Improvement of Transportation Reliability by Mutual Backup System for Controllers

Koji Yoshida* and Katsuhiko Suzuki*

1 Introduction

To ensure reliable transportation is one of the major missions of any railway company. So far we have been approaching the problems from the aspects of both hardware and software, for example, through countermeasures taken to prevent individual car troubles, deployment of the countermeasures for preventing similar troubles from recurring, and review of the design to feed the results back to the designing phase. However, to obtain further confidence of the passengers, it is necessary to improve the transportation reliability from a great variety of aspects.

In this project, our objective is to minimize the impact on transportation in the event of a possible breakdown. To achieve this objective, we have been utilizing the function of a car data transmission device to build a system, based on a new concept that the same devices on other sections in the trainset would back up the functions of a faulty device.

We have developed a mutual backup system for an “ATS-P device” as automatic train protection device and “door-operating controller” that controls the opening and closing of doors for passengers, which may cause a big transportation problem if a breakdown occurs.

2 Mutual backup system for ATS-P device

2.1 System overview

2.1.1 System concept

The ATS-P system controls the braking command in response to the car’s running speed and according to the conditions such as the distance from the leading portion of the trainset to the stop signal and the gradient. Especially when the departure signal and home signal indicates a stop aspect, it is necessary to meet the requirements of the function of issuing a braking command when the leading portion has passed by the ground coil located immediately below the signal. Even in the backup control mode, the control message from the wayside equipment must be received by the cab coil installed on the leading car and must be placed under control. To send this message to the ATS-P device mounted on the driver's cabin at the rear in the backup mode, we have adopted a method of sending it using a data transmission device located in the car, instead of using an exclusive line.

2.1.2 Comparison with conventional control

Fig. 1 shows the system overview of the conventional ATS-P device. Fig. 2 is a general view of the backup system. The ATS-P device is...
mounted on each of the two driver's cabins. This device is independent of each other in the current design. So if an error has occurred to the ATS-P of the leading car, it is not possible to fulfill the function of a train protection device. The backup system is designed in such a way that the data transmission device in the trainset is used to back up the functions of the ATS-P device of the driver's cabin in the rear according to the control message received by the leading car.

2.2 System

2.2.1 Device configuration

The simplified converters (backup transmitter-receiver) with their functions limited to transmission and reception of control messages were mounted on both ATS-P devices in the two driver's cabins. In the prototype production this time, the major emphasis has been placed on early implementation of the system evaluation, and the circuit boards of the conventional ATS-P were utilized. The major specifications are given in Table 1, and the external view of the prototype is shown in Figs. 3 to 5.

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic function</td>
<td>Conforms to ATS-P for Type E231.</td>
</tr>
<tr>
<td>Major component equipment</td>
<td>Transmission/reception controller, simplifier converter, relay</td>
</tr>
<tr>
<td>Message receiving position</td>
<td>Leading car</td>
</tr>
<tr>
<td>Message transmitting medium</td>
<td>Data transmission device for AC train</td>
</tr>
<tr>
<td>Backup switching</td>
<td>Manual</td>
</tr>
</tbody>
</table>

Table 1 Main specifications

2.2.2 Operation overview

The simplified converters with their functions limited to transmission and reception of control messages are mounted on ATS-P devices on both driver's cabins. In the event that the transmission/reception controller has failed, control messages are sent to the transmission/reception controller at the rear through this simplified converter and data transmission device. The driver's cabin in the rear performs the same speed checking operation as that in the conventional control mode according to the control message having been received, and sends various braking commands to the data.
transmission device. Upon receipt of the braking command issued from the ATS-P device in the rear driver's cabin, the data transmission device sends the braking command to the brake control unit (BCU).

2.2.3 Considerations on control

(1) Response time
In the conventional ATS-P system, the brake pattern is set up on the condition that the maximum delay (response time) from reception of control messages to transmission of the brake command is 500 ms. We studied the response time for the mutual backup system. This is because the backup control contains a process of sending the control message from the front to the rear, and this process is not found in the conventional control mode. Table 2 shows the assumed response time in the backup control mode.

![Sequence number information](image)

Table 2 Response time (in backup control mode)

<table>
<thead>
<tr>
<th>Section</th>
<th>Assumed time</th>
<th>Standard time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cab coil (front) □ backup receiver (front)</td>
<td>50ms</td>
<td>-</td>
</tr>
<tr>
<td>Backup receiver (front) □ data transmission device (front) □ (rear) □ control unit (rear)</td>
<td>55ms</td>
<td>-</td>
</tr>
<tr>
<td>Speed checkup time</td>
<td>280ms</td>
<td>-</td>
</tr>
<tr>
<td>Control unit (rear) □ data transmission device (rear) □ (front)</td>
<td>55ms</td>
<td>-</td>
</tr>
<tr>
<td>Data transmission device (front) □ BCU</td>
<td>55ms</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>495ms</td>
<td>500ms</td>
</tr>
</tbody>
</table>

(2) Checking the control message
In the backup control mode, a data transmission device is mounted between the simplified converter of the leading car and transmission/reception control unit of the rear driver's cabin. Thus, arrangement has been made to ensure that the quality of the message can be determined by the ATS-P device. Apart from checking the serial number to verify the state of transmission with the data transmission device, “sequence number” information is added by the simplified converter of the leading car, and the sequence number is checked by the transmission/reception control unit in the rear. In the event of an error, the system is regarded as faulty, and the emergency/service brake command is output.

(3) Control output method
According to the conventional manner, wired output by a relay circuit is used to transmit the service braking command from the ATS-P device to the data transmission device. The final output of the current service brake is the command sent from the data transmission device to the brake control unit. In view of this arrangement, the output is provided by transmission directly from the ATS-P, thereby reducing the number of relays. Likewise, arrangement has been made to transmit commands for shutting off the circuit for power running and starting regenerative brake.

Further, the method of transmission is also used in the ATS-P indicator and bell circuits to reduce the number of relays. At the same time, these arrangements help to reduce the addition of the through-cables in the trainset in the backup control mode.

(4) Procedure for a driver
Since the backup control mode is selected after confirming that an error has occurred in the ATS-P device of the leading car, an "ATS-P backup" switch is provided in the driver's cabin so that it is operated by a crew member. In the event that an error has occurred in the backup control mode, the ATS-P devices of both driver's cabins can be opened by operating the current "ATS-P Release" switch, without a special-purpose releasing switch being installed. This is intended to ensure uniform handling.

2.3 Test
We have conducted a bench test and field test in combination with the AIMS (Advanced Train Information Management System) developed as a car data transmission device for the AC train.

(1) Combination test
AIMS central device and terminals were combined with two of the prototype ATS-P devices, and various basic function tests, switching function tests and response time measurement tests were conducted on the ATS-P in both the conventional control mode and backup
control mode. It has been verified that there is no problem. To illustrate the examples of measurements, the results of measuring the response time are given in Figs. 7 and 8. The response time in the backup control mode was 390 ms, with respect to the response time of 495 ms where the maximum delay due to the timing in each transmission cycle was assumed. It has been verified that the designed performance requirements are satisfied.

(2) Field test
The simulated ATSP control message was entered from the cab coil, and we conducted various basic function tests, switching function tests and other tests on the ATSP in both the conventional control mode and backup control mode. It has been verified that there is no problem.

2.4 Future challenges
It has been verified by the tests that the basic functions of backup control can be performed successfully. We will carry out overall evaluation in field tests using actual cars, and at the same time, will undertake the project of downsizing the equipment by integration of circuit breakers or other means.

3. System overview

3.1 System concept
A car has multiple doorways (three on each side of the AC train), and the door-operating device mounted on each opens and closes the door. This device comprises a mechanical portion and electrical

<table>
<thead>
<tr>
<th>Door drive system</th>
<th>Backup system</th>
<th>Open/close operation</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driven by rotary</td>
<td>Same side type</td>
<td>Simultaneous opening</td>
<td>Since the method of using pulses to detect the door position is not adopted, operation can be performed by parallel connection of the DC motor. However, opening/closing speed is reduced.</td>
</tr>
<tr>
<td>machine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Driven by linear</td>
<td>Simultaneous</td>
<td></td>
<td>The method of using pulses to detect the door position is adopted. So after the control of one door has been terminated, control of the other door starts.</td>
</tr>
<tr>
<td>motor</td>
<td>opening/closing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opposite side type</td>
<td>Independent</td>
<td></td>
<td>Since the control unit of the opposite side type is used, door opening/closing speed and open/close operation timing can be made the same as those of the conventional door.</td>
</tr>
<tr>
<td></td>
<td>opening/closing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
portion (door-operation control unit). If a problem has occurred in the door-operation control unit responsible for the control of door open/close operation, passengers cannot get on or off the car through the doorway. This may cause the train to be delayed. To prevent this, we have developed a mutual backup system. When the door-operation control unit of a doorway has been damaged, this backup system is activated in such a way that the door-operation control unit of another doorway provides a backup function to the damaged door-operation control unit (to open or close the door). The backup system is available in two types. One is the opposite type backup system where the backup function is provided on the opposite side with respect to the direction of running, and the other is the same side type backup system where the backup function is provided on the same side. (See Fig. 9). Two types of door drive system were developed: a rotary machine drive system used in the mass-produced cars and a linear motor system.

3.1.2 Operation flow
The following describes the operation flow of this system when a problem has occurred with the door:
- The conductor switch is operated, and a problem has occurred when the door is opened.
- The AIMS recognizes that the door-operation control unit is not normally operated.
- The AIMS identifies the trouble and lights up the door trouble indicator lamp mounted close to the conductor switch.
- A conductor looks at the lamp to identify the trouble, and press the backup switch located close to the lamp to select backup mode.
- Upon receipt of the command from the AIMS, the system is set to the mode where a conventional door-operation control unit takes the place of the damaged door-operation control unit to control the door.
- The backup processing lamp located close to the door open/close switch lights up.
- The conductor checks that the backup processing lamp is on, and operates the Open switch again to open the door.

If backup selection does not terminate at the end of the above-mentioned procedure, the mechanical portion may be damaged. In this case, the door must be provided with some treatment such as...
locking doors. Fig. 10 shows the backup control panel, and Fig. 11 shows a monitor display.

3.1.3 Rotary machine drive system
The door-operating device driven by a rotary machine detects the current and voltage applied to the motor, thereby detects the door position by calculating the number of motor's rotations. Since the method of using pulses to detect the door position is not adopted, two doors can be operated at the same time. This makes it possible to perform simultaneous operation of the same side type by making effective use of this feature. Two backup relays are built inside the control unit, and the motor drive power and the like can be sent from the conventional control unit to the faulty position. This method ensures a comparatively small amount of wiring between control units.

3.1.4 Linear motor system
In this method, the motor system uses the linear synchronous motor, and detects the door position by integrating the number of pulses from the reference position, thereby performing control functions. Thus, if there is any difference in the position of the two doors, the doors cannot be controlled by one control unit. To avoid this situation, a sequential method has been adopted in the same side type. The door control is switched to the fully closed position where the door operation has been completed, or at the fully opened position. In the opposite side type, backup function is provided by the door-operation control unit located on the side opposite to the place where the door is opened or closed. The door opening/closing speed and opening/closing startup timing can be made the same as those of the normal door. If the backup function is to be used whenever one of the paired door-operation control units has been damaged, it is necessary to capture the opening/closing signal and position of the detecting signal of the door-operation control unit, and to switch the output to the motor. To meet this requirement, a switching circuit and an interface circuit for the input/output signal of the paired door-operation control unit have been added to the conventional door-operation control unit. To reduce the amount of wiring between the circuits to be added, the wiring for two door-operation control units has been stored in one box. (See Fig. 12). When the door is opened, operation is performed after matching has been made between the open command from the AIMS, the open permit signal of the through-cable, and door positions. In the opposite side type, further, we have changed the shape of the connectors on the door-operation control unit on the right and left with respect to the direction of travel. This is intended to avoid a possible error in wiring between the door-operation control unit and car body. At the same time, the wiring in the controller box and signals on the circuit board are separated and a sufficient distance is provided to prevent possible error contact.

3.2 Results and our subsequent actions
We have developed mutual backup systems for three types of door-operation control units that differ in the drive type and opening/closing operation. These systems have been mounted on the AC train for field testing. It has been verified that operations are satisfactory in each type. We are planning to study the durability and optimum method for the backup system.

4 Conclusion
In this development project, we have verified the validity of the backup system using the data transmission device. We believe that we have succeeded in paving the way for deployment of these technologies in other devices.

Fig. 12 Door-operation control unit with backup function