Latest Technology towards Improvement of Rail-vehicle Safety

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Safety enhancement was one of the four R&D objectives set out in the 2010-2014 basic plan for research of RTRI, 'RESEARCH 2010'. This paper introduces three areas related to the latest technologies developed in the course of our research aiming at enhancing railway vehicle-safety. The first introduces results of surveys on failure tendencies of on-board train-protection devices (ATS/ATC) in order to improve reliability of on-board electronic devices [1]. The second is the development of air wipe blowers, designed to increase wheel to rail adhesion in wet conditions [2]. The third area is modeling and evaluation approaches to meet standard value in induction interference tests [3].

Keywords: electronic device, reliability, protection device, adhesion, air wipe, induction interference, EMC (electro-magnetic compatibility)

1. Failure tendencies of on-board train protection device

Since 2002, RTRI has been organizing the "Review meeting for preventing failures of electronic devices on railway vehicles," bringing together 36 railway operators, 13 devices and vehicle manufactures, and RTRI. ABC failure surveys were conducted (except for Shinkansen trains, where JR was only involved in AB failure) each year to compile failure records, log causes, analyze the results incorporating manufactures' knowledge, and discuss failure prevention measures for electronic devices, ideal practice of maintenance and requirements for future electronic devices.

The scope of the study included drive inverters, auxiliary power supplies, braking control devices (electronic devices only), and on-board train protection devices (ATS/ATC). This paper describes failure tendencies observed in on-board train protection devices (hereinafter 'subjects devices') which were investigated since 2004 (fiscal year).

1.1 Subject devices and failure rates

Figure 1 indicates the cumulative number of subject devices (classified by type of protection device) and failure rates [%] (= reported number of failures / number of devices * 100) for each fiscal year. The number of subject devices for fiscal year 2010 was approximately 25,000 units. On-board ATS devices occupy 86% of the total. Note that the integrated model of ATS and ATC is referred as an "ATS+ATC device." The failure rate in each fiscal year remained below 1.0%.

Figure 2 shows the change in annual failure rate % over time (= number of failures / number of units * 100). Values were calculated only taking major repairs into consideration (replaced parts after failure were reset annually), with data spanning 7 years, from 2004 to 2010 (a total of 1,309 pieces). The failure rate is tended to be high in the first year following introduction of a new device, followed by a decrease after 2 years, a subsequent rise again in the 7th years followed by another fail thereafter.

Further analysis of data identified failure prone com-

ponents, namely: "On-board antenna and coil," "receiving and transceiver," "speed comparing components (logics)," "common receiving components," "relaying components," "input/output units," "power supply components," "inspecting components," and "recording components."

Fig. 1 Cumulative number of units and failure rates

Fig. 2 Failure rate for number of years elapsed

1.2 Failure tendency

Although a number of failures due to the same cause tend to be concentrated on a specific type of device, it does not necessarily mean that probability of failure occurrence will always be elevated on the same devices in all other rail companies. Accordingly, current failure rates were exam-

ined using relatively latest data (FY 2010).

Figure 3 shows the results of analysis of failure spots. Failure was highest (34%) among receiving and transceiver components, followed by speed comparing components (logics components) (26%), power supply components (14%), input/output devices components and tachometer generator (5%). The following characterized the failures:

(1) Receiving and transceiver components

Failure successfully identified and linked to PCBs (printed circuit board)-level occupied approximately 40%.

The PCB parts found to be responsible for the failures approximately 30% of the problem, and included a broad range of parts including ICs, transformers, solders, aluminum electrolytic capacitors, quartz oscillators, mica capacitors, ceramic capacitors, and relays. The cause of the most frequent failures found on ICs including failures in isolation and cosmic radiation (that may have caused the rewrite of RAM data).

(2) Speed comparing components (logics components)

Software defects accounted for 20% of failures.

The PCB parts responsible for failures occupied approximately 50%, and including switches and diodes predominantly, followed by ICs, resistors, solders, relays, and photo couplers. Among them, switch failures were attributable to conductance failures due to presence of foreign matter and degradation, while diodes failure caused by short-circuiting as a result of surge voltage exposure.

(3) Power supply components

Degradation was the highest source of failure (60%), followed by failure in isolated item components (13%) and defective design (7%).

(4) Input/output units and tachometer generators

Tachometer generator failure accounted for 50%.

1.3 Efforts to enhance reliability

Determining how degradation progresses, sampling surveys, planning and implementation of repairs and replacements, policies on how to manage discontinued parts, feedback for design, feedback for design, and troubleshooting are all important to enhance the reliability of on-board electronic devices.

2. Development of air-wipe blowers

When braking is applied in wet condition, the probability of wheel sliding increases. Sliding in turn causes longer braking distances and wheel flats on the tread because of locking wheels.

Adhesion control measures have been used therefore to stabilize braking distances and prevent wheel flats. These solutions do not necessarily immediately increase the adhesion coefficient, or maximum coefficient of friction, between the wheel and the rail. Although sanding and spraying ceramic or other hard particles are also means to improve the adhesion coefficient, these approaches are not greatly welcomed by railway operators, because of the adverse effect on the wheel tread.

For this reason, other work has been conducted to develop a new system using "air-wipe blowers" which can remove the film or humidity on the rail surface using compressed air. This method which can decrease braking distance and thus enhance safety is described below:

Fig. 3 Results of failure analysis (On-board train protection device)

2.1 On-board air-wipe configuration and expected performance

The prototype air-wipe system comprises a set of air nozzles mounted on the front edge side of bogie (Fig. 4), which blows continuous supply of compressed air onto the top of the rails and wheel treads. By removing the films of water, the system is designed to increase the friction coefficient and bring it as close to as possible to that obtained in dry conditions, and thus “to suppress as far as possible any drop in the adhesion coefficient due to wet conditions.” The system should also decrease water run-off from the rails during train operation.

2.2 Effect on main line running test

A 3-car electric train for conventional lines (Fig. 5) was used to test performance of the air-wipe system when applying emergency braking from a train speed of 130 km/h in wet conditions obtained by sprinkling the rails. To allow the air nozzle to blow a stable supply of compressed air onto the top surface of each rail, the nozzle was mounted on the bogie axle box at an elevation of 33 mm from the top surface of the rail (Fig. 6). The distance from the top of the rail surface used in these test was derived from traction tests previously conducted at the Shiozawa test site, where it was determined that the blowing pressure on an object did not depend on running speed, but rather on the elevation from the top surface of the rail.

Wet conditions were obtained by sprinkling 4 liters of water per minute onto each wheel, and the performance of the system was tested using a blowing pressure of 700 kPa.

Fig. 4 On-board air-wipe configuration

Fig. 5 Test train layout for air-wipe performance test

Fig. 6 Mounted position of air-wipes blowers

Fig. 7 Comparison in mean braking force and braking distance

The performance of the system was evaluated through visual checks and by measuring changes in mean braking force and mean braking distance.

Running test results indicated a 5% or more improvement in mean braking force and a 3% shortening of the braking distance compared to where air-wipes were not used (Fig. 7). This demonstrates that the extent of sliding could be reduced, but not eliminated. Present research is aimed at further minimizing the fail of the coefficient of adhesion in wet conditions.

Although the present research focused on rail adhesion in wet conditions in braking, the method proposed can also be effective against wheel slipping in powering due to leaves or similar light weight objects with large surface areas, on the rails.

3. Modeling and evaluation methods to meet the standard values set in induction interference tests

In a growing number of cases, meeting standard induction interference test values is taking longer and longer, following the construction of a railway vehicle. Induction interference includes both conductive emissions into return current circuit and radiated emissions to signal equipment via free space. However, countermeasures to deal with these two issues have to date largely only provided a solution to the symptoms and not the heart of the problem, and adjusting devices after they have been mounted is very difficult. In some extreme cases, railway vehicles have been delayed up to two years after completion because of recurrent non-compliance with induction interference test values.

An increase in the number of inverters and other power conversion equipment with switching functions, along with higher switching frequencies have been singled out as forming the background to this problem. It is posited that a number of factors contribute to this problem, and indeed, a number of countermeasures have been implemented, including the fact that radiated emissions may be attributable to higher frequencies which facilitate radio wave emissions. However, these measures have not yet produced any

tangible benefit.

Solution for these problems includes EMC (Electro-Magnetic Compatibility) environment measures and concurrently, others to enhance safety by minimizing the influence on signal circuits.

3.1 Nature of radiated emissions

“Radiated emissions” are often associated immediately with electromagnetic waves. However, when dealing with induction interference, it is enough to talk about just magnetic fields. There are two reasons for this, the first is that frequencies are limited to a maximum of 3 MHz and secondly the affected devices are located at close proximity. When the source of the interference and an affected device are within a distance of one-hundredth of a wavelength, the magnetic field becomes predominantly superior to electric field, and thus the only possible suspected noise source becomes the electric current.

Based on this principle of physics, the source of the interference can be found simply by searching for the wire which has the same or similar frequency to that of the affected signal device, and this in turn facilitates to devise remedial measures.

In this case, care should be exercised not only in the wiring outside of the subject device, but also in the internal wiring of the device.

3.2 Quantification of radiated emissions from traction motor wiring

The most likely noise source in vehicles currently in operation is the wiring between the traction inverter and motor (hereinafter, called “traction motor wiring”). Traction motor wiring includes 3-phase wires for rotating the motor and motor frame wires for noise prevention.

Conventional wisdom is that- the loop section through which the common mode current flows is related to radiated emissions. If this logic is followed, fitting the motor frame wires close to the 3-phase wires should reduce the value of the radiated emissions. However, maximum wavelength at 3 MHz of the signal device is approximately 1.0 m, therefore doubt still remains about whether the difference of a few centimeters will significantly affects the magnitude of the radiated emissions.

Consequently, thinking not only the loop but rather of the entire system prompted the circuit proposed and illustrated in Figure 8. Fitting the motor frame wires allows the common mode current to partially return to the traction inverter. This current offsets the magnetic field with the common mode current in the reverse direction. Further, the motor frame wires are connected with the bogie frame and grounding brush and thus outward current leakage exists. If then appears logical to assume that this leaking current is the source generating the magnetic field.

Based on this concept, the question of radiated emissions is clarified regardless of the presence or absence of motor frame wires. The leaking current can be measured with current sensors by bundling four wires; the 3-phase wires and a motor frame wire. The mutual inductance between the traction motor wiring and track antenna beacon of signal device is calculated from the geometric layout of

Fig. 8 Modeling of the nature of induction interference (radiated emissions)

the both. The equivalent circuit of each is represented by a concentrated constants model by taking the wavelength into consideration. Thus, the leaking current can be associated quantitatively with the radiated emissions.

3.3 Reverse calculation of upper limit values

The previous sections therefore establish that radiated emissions are essentially “magnetic fields” which are linked to leaking current.

The value of the current leak, obtained by reverse calculation from the maximum permissible radiated emission voltage for the signal device side, is directly responsible for exciting the magnetic field to the limit value in inductance interference tests. Therefore a limit can be set for this current leak, which will in turn facilitate to suppress interference.

Consequently, trials can be implemented by manufacturers at an early stage whilst devices are being assembled, to determine interference sources, and this can be remedied before mounting the device on vehicles in order to ensure that they remain below the permissible limits. Adopting this approach should guarantee that the standard values are satisfied when the vehicles has been completed. In turn, this should greatly reduce the need for subsequent corrective or adjustment work.

At present, the calculation of allowable upper limit values in current leakage on signal devices for Japan Railway Corporation Companies (JRs) is almost complete, and some railway operators have now begun their own trials.

4. Conclusion

Three areas of recent research aimed at improving vehicle safety have been presented. To enhance safety which is a prerequisite in railway transportation, our division continue working on conduction of a state of the art survey, technology development to solve problems, and devise evaluation methods for the operating stage including checks to be performed prior to bringing into service.

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