history of the train speed during the normal operation and late brake application (resulting in automatic braking).

1.2 Present condition of ATS-P in JR-East

In JR-East, the ATS-P system is used to improve the safety of train operation on a total of 1035km lines in the Tokyo metropolitan area. The forth construction work is practiced currently to introduce the ATS-P system to conventional lines. After the construction work is complicated, Total lines guarded by the ATS-P system is extended to 1490km 28 lines as Fig. 1.2. And corresponding to those widely expanded ATS-P lines, a lots of ATS-P on-board system have been installed to trains since 1988. Total 2,448 cars of 4,099 driving cars hold in JR-East ware furnished by those system.
2 Existing ATS-P on-board system

2.1 Schema of existing system

Fig. 2.1 shows the existing ATS-P on-board system composed of an pickup coil, two main devices (a receiver and speed check block), a relay block, recording block, a train number setting switch and so forth. Each of these devices was designed separately with its individual role in mind. For example, the receiver block inspects telegraphic messages by CRC-check and accepts only genuine information while the speed check block is responsible just for the generation of the speed verification patterns. The only combination of the components performs as an effective ATS-P on-board system. The individual focus for optimum performance of each component results in component redundancy such as separate 8bit micro-processors, interfaces, power supplies, and relays.

2.2 Issue for the existing system

The complexity of the system’s assembly and wiring are responsible for the high manufacturing costs. Since its initial use in 1987, the on-board system’s basic design had been static, with no modifications to its cost, reliability and usefulness. About 10 years has passed since the first ATS-P on-board system had been equipped in trains on Keiyou line at 1987, troubles occurred in on-board systems are fairly increasing lately. Fig.2.2 shows the Fig.2.2 Failure rate occurred to every fiscal year
failure-rate of ATS-P on-board system made in 1989 per every fiscal year since 1989 to 1997.

The largest number of the on-board system was made in 1989. In 1991 those system are tested and amended overall for reduction of breakdown, so the failure-rate at this year is diminished. The failure-rate of the system made in 1989 is increased every year linearly. And this upward tendencies of failure rate are similar to the on-board system made in other-years.

![Fig. 2.3 The result of recurrent test in manufacture factories](image)

After emergency brakes in trains were worked by breakdown in ATS-P on-board system, the system was always tested to detect the causes in manufacture factories. The effect of tests shown in Fig.2.3 teaches you that the recurrence of breakdown is 51% at the most in last 9 years. Half of breakdown cause are unknown. The recording block of existing ATS-P on-board system is designed mainly for the train operation recording triggered by emergency brake actions. It’s clear that the conventional recording style doesn’t suit with the cause resolution of those breakdown.

3 Integrated ATS-P on-board System

3.1 Schema of integrated system 2)

Authors developed the integrated ATS-P on-board system completely changed from the existing ATS-P on-board system in order to improve the cost and reliability, simplify the cause resolution and add new functions meeting the needs of users to the integrated system. In pursuit of ATS-P cost reduction, the existing on-board system was revamped. The redesign effort resulted in the integration of the separate blocks in the on-board system which eliminated redundancy and reduced both cost for material and maintenance labor.

The recently developed system, shown in Fig.3.1, integrates the equipment which constituted the on-board system described before (receiver, speed check block, relay block, recording block) into a control block connected to a small relay block and a memory unit.
The operation unit of the new control block, shown in Fig. 3.2, employs a high efficiency 32bit MPU. This unit integrates the functions of the speed check block, receiver block and recording block. Correspondingly, only one power supply is needed; three were needed before, one for each separate component.

In total, the number of boards in the integrated system is halved, from 16 to 8. The specially developed removable RAM unit for the recording block was replaced by a general-purpose IC card built into the control block.

Wiring between the independent components was also eliminated through the design for integration as each board connects to one piece of the mother board backside the control block. The integration thus reduces ATS-P costs.

The relay block in the existing model compiles output orders from the speed
check block by means of a relay circuit and outputs various brake orders to the
train side. In the revised design, software in the control block processes this relay
circuit, resulting in significant reduction of relay function and size. Consequently, the wiring to the relay block is reduced.

The relay circuit was further reduced with the elimination of the circuit that
controlled the release of the emergency brake and synchronized the initialization
of the various device, when power was applied.

As a result of these changes, the relay unit is responsible for the remaining
eleven out of the twenty-five original important relays necessary for fail-safe
operation that could not be incorporated into the software.

3.2 Results

3.2.1 Reduction of cost, weight and size

Fig. 3.3 shows the control block and the partner relay block in the integrated
system. Table 3.1 compares the cost, weight and size of the integrated on-board

![Control block and Relay block diagram]

Fig. 3.3 Dimensions of the control block and relay block

system developed to the newest on-board system currently installed on
trains. The new redesign is estimated to reduce material cost down to 72%,
weight down to 47% and size down to 72%. The greatest expenses of existing
on-board system are contributed by construction (such as of equipment), installation

| Table 3.1 Comparison of existing and integrated on-board systems |
|-------------------|----------------|----------------|----------------|----------------|
|                   | Cost | Weight | S & R block | Speed check block | Recording block | Relay block |
| Existing newest system | 100% | 48kg  |             |             |               |             |
| Integrated system    | 72%  | 22kg  | Control block |             |               | Relay block |
|                      |      |       |               |               |               | 0.061m³     |

and wiring. Due to the reduction in volume and weight, the system can be
shifted from under the train floor to on top. This modified placement eliminates
the need for the original housing costing about 0.4 million yen and also does not require cable to be pulled underneath.

Above mentioned methods decrease number of components and also bring high reliability in the integrated system.

Table 3.2 Failure-rate comparison between two systems

<table>
<thead>
<tr>
<th>Kind of on-board systems</th>
<th>Conventional system for 113 series train</th>
<th>Advanced system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Send and receive block</td>
<td>62,274</td>
<td></td>
</tr>
<tr>
<td>Speed check block</td>
<td>23,082</td>
<td></td>
</tr>
<tr>
<td>Controller block</td>
<td>4,860</td>
<td>66,342</td>
</tr>
<tr>
<td>Relay block</td>
<td>90,216</td>
<td>67,713</td>
</tr>
</tbody>
</table>

Thereupon we tried to compare the integrated system and the existing system which is the smallest size in the conventional ATS-P on-board system, installed in the 113 series train using by JR East, in the relation of the failure-rate and reliability. The failure-rate of both system is shown in Table 3.2. Those failure-rate calculations include only the devices concerning safety. The recording part and the automatic investigation part, which isn’t installed in the existing system, are both excluded from those calculations. Those calculation presume that the severity factor is 2.5 for consideration of the operation condition on trains and the mechanical factor is 1.2. While the MTBF (Mean Time Between Failure) of the existing system is about $1.11 \times 10^4$ (hour), that of the integrated system is about $1.48 \times 10^4$ (hour). So the reliability of the integrated system increases by about 33% comparing with that of the existing system.

3.2.2 Simplification for the cause resolution of breakdowns

As a result of using a IC card, the memory unit in the integrated system has twice of recording content and capacity than that in the existing system. The recording content has 72 items of the information for not only the train operating status, which is recorded as 35 items in the existing system, but also system behavior. As shown Fig. 3.4, the recording device is a part of memory unit and uses a IC card as a memory medium.
The information for system behavior is actively utilized for the cause resolution of system breakdown. In the integrated system MPU always checks the behavior of every device of system. If MPU detects a disorder in any device, it indicates malfunction and activates emergency brakes.

We show an example that the power decline of energy transmission wave (245kHz) from a train antenna causes system breakdown and activates emergency brake but the system recover from a trouble condition to normal operating state after a train driver restarted the system.

<table>
<thead>
<tr>
<th>Train status</th>
<th>Recording contents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>breakdown</strong></td>
<td>Failure in the receiver block</td>
</tr>
<tr>
<td>The pilot lamp turned on 'Failure'</td>
<td>Emergency brake activated</td>
</tr>
<tr>
<td>Emergency brake activated</td>
<td>No information for precise causes of breakdown</td>
</tr>
<tr>
<td><strong>After reset</strong></td>
<td>Easy detection of precise causes and its applicable boards of breakdown</td>
</tr>
<tr>
<td>The pilot lamp turned off 'Failure'</td>
<td>Power decrease of the energy transmission</td>
</tr>
<tr>
<td>Emergency brake released</td>
<td>Emergency brake activated</td>
</tr>
</tbody>
</table>

Fig.3.5 Fault analysis based on conventional recording contents

The information according to this malfunction is very vague to detect the precise. Therefore the cause resolution tests performed in manufacture factories tend to fail. And by unknown causes, same malfunction will occur again in train operations.

Fig.3.6 Fault analysis based on new recording contents

Train brake and the system behavior condition with the power decline of energy transmission wave in the pickup coil. The information according to this malfunction is so accurate to detect the causes occurred in
the energy transmission board. Therefore the cause resolution tests in manufacture factories should be tried to find the troubles about parts of this board in detail.

3.2.3 Additional functions corresponding to users’ needs

The automatic self-testing function is installed first in the integrated ATS-P on-board system. An outside personal computer (PC) connected to the I/O conversion unit in the control block in integrated systems automatically commands and evaluates according to testing items set up in advance.

When a maintenance staff handle the personal computer to perform the automatic self-testing in the integrated system, menu picture as shown in Fig.3.7 appears on the PC display. A staff can selects any kind of test as an overall inspections or some individual inspections or so on. After choosing a necessary inspection item, the menu picture changes to a inspection picture shown in Fig.3.8. Fig.3.8 indicates the automatic inspection to ensure a switchover from ATS-SN mode to ATS-P mode. Good or bad judgment is also shown in the PC’s display after each inspection was executed. A maintenance person, who is handling a brake lever or so on, performs those inspection according to the instruction on the display with confirming the inspection results on real time. Those testing results also can be printed after inspections.
Using the conventional inspection installation composed of a wayside and an on-board device, two maintenance staff and almost one hour are necessary to execute the characteristic inspection. But the automatic self-testing functions in the integrated system necessary only one staff and about 30 minutes or less.

Moreover, the integrated system has the communication function to outside equipment as the train number setting switch, the train information management system (TIMS) or PCs. For example, the integrated system connects with TIMS, the train number can be set through typing operation on the touch-panel display of TIMS. And the automatic testing is also performed through the TIMS.

4 Conclusion

The integrated ATS-P on-board system is realized with further cost reduction, reliability increase, size decrease, and the addition of an on-board self-testing function used to automate maintenance.

The interface circuitry with the train information management system (TIMS) can send various ATS-P information to the driver cab of trains. The Performance and safety of the integrated ATS-P on-board system was executed through the many kind of tests in manufacture factories and on-track tests using a 113 series electric cars on both Tohoyu and Jyoban line. Test results are good and therefore the realization of its functions and performance can be confirmed.

The integrated on-board system has been installed in newly-built E 231 series 350 trains since November 1999.

References