

Newsletter on the Latest Technologies Developed by RTRI

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# Railway Technology Avalanche

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# International Activities of Railway Technical Research Institute

## Isao OKAMOTO

Director, in charge of International Affairs

I have been in charge of the Information & International Affairs Division of Railway Technical Research Institute since August of last year. This institute engages in the research and development of basic and applied railway technologies. It also emphasizes various international activities, including technical exchange and technical cooperation with railway operators, research institutes and other organizations around the world.

For example, as a member of the UIC, the institute dispatches staff to the UIC to grasp current international railways trends. The institute takes part in joint research projects of the World Executive Council (WEC) and carries out research for the development of railway technology around the world. In addition, the institute has its experts actively attend major international conferences on railways, such as the World Congress on Railway Research (WCRR) and the Eurail Speed, to deliver lectures and present papers. Furthermore, the institute has carried out joint research with the French National Railways, the China Academy of Railway Sciences, the Korea Railroad Research Institute, and others. It participates in business conferences and specialist meetings sponsored by the Ministry of Land, Infrastructure and Transport to promote technical exchange with the United Kingdom, India, China, the United States and other countries. At the request of Japan Railway Technical Service (JARTS) and other agencies, the institute receives trainees in railway technology from overseas. Recently, at the request of JARTS in connection with the Taiwan Shinkansen, the institute is sending an increasing number of experts to Taiwan to promote technical support. Since the signing of an agreement with the Transportation



Technology Center, Inc. (TTCI) of the United States for the use of its Pueblo experimental line, the institute has carried out various tests on this experimental line.

The Railway Technical Research Institute intends to continue making contributions to the progress of the world's railway technology through various international activities.

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Mr. Isao OKAMOTO

# Wear Tester for Current Collecting Materials for High Speed Railway

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This tester consists of a revolving disk to which a ring made of copper plates (simulated contact wire) is fitted. With a pantograph contact strip pressed against the simulated contact wire, an electrical current is passed to them to turn the simulated contact wire, in order to measure the coefficient of friction, the rate of contact loss, wear of the contact strip and simulated contact wire, and the sliding surface conditions (Fig. 1 and Fig. 2). This tester has made it possible to grasp the tribological characteristics of various current collecting materials under various sliding conditions. The tester was completed in December 2003, replacing to the former wear tester introduced in the 1970s.

A pantograph contact strip slides on the contact wire at the train's running speed. A current as large as about 100 to 1,000 A passes to it. The contact strip must have enough strength as an important vehicle component, high electric conductivity as an electrical material, and high lubricating ability and wear resistance as a frictional material. The frequency of contact strip replacement depends on its wear resistance, and the contact wire life is significantly influenced by the contact strip's lubricating ability. Therefore, from the standpoint of railway management as well, improving the performance of the contact strip material is an important issue. On the other hand, with the increase in train speed and the decrease in the number of pantographs per train in recent years, the conditions under which the contact strip is used have become increasingly severe. This tester is used to develop high performance contact strip materials which can be reliably used even under the rigorous conditions of recent years.

As a tester for current collecting materials, the apparatus boasts the highest performance in Japan, allowing for a



Figure 1. Scheme of wear tester for current collecting material for high speed railway.



Figure 2. Appearance of wear tester.

maximum sliding speed of 500 km/h, hence can easily respond to future increases in train speeds. Fig. 3 shows the wear characteristics of various contact strip materials measured at sliding speeds of up to about 300 km/h. In the future, the apparatus will permit the wear characteristics of various contact strip materials at higher speeds to be grasped. The maximum current that the tester can pass to each contact strip is 500 A (DC/AC). The tester accepts not only actual contact strips but also small test pieces. This permits testing even of contact strip materials which are still in the prototype stage. Plates of pure copper are used for the simulated contact wire. However, a material other than pure copper can be substituted as long as it is in the form of a plate. The sliding conditions are either constant speed, constant current, or programmed conditions in which the speed and current are varied according to the actual train running conditions.

The greatest factor causing contact strip wear is arc discharge, which occurs when the pantograph loses contact. It has been known that the rate of contact strip wear increases nearly in proportion to the rate of occurrence of arc discharge due to contact loss. The contact strip holder of the tester is provided with an vibrator, which is capable of forcing a contact loss to occur, making it possible to check the wear characteristics of a contact strip under conditions close to the actual pantograph conditions.

The specifications of the tester are as follows.

- (1) Simulated contact wire: Pure copper ring (2 m in diameter, 5 mm in width).
- (2) Contact strip test piece: Full-scale contact strip (270 mm in length, 40 mm in width, 30 mm in thickness); smaller test piece (90 mm in length, 50 mm in width, 30 mm in thickness).
- (3) Maximum sliding speed: 500 km/h.
- (4) Maximum current: 500 A (100 V DC/AC; polarity reversing possible with DC).
- (5) Applied force: 9.8 to 196 N (1 to 20 kgf).
- (6) Items that can be measured simultaneously during tester operation: friction coefficient (frictional force/applied force); current passed; contact loss rate (voltage drop and occurrence of arc between contact strip and simulated contact wire); contact strip temperature.
- (7) Items that can be measured with tester out of operation: shape of wear and surface condition of simulated contact wire; amount of wear of contact strip material.



Figure 3. Examples of measured wear characteristics of various contact strip materials.

## Ladder Track Structure and Performance

#### **Kiyoshi ASANUMA**

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## 1. Introduction

Sleepers, slabs and other rail supporting members play a vital role as the interface to connect rails with the track bed and structures. They are closely related to the issues of safety, economy, maintenance, and track-system environment. We have developed a "ladder sleeper," an innovative new interface that has remarkable advantages for the above issues. Using this new sleeper, we are proposing a ballasted ladder track and a floating ladder track.

#### 2. Structure of the ladder sleeper

The ladder sleeper, as shown in Fig. 1, is a mixed laddershaped structure composed of twin prestressed concrete longitudinal beams and transverse steel pipe connectors. The transverse steel pipe connector, which is made from a thick-walled pipe, is rigidly joined to the longitudinal beam by inserting it between indented prestressing strands, which are arranged close to the top and bottom surface of the longitudinal beam. Sufficient reinforcement is provided around the steel pipe and then high-strength concrete is cast to be monolithic.

#### 3. Ladder track system

Using the ladder sleeper, we have developed a ballasted ladder track and a floating ladder track. The fundamental structural concept of the ladder track is a "combined rail" composed of the steel rail and concrete longitudinal sleeper (see Fig. 2). It features high rigidity and remarkable stability against track buckling.

## 4. Performance of ballasted ladder track

The ballasted ladder track significantly reduces maintenance work compared with the crosstie track, owing to the reduction of dynamic load transferred to the ballast. In order to evaluate structural durability and the effect of reducing maintenance of the ballasted ladder track, we conducted an accelerated endurance test using a heavy-haul freight train, having a static wheel load of 175 kN, at the Transportation Technology Center, Inc. (TTCI) in Pueblo, Colorado, U.S.A. (see Fig. 3). By the end of the test, the passing tonnage reached 150 million. The longitudinal prestressed concrete



beams bore without a single crack or any other damage, and all the steel pipe connectors remained sound. Then, we could confirm the appropriateness of the design of the ladder sleeper. In addition, we also confirmed the remarkable effectiveness of the ladder sleeper at reducing maintenance, because the ballasted ladder track required no maintenance throughout the endurance test, while the crosstie track has required thorough tamping five times (see Fig.4).

#### 5. Performance of floating ladder track

The floating ladder track is a lightweight, vibration-proof track system that is floated from the concrete track-bed by supporting the ladder sleepers with low-stiffness springs at a constant interval. Owing to the vibration-isolation effect of low-stiffness springs, the floating ladder track can significantly reduce the structure-borne noise. In order to evaluate the effectiveness of the reduction, we measured the vertical vibration of the concrete track-bed under a floating ladder track and a non-ballasted crosstie track on a rigidframe viaduct (see Fig. 5). Fig. 6 illustrates the frequency analysis of the vertical vibration level of velocity, which has a close relation to structure-borne noise, and it shows that the floating ladder track can reduce the vibration level of velocity by approximately 13.4 dB (all-pass filtered) over the nonballasted crosstie track. As a matter of fact, no structureborne noise was audible under the viaduct at the site.



Figure 1. Ladder sleeper.



Figure 2. "Combined rail" — structural concept of ladder track.



**Figure 3.** Ballasted ladder track in TTCI.





Figure 5. An example of floating ladder track laid out for testing.



Figure 6. Comparison of track-bed vibration level of velocity.

## Optimum Cross Sleeper Length and Ballast Tamping Area for Narrow Gauge Tracks

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Ballasted tracks are subject to differential settlement under repeated load during train operation. This differential settlement causes track irregularity. To correct track irregularity, ballast tamping, in which ballast is pushed underneath the sleepers, is performed (Fig. 1). Normally, however, the ballast under the central part of the sleeper is not tamped. Therefore, the density of the ballast there becomes lower than that of the ballast at either side. As train load is applied to ballast areas that differ in density, they are either compressed vertically or flowed laterally, resulting in further ballast settlement (initial settling process). In the subsequent process, in which the uneven density distribution is corrected to a certain degree and the settlement continues (gradual settling process), in the case where a conventional sleeper (length: 2 m) is used, a void occurs between the sleeper and the ballast near each end of the sleeper, due to the dependence of ballast strength on its confining pressure. As this void widens, the settlement of the ballast increases.

This paper describes the results of a cyclic loading test carried out on a full-scale track model to study the effects of sleeper length and ballast tamping area on ballast settlement properties (Fig. 2).

The amplitude of sleeper displacement after a repeated load was applied once and  $10^6$  cycles, respectively, is shown in Fig. 3. The changes in average amount of sleeper settlement and in degree of sleeper differential settlement are shown in Fig. 4. In the area of ballast tamping, "ordinary" means that the ballast in the area up to about 400 mm on each side from the rail center was tamped, and "entire length" means that the ballast along the entire length of the sleeper was tamped. From Fig. 3(a), it can be seen that when repeated load is applied once, the longer the sleeper length, the smaller the sleeper displacement tends to become at each end, and that with a given sleeper length, the sleeper

displacement at each end is smaller when the ballast is tamped along the entire length of the sleeper. In "ordinary" ballast tamping with sleeper length l = 2.0 m and l = 2.3 m, respectively, the sleeper displacement at



each end is greater than that at the center. In the other cases, the sleeper displacement at each end is smaller than that at the center. From Fig. 3(b), it can be seen that after the repeated load is applied 10<sup>6</sup> cycles, the change in sleeper deformation in "entire length" ballast tamping with sleeper length l = 2.3 m and in "ordinary" ballast tamping with sleeper length l = 2.6 m, respectively, is smaller than the change in sleeper deformation after the repeated load is applied once. The implication is that "l = 2.0 m, ordinary" and "l = 2.3 m, entire length" increase the sleeper support at the center, whereas "l = 2.6 m, entire length" increases the sleeper support at each end. Fig. 4 indicates that both the average amount of differential settlement and the degree of differential settlement are small when the sleeper displacement at the center is slightly larger than that at each end after the initial application of the repeated load, since the sleeper deformation does not change under repeated load.

From the above facts, in order to reduce the ballast settlement effectively when the area of ballast tamping is "ordinary," it is necessary to increase the sleeper length to 2.6 m. The reason for this is that even when the sleeper length is extended, the ballast under the extended portion is not tamped sufficiently. However, by adopting "l = 2.3m, entire length," it should be possible to obtain a ballast settlement reducing effect comparable to that obtained by "l = 2.6 m, ordinary."



**Figure 2.** Cyclic loading test on full-scale track model.

Figure 4. Transition in amount of sleeper settlement.

# Detecting High Resistance Grounding Faults in DC Electric Railways Using High Frequency Current Injection

## Akinobu OKUI

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It is difficult to distinguish the current that flows through the DC feeding circuit during a high-resistance grounding fault having a resistance of several ohms from the electric car current. Detecting it has long been a problem.

Recently we developed a method of detecting a highresistance grounding fault. In this method, a high frequency current is injected into the DC feeding circuit to distinguish between the electric car current and the high-resistance grounding fault current. This paper describes the principle of detection and provides an outline of the detector.

#### Principle of detection

When a micro high-frequency voltage is applied to the DC feeding voltage at the substation, the impedance as viewed from the substation differs between the electric car current and the high-resistance grounding fault current. In principle, therefore, it is possible to distinguish between them (Fig. 1).

In Fig. 1, assuming the impedance as viewed from the substation when frequency  $f_1$  (angular frequency  $\omega_1$ ) is injected as  $Z(\omega_1)$ , the following equation holds true. The resistance of the feeding circuit is assumed to have a characteristic proportional to the frequency, and is expressed as  $\omega_1 r_F$ .

## $Z(\omega_1) = (j\omega_1 L_F + \omega_1 r_F)l + (R + j\omega_1 L) \dots \dots \dots \dots (1)$

In the above equation,  $j\omega_l L_F + \omega_l r_F$  denotes the impedance per unit length of the feeding circuit, and *l* denotes the distance from the substation to the electric car or highresistance grounding fault point.  $R+j\omega_l L$  is the electric car impedance or the resistance of the high-resistance grounding fault. Observing the resistance component and reactance component of  $Z(\omega_l)$ , the value of  $l\omega_l r_F$  in the resistance component,  $l\omega_l r_F + R$ , is larger than the value of Rdue to the skin effect (Fig. 2) and hence it is difficult to distinguish between them. In order to detect R separately, we consider injecting an angular frequency,  $\omega_2$ , which is relatively close to  $\omega_l$ . In this case, the impedance can be expressed by the following equation.

## $Z(\omega_2) = (j\omega_2 L_F + \omega_2 r_F)l + (R + j\omega_2 L) \dots (2)$

From the above equations (1) and (2), R can be obtained as follows.

$$R = \frac{\omega_2 Z(\omega_1) - \omega_1 Z(\omega_2)}{\omega_2 - \omega_1}$$

Thus, by injecting two different frequencies, it is possible to reduce the error



in calculation of R due to the skin effect on the feeding circuit.

#### High-resistance grounding fault detector

The high-resistance grounding fault detector, developed on the principle of detection mentioned above, consists of an inverter unit and an injection unit. It detects the impedance and R of the feeding circuit from the amplitudes and phases of the injected voltage and injected current (Fig. 3).

Considering the influence of the detector on the track circuit (signal), we inserted a filter into the inverter unit and injection unit. In addition, we adopted a frequency of the harmonics generated by the rectifier  $\pm 10$  Hz as the injection frequency, so that it does not affect the signal track circuit and is free from the influence of harmonics generated by the rectifier (Fig. 4).

According to the test results obtained by the detector, the frequency-dependent component of R during a high-resistance grounding fault is eliminated, making it possible to detect the resistance component (Fig. 5). This result suggests the possibility to detect a high-resistance grounding fault.

From the test results obtained by our high-resistance grounding fault detector, it was made clear that the detector is capable of detecting a high-resistance grounding fault without adversely affecting the track circuit. However, in order to put the detector into practical use, it is necessary to provide measures against the variation of R due to sudden changes in electric car load and verify a method of distinguishing between the electric car load and high-resistance grounding fault when they occur at the same time.



## A Measure to Reduce Contact Wire Wear in Shinkansen Overlap Sections

## Masatoshi SHIMIZU

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The Shinkansen overlap section consists of four spans, in which the height of two contact wires are changed, up for one and down for the other, at their central supporting point. Compared with the contact wire in the ordinary section, the one in the overlap section tends to wear easily. This is a weak point in the overlap equipment (e.g., the contact wire needs to be replaced relatively frequently). It is possible to reduce the wear of the contact wire in an overlap section by setting the contact wire height and deviation properly.

Fig. 1 shows an example of measured wear, height and deviation of contact wires in an overlap section. In the figure, wire A is the contact wire with which the pantograph makes contact before it passes through the overlap, and wire B is the contact wire with which the pantograph makes contact after it passes through the overlap.

In the overlap, the wear of wire B is conspicuous. The wear of the wire portion enclosed with circle 1 has occurred within a relatively narrow range. It is due to an improper height of the wire (wire B is 20 mm down at the intersecting point). On the other hand, the wire portion enclosed with flattened circle 2 has worn uniformly in a wide range. This range coincides with the one in which the wire deviation is 150 mm or more. Thus, the wear is due to a large deviation of the wire. The deviation of 150 mm is the standard deviation set for the contact wire in the ordinary section.

When the contact wire height in the overlap section is set improperly, the contact wire is subject to impact and vibration, which cause the contact force with the pantograph to increase. This in turn causes the wear of the contact wire to increase. Fig. 2 shows the contact force characteristic obtained by a dynamic simulation of a catenary/pantograph system. It can be seen from the figure that the overlap configuration that permits the pantograph to move smoothly without being subject to impact is one in which wire B is set about 20 mm higher than wire A.







reduces frictional wear of Shinkansen contact wire.



**Figure 4.** Correlation of contact wire deviation and wear rate and metal deposition rate.



In the overlap section, the standard space between the right and left contact wires is 300 mm. Because of this, the contact wire deviation in the overlap section tends to become larger than that in the ordinary section (standard deviation: 150 mm).

The contact wire used for the Shinkansen is made of copper alloy, and the slider is made of iron-based sintered metal which has lubricating ability. As the slider slides along the contact wire, the metal having lubricating ability and a low melting point melts and deposits on the sliding surface, thereby preventing the wear due to friction between the contact wire and the slider (Fig. 3).

Fig. 4 shows the relationship between the rate of contact wire wear relative to deviation and the rate of deposition of the metal having lubricating ability on the sliding surface. As the deviation exceeds 150 mm, the rate of metal deposition decreases and the rate of contact wire wear increases. Fig. 5 shows a thermograph of a pantograph in operation. It can be seen that the slider portion corresponding to the deviation of 150 mm or less has turned white, indicating that its temperature has risen. On the other hand, the temperature of the slider portion corresponding to deviations greater than 150 mm has remained the same. This accounts for the low rate of deposition of the metal having lubricating effect and the high rate of contact wire wear where the contact wire deviation is large.

From the facts mentioned above, in order to reduce the wear of contact wire in the Shinkansen overlap section, it is effective to set wire B about 20 mm higher than wire A and keep the contact wire deviation within about 150 mm.



Figure 2. Results of dynamic simulation of contact force.



**Figure 5.** Thermograph of pantograph in operation.