Development of Simple Catenary Equipment Using PHC Contact Wire for Shinkansen

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Abstract: The simple catenary system has demonstrated adequate performance for speeds of up to 300 km/h, which is the maximum speed on commercial Shinkansen lines. This type of equipment is used on the projected Shinkansen lines (two pantographs, 50 m distance) and previous simulation and high-speed running-test results, the vibration of simple catenary equipment at the second pantograph must be reduced at speeds exceeding 300 km/h will be needed.

Public awareness of global warming and recycling has created a demand to respect environmental conservation and reduce the environmental burden posed by railways. To this end, it is necessary to extend the replacement frequency of the contact wire in the overhead contact line system and apply a copper alloy to improve its recycling efficiency. We therefore selected a new type of equipment (known as PHC simple catenary equipment) through research into the overhead contact line system, performance calculations from simulation, and running tests at our institute. In the final stage of development, we installed the PHC simple catenary equipment on a commercial line to confirm its performance.

Keywords: current collection, high-speed operation, simple catenary equipment, PHC contact wire, damper hanger

1. Introduction

CS simple catenary equipment featuring low-cost design and satisfactory high-speed performance was developed as an overhead contact line for projected Shinkansen lines. This type of equipment is used on the Hokuriku Shinkansen line from Takasaki to Nagano [1], the Tohoku Shinkansen line from Morioka to Hachinohe and the Kyushu Shinkansen line from Shin-Yatsushiro to Kagoshima-Chuo. It was confirmed in a Tohoku Shinkansen running test that CS simple catenary equipment demonstrated adequate performance for speeds of up to 300 km/h, which is the maximum speed on commercial Shinkansen lines [2]. However, demand for higher-speed operation on Shinkansen lines leads us to believe that an overhead contact line system for speeds exceeding 300 km/h will be needed.

Public awareness of global warming and recycling has created a demand to respect environmental conservation and reduce the environmental burden posed by railways. To this end, it is necessary to extend the replacement frequency of the contact wire in the overhead contact line system and apply a copper alloy to improve its recycling efficiency. We therefore selected a new type of equipment (known as PHC simple catenary equipment) through research into the overhead contact line system, performance calculations from simulation, and running tests at our institute. In the final stage of development, we installed the PHC simple catenary equipment on a commercial line to confirm its performance.

This paper describes the characteristics of the PHC simple catenary equipment in installation testing.

2. Outline of PHC simple catenary equipment

2.1 Structure of PHC simple catenary equipment

Figure 1 shows an outline of PHC simple catenary equipment. A precipitation-hardened copper (PHC) alloy is used as the contact wire, and hard drawn copper wire strands (PH150 mm²) are used as the messenger wire in this equipment. The PHC contact wire consists of chromium- and zirconium-added copper-alloy-based oxygen-free copper. Its tensile strength is comparable to that of copper-steel (CS) contact wire, and its conductivity is similar to that of bronze contact wire. Table 1 shows the characteristics of major types of contact wire. The wave velocity of PHC simple catenary equipment has been improved by using PHC110 mm² tensioned at 19.6 kN. The environmental load of PHC contact wire is less than that of CS contact wire over its life cycle [3].

With due consideration of the pantograph conditions on the projected Shinkansen lines (two pantographs, 50 m distance) and previous simulation and high-speed running-test results, the vibration of simple catenary equipment at the second pantograph must be reduced at speeds exceeding 300 km/h.
of over 300 km/h. To achieve this, we used four damper hangers near the support in the PHC simple catenary equipment [4].

2.2 Specifications of damper hanger

Figure 2 shows the specifications of the damper hanger, which consists of a coil spring and a damping mechanism due to friction. We installed two types of damper hanger (Type A and Type B) on a commercial line.

<table>
<thead>
<tr>
<th>Wire type</th>
<th>Mass of unit length (kg/m)</th>
<th>Conductivity (%)</th>
<th>Tensile strength (kN)</th>
<th>Wave propagation velocity (km/h)</th>
<th>Limit of residual diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT10 mm²</td>
<td>0.988</td>
<td>97.5</td>
<td>38.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GT-Sn10 mm²</td>
<td>0.982</td>
<td>70</td>
<td>40.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CS10 mm²</td>
<td>0.935</td>
<td>60</td>
<td>65.1</td>
<td>521</td>
<td>8.34</td>
</tr>
<tr>
<td>PHC110 mm² (trial product)</td>
<td>0.989</td>
<td>80.6</td>
<td>64.0</td>
<td>506</td>
<td>8.20</td>
</tr>
</tbody>
</table>

Table 1 Characteristics of major contact wire

3. Conditions of installed PHC simple catenary equipment

3.1 Static height of installed PHC simple catenary equipment

Table 2 shows an outline of the PHC simple catenary equipment installed on a commercial line. We installed the equipment on the Tohoku Shinkansen line for trial.

3.2 Results of measurement by an inspection car

Figure 4 shows the results of measuring the installed PHC simple equipment using an inspection car. This figure also includes data for the catenary equipment near the installed PHC simple catenary equipment. We were able to confirm the dynamic conditions of the equipment through these results. According to Fig. 4, the contact wire deviation of the installed PHC simple catenary equipment was within 150 mm, and the standard deviation of the pantograph height was 12.7 mm. As the standard deviation in this equipment was less than that in the adjoining catenary equipment types, it can be thought that its installation accuracy was better.

4. Wear transition of PHC contact wire

To evaluate the wear transition of the PHC contact wire in the installed PHC simple catenary equipment, we measured its residual diameter over a period of four years. Figure 5 shows the wear transition (i.e. the wear rate of the area) of the PHC contact wire. For comparison, Fig. 5 also shows the wear transition of the CS contact wire in the same section as the installed PHC simple catenary equipment. The figure shows that the wear rate of the area was 0.054 mm²/10⁴ pantographs in PHC contact wire over four years, which was less than that of the CS contact wire. Since local wear of the PHC contact wire is not seen in Fig. 2, we can conclude that its wear condition was satisfactory.
5. Development of conducting hanger

Local wear might occur as a result of the static height of the contact wire or the load of metal fittings (such as pull-off arms or electrical connectors) in overhead contact lines. This wear would increase the replacement frequency of the contact wire. Such local wear can be checked by adjusting the static height of the contact wire or by using lightweight metal fittings. As this wire is directly connected to the messenger wire in simple catenary equipment to make the electrical connector larger than that of compound catenary equipment, wear on it tends to increase. We therefore developed a conducting hanger to unify the functions of the conventional hanger and electrical connector.

5.1 Specifications of conducting hanger

We considered the specifications and performance of the conducting hanger in the development of this unit. The hanger was applied to the PHC simple catenary equipment shown in Fig. 1. Four of the hangers in each span were damper hangers, and the others were conducting hangers. The basic specifications of the conducting hanger were based on the standard of the conventional hanger and the electrical connector for Shinkansen lines. Table 3 shows the basic specifications of the conducting hanger, and Table 4 shows its basic performance. Since the current conducted to the contact wire by one electrical connector branches off at plural conducting hangers, the electrical performance of the connector is more than sufficient as that of the conducting hanger. We therefore provided the tolerable current of the conducting hanger as 500 A (for 9 seconds), considering its thermal rise and the collected current of the relevant trains. We provided the tolerable series current of the conducting hanger as 120 A, considering the specifications of the lead wire where the conducting hanger is fitted. The tolerable value is sufficient to deal with the maximum current of an auxiliary machine (30 A) in a stopped train.

![Fig. 5 Wear transition of PHC contact wire](image)

![Fig. 6 Trial product of conducting hanger](image)

### Table 3 Basic specifications of conducting hanger

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catenary equipment</td>
<td>PHC simple catenary equipment</td>
</tr>
<tr>
<td>Longest span length</td>
<td>60 m</td>
</tr>
<tr>
<td>Standard system height</td>
<td>950 mm</td>
</tr>
<tr>
<td>Standard hanger distance</td>
<td>5 m</td>
</tr>
<tr>
<td>Shortest hanger length</td>
<td>400 mm</td>
</tr>
<tr>
<td>Longest hanger length</td>
<td>950 mm</td>
</tr>
</tbody>
</table>

### Table 4 Basic performance of conducting hanger

<table>
<thead>
<tr>
<th>Endurance test</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration test*1</td>
<td>Over 2 × 10⁶ times</td>
</tr>
<tr>
<td>Tensile load test*2</td>
<td>3000 N for 1 minute</td>
</tr>
<tr>
<td>Torsional moment test*2</td>
<td>2500 N-cm for 1 minute</td>
</tr>
<tr>
<td>Sliding test*2</td>
<td>1000 N for 1 minute</td>
</tr>
<tr>
<td>Hanger tensile test*2</td>
<td>No marked deformation</td>
</tr>
<tr>
<td>Hanger bend test*2</td>
<td>Over 16 times</td>
</tr>
<tr>
<td>Resistance ratio*2</td>
<td>Under 1.0</td>
</tr>
<tr>
<td>Tolerable temperature*2</td>
<td>Under tolerable temperature of contact wire or messenger wire or lead wire</td>
</tr>
<tr>
<td>Tolerable current</td>
<td>500 A (for 9 seconds)</td>
</tr>
<tr>
<td></td>
<td>120 A (continuance)</td>
</tr>
</tbody>
</table>

*1 Amplitude: ± 25 mm, Frequency: 3 ~ 5Hz
*2 Case of installing in contact wire after vibration test

5.2 Outline of trial product

Figure 6 shows a trial product of the conducting hanger with the performance described in the previous section. Since its upper part must have strength to the vibrations of the overhead contact line, we applied the phosphor bronze used in the conventional hanger to this part. However, as phosphor bronze has low conductivity, we applied chromium-zirconium copper alloy (MCZ/TL) to the lower part of the conducting hanger. This alloy has higher conductivity than phosphor bronze, but is equal in strength. We also applied wire strands of tin-indium copper alloy to the lead wire to give suffi-
cient strength and conductivity. In addition, precipitation-hardened copper alloy (CRM-B) was applied to the ear and the clamp due to its properties as a highly conductive and useful material for metal fittings.

5.3 Installation test of conducting hanger

We installed the trial product of the conducting hanger on a commercial line to confirm its characteristics. We removed the existing electrical conductor and replaced conventional hangers with conducting hangers, except for damper hangers used in two spans. Measurements were taken before and after the installation of these conducting hangers. The targets of measurement were contact wire uplift at supports, contact wire strain at supports and conducting hangers, axial load and strain on conducting hanger bars, and the current of electrical conductors and conducting hangers. Table 5 shows the maximum measurement values in commercial cars running at speeds of 210 km/h and 270 km/h.

The measurement value of the contact wire uplift was less than 100 mm, and that of the contact wire strain was less than $500 \times 10^{-6}$ in both the conducting hanger and the electrical conductor. These values are tolerable in the overhead contact lines of the Shinkansen system. The measurement value of the conducting hanger was more than that of the conventional hanger, but was less than 1500 N as the basic performance of its tensile endurance in hanger tensile testing. Since the tolerable strain of the hanger bar is 2000 N according to its material characteristics, the measurement value of the hanger bar strain in the conducting hanger was sufficiently small. Since current is passed through plural conducting hangers, the conducting hanger current was smaller than the electrical conductor current, with a measurement value of 123 A. Considering the relevant train conditions, the conducting hanger current would not exceed 500 A even if there was only one conducting hanger in a span. We can therefore conclude that the performance of the conducting hanger was sufficient for metal fittings on a commercial line.

5.4 Wear of PHC contact wire hang with conducting hanger

We confirmed the extent of local wear reduction in the contact wire as a result of replacing the electrical conductor of the PHC simple catenary equipment with the conducting hanger. We measured the residual diameter of the PHC contact wire once after making the replacement, and again 20 months later. Table 6 lists the average wear on the PHC contact wire, and shows that wear at the electrical conductor averaged six points, while that at the conducting hanger averaged ten points in the PHC simple catenary equipment.

Wear at the electrical conductor averaged 0.15 mm, which was 1.27 times more than the value for the conducting hanger. The wear at the conventional hanger averaged 0.10 mm, which was smaller than that at the conducting hanger. The weight of the conducting hanger was greater than that of the conventional hanger by 0.49 kg, and the equivalent weight on the contact wire of the conducting hanger was greater than that of the conventional hanger by 0.15 kg. Since Fig. 2 and Fig. 3 show that the contact wire height condition of the PHC simple catenary equipment installed on a commercial line was satisfactory, we inferred that the wear difference between the conducting hanger and the conventional hanger resulted from their difference in weight. However, as the wear at the conducting hanger was smaller than that at the electrical conductor, we conclude that it can be one of provisions for local wear at the electrical conductor to use the conducting hanger.

Table 6 Average wear of PHC contact wire on a commercial line (over 20 months)

<table>
<thead>
<tr>
<th>Item</th>
<th>Average wear (mm)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical conductor</td>
<td>0.15</td>
<td>1.27</td>
</tr>
<tr>
<td>(6 points)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conducting hanger (10 points)</td>
<td>0.12</td>
<td>1.00</td>
</tr>
<tr>
<td>Conventional hanger (110 points)</td>
<td>0.10</td>
<td>0.87</td>
</tr>
</tbody>
</table>

6. Characteristics of PHC simple catenary equipment in high-speed running tests

We carried out running tests with a Shinkansen high-speed testing car on the Tohoku Shinkansen line. The results confirmed the characteristics of the PHC simple catenary equipment at speeds of over 300 km/h.

6.1 Results of ground measurement

Measurements focused on the contact wire uplift and
strain at supports in the conventional hanger part and the damper hanger part, and were also taken in the conducting hanger part shown in Fig. 7. We also measured the cylinder stroke of the damper hanger in this part to confirm that it remained within the cylinder’s movable length.

Two types of pantograph (Type A and Type B) fitted for high-speed running were used in this high-speed test. Figure 8 and Table 7 show the pantograph conditions of the testing car. The running speed of the car with two Type-A pantographs was from 275 km/h to 315 km/h, that with one Type-A pantograph was from 325 km/h to 355 km/h, and that with one Type-B pantograph was from 275 km/h to 355 km/h. Here, the maximum speed in the section fitted with the PHC simple catenary equipment was 355 km/h in consideration of track conditions.

As a measurement example, Fig. 9 shows time series waveforms from when the testing car passed at a speed of 315 km/h. Comparing the damper hanger part with the conventional hanger part, it was apparent that the vibration of the contact wire uplift continued in the waveform of the conventional hanger part, but decreased in that of the damper hanger part.

Fig. 8  Outline of high-speed testing car

Table 7  Pantograph conditions of running test on PHC simple catenary equipment

<table>
<thead>
<tr>
<th>No.</th>
<th>Speed (km/h)</th>
<th>Pantograph type</th>
<th>Pantograph number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>275 ~ 315</td>
<td>Type A</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>325 ~ 355</td>
<td>Type A</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>275 ~ 355</td>
<td>Type B</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig. 9  Measurement waveforms at support in high-speed running test (315 km/h)

6.1.1 Contact wire uplift

Figure 10 shows the results of measuring contact wire uplift at a support in the conventional hanger part, and Fig. 11 shows the same in the damper hanger part. The maximum value was 58 mm, which was measured in the damper hanger part. In each part, measurement values remained within 100 mm, which is a tolerable level, and there was a sufficient margin in the contact wire uplift. The increase in the aerodynamic upward force of the first pantograph in condition No.1 (i.e. two-pantograph running) also caused an increase in the contact wire uplift.

6.1.2 Contact wire strain

Figure 12 shows the results of measuring the contact wire strain at a support in the conventional hanger part, and Fig. 13 shows the same in the damper hanger part. The maximum measurement value in the conventional hanger part was 713 × 10⁻⁶, and that in the damper hanger part was 594 × 10⁻⁶. The larger amplitude of contact wire strain in the conventional hanger compared to that in the damper hanger confirmed that the latter reduced contact wire strain. Even in the damper hanger part, measurement values exceeded the contact wire’s tolerable strain of 500 × 10⁻⁶ at speeds of over 335 km/h. However, since the specifications of the PHC contact wire were reviewed and a high-strength-type PHC contact wire tolerable strain of 1000 × 10⁻⁶ was reported [6], we conclude that commercial cars can run at speeds in excess of 300 km/h with PHC simple catenary equipment. Moreover, even in the conventional hanger part, as the contact wire never exceeded its tolerable strain at speeds of under 300 km/h, we conclude that commercial cars...
can run within this speed with the PHC simple catenary equipment used for the conventional hanger.

6.1.3 Dynamic cylinder stroke in damper hanger

Figure 14 shows the results of measuring the cylinder stroke in the damper hanger. The maximum measurement value was 45 mm, and there was sufficient margin in the cylinder’s movable length of the Type-B damper hanger (see Fig. 2). In addition, since there was also sufficient margin in that of the Type-A damper hanger (which had the same mechanical characteristics as Type B), we conclude that there would be no problem running at speeds in excess of 300 km/h on a commercial line.

6.2 Results of on-train measurement (contact loss ratio)

We placed a system to measure contact loss on the testing car to record the loss in the high-speed running test. Figure 15 shows the measurement results of the contact loss ratio in the Type-A pantograph, and Fig. 16 shows the same for the Type-B pantograph. As the contact loss ratios are calculated from the measurement values of every overhead contact line between sections, the ratio for the PHC simple catenary equipment includes measurements for the conventional hanger part and the damper hanger part. In addition, Fig. 15 and Fig. 16 also show the values measured in the heavy compound catenary equipment for high-speed running adjoining the PHC simple catenary equipment. In the heavy compound catenary equipment, the wave velocity was improved by using PHC110 mm² as the contact wire. We got the contact loss ratio to measure the collected current in the two-pantograph running test and to detect the arc between pantograph and contact wire in the one-pantograph test.

In the two-pantograph running test with the Type-A pantograph, the contact loss ratio of the PHC simple catenary equipment was a maximum of 12%, which was relatively high. A large contact loss with the PHC simple catenary equipment occurred in the second pantograph. The large aerodynamic upward force caused by the first pantograph increased the vibration of the overhead contact line, and the second pantograph could not follow such vibrations with its lower degree of aerodynamic upward force. Although this inferred that contact loss was apt to occur in the second pantograph, the contact loss ratio of the PHC simple catenary equipment was just 3.8% at most in the one-pantograph running test with the Type-A pantograph, and its current collection performance was satisfactory.

In the Type-B pantograph running test, contact loss occurred in the PHC simple catenary equipment at speeds in excess of 300 km/h. However, the loss ratio was just 0.5% at most, and was less than that in the one-
pantograph running test with the Type-A pantograph. This was because the design of the Type-B pantograph was suitable for high-speed running at over 300 km/h. There was a slight difference between the contact loss ratio of the PHC simple catenary equipment and that of the heavy compound catenary equipment. However, it was not possible to compare the contact loss ratio simply for the height fluctuation measurements in Fig. 3. As described above, we expect sufficient performance of current collection at speeds in excess of 300 km/h by maintaining the height of contact wire satisfactorily in the PHC simple catenary equipment.

7. Conclusions

In consideration of the lifecycle energy for contact wire, we developed PHC simple catenary equipment, which is a new system to enable travel at speeds exceeding 300 km/h. We installed this equipment on the Tohoku Shinkansen line to confirm its characteristics and current collection performance. The results are summarized below.

1) The wear rate of the area was 0.054 mm²/10⁴ pantographs on the PHC contact wire over a period of four years. Since no local wear was seen on the wire, its wear characteristics can be said to be satisfactory.
2) The installation test results for the trial product of the conducting hanger showed that it maintained the mechanical and electrical characteristics required on commercial lines.
3) The contact wire strain in the conventional hanger part and the damper hanger part exceeded the contact wire’s tolerable strain of 500 × 10⁻⁶. However, since the specifications of the PHC contact wire were reviewed and a high-strength-type PHC contact wire tolerable strain of 1000 × 10⁻⁶ was reported, we can conclude that trains can run at speeds of over 300 km/h with these hangers.
4) The measurement value of the contact wire uplift at supports and that of the damper hanger cylinder stroke were appropriate for their tolerances.
5) There were instances where the contact loss ratio was up to 12% at speeds of over 300 km/h under two-pantograph running conditions. However, the ratio’s maximum value was 3.8% in one-pantograph running.

Acknowledgment

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References