Methods for Detecting Pantograph Defects Using Sensors Installed on Contact Lines

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Defects on pantographs may lead to serious accidents resulting in widespread damage to contact lines. Therefore, it became necessary to develop an early detection system for such defects. The authors developed a method for detecting step-shaped wear on contact strips, which is one of the typical defects found on pantographs, by measuring the axial forces exerted on steady arms installed on three adjacent supporting points. Since the method only needs to measure the axial forces of three adjacent steady arms, it can easily be applied to operational lines. In addition, the authors also developed a compact, light-weight and power-saving data acquisition device consisting of a dynamic strain amplifier and data telemetry system which is suitable for this method.

Keywords: pantograph, contact strip, step-shaped wear, contact line, detection method, data acquisition system, steady arm

1. Introduction

Pantograph defects may lead to serious accidents resulting in widespread damage to contact lines, leading in turn to extensive downtime. Step-shaped wear on contact strips, which is one type of uneven wear which forms on the surface of contact strips, is one of the most common types of pantograph defect. If step-shaped wear progresses rapidly, the pantograph head may break, resulting in widespread damage to contact lines in the most serious cases. As such it was important to develop a method for early detection of step-shaped wear. In the previous study, the authors developed two kinds of step-shaped wear detection method by measuring contact wire vibrations [1]. Although these methods can accurately detect step-shaped wear they are hard to apply in practice because they require installation of a large number of sensors on the contact wires. This paper therefore describes an alternative step-shaped wear detection method which can be applied to railway lines in operation, without any difficulty. In addition, the authors also developed a compact, light-weight and power-saving data acquisition device consisting of dynamic strain amplifier and data telemetry system which is suitable for this method.

2. Detection method of step-shaped wear on contact strips

2.1 Characteristics of step-shaped wear

Contact strips suffer gradual and uniform wear resulting in flat or gently inclined shape sliding surfaces (Fig. 1 (a)). Sometimes however, wear can be localized on the contact strip, causing the surface to become step-shaped (Fig. 1 (b), (c)). This kind of wear is classified as “step-shaped wear.” In particular, wear shown in Fig. 1 (c) is called “groove-shaped wear.” Figure 1 (d) shows an example of step-shaped wear (groove-shaped wear) found on a line in operation. The characteristics of step-shaped wear are listed below;

Fig. 1  Contact strip wear modes (side view of contact strips)
Step-shaped wear is found in DC and AC sections.
- Step-shaped wear is generated regardless of the train speed, the number of pantographs mounted on a train, and the type of pantograph.
- The shape and depth of the step-shaped wear varies.
- Although step-shaped wear occurs at the center of the pantograph head or in the boundary area between the contact strip and the auxiliary contact strip in many cases, it does sometimes appear elsewhere.

After step-shaped wear has been generated on contact strips, the contact wire slides continuously along the bottom part of the step-shaped wear, since lateral movement of the contact wire on the contact strip is prevented by the step-shaped wear. Consequently, the worn area deepens worsening the step-wear leading to defects in the contact strip and pantograph head. Furthermore, although regular visual inspections are carried out on contact strips, the time between step-shaped wear beginning to when a defect appears on the contact strip is sometimes shorter than the interval between inspections.

2.2 Requirements for the detection method for step-shaped wear on contact strips

Based on the above characteristics of step-shaped wear, the detection method must satisfy the following requirements:
- Ability to detect step-shaped wear regardless of where it occurs on the contact strip, the train speed, the number of pantographs mounted on the train set, and the type of pantograph.
- Ability to detect wear which restrains lateral movement of the contact wire.

There are two ways to satisfy these requirements: the first is to detect step-shaped wear through sensors mounted on the roof top of the train near the pantograph; the second is to mount sensors on trackside equipment (e.g. a hinged cantilever, a contact wire and a pole). Although the former provides very frequent detection because of continuous monitoring, it is costly to install sensors for all pantographs. The initial cost of the latter approach however is lower than the first. In addition, although it does not allow continuous inspection of all pantographs, the second approach makes it possible to conduct more frequent inspections than the current visual inspections at a lower cost than first one. As a result, the detection method was developed on the basis of the second approach.

2.3 Behavior of the contact line when a pantograph with step-shaped wear passes

When a pantograph with step-shaped wear on the contact strip (Fig. 2(a)) passes through a section in which a stagger is arranged by steady arms (Fig. 2(b)), the contact wire is deformed in the lateral direction as shown in Fig. 2(c) since the contact strips with step-shaped wear restrain the contact wire in the lateral direction. Axial compressive or tensile forces are exerted on the steady arms, simultaneously.

![Fig. 2 Behavior of the contact line when a pantograph with step-shaped wear on the contact strips passes](image-url)
3. Method for detecting step-shaped wear on contact strips by measuring axial force on steady arms

The authors developed a method for detecting step-shaped wear on contact strips by measuring the axial force acting on steady arms. In this method, the axial force acting on a steady arm is measured by strain gauges which are wrapped around the curved part of the steady arm (Fig. 3). To understand the influence of the step-shaped wear on the axial force acting on steady arms, the authors carried out some tests.

![Fig. 3 A steady arm with sensors (strain gage) to measure its axial force](image)

### 3.1 Static load test

The authors carried out static load tests on contact lines. In these tests, three steady arms with a sensor (No.1-No.3) were installed on three adjacent supports (Fig. 4). When a static load \( F_s \) was applied in the lateral direction to the contact wire, the change in axial force \( F_{pi} \) (\( i \) indicates the number of the steady arm equipped with a sensor, \( i = 1, 2, 3 \) acting on each steady arm was simultaneously measured by the strain gauges. In addition, \( R_i \), which is the ratio of \( F_{pi} \) to \( F_s \), was calculated:

\[
R_i = \frac{F_{pi}}{F_s} \quad (1)
\]

When the ratio \( R_i \) equals 1.0, it means that static force can be measured completely by measuring axial force acting on steady arms.

The results of the tests are shown in Fig. 5: The position where static load \( F_s \) is applied in the rail direction is plotted on the horizontal axis of Fig. 5; \( R_i \), the vertical axis. The ratio \( R_i \) nearly equals 1.0 when the static load \( F_s \) is applied near a steady arm with a sensor. However, the ratio \( R_i \) falls as the position of static load \( F_s \) moves away from the steady arm. \( R_i \) equals 0.38 when the position is the center of the span. This result indicates that when a contact strip with step-shaped wear which pushes or pulls the contact wire at a position located far from the steady arm, it may not be detected if only a single steady arm is equipped with a sensor. Figure 5 also shows the differences in \( R_i \) between the three adjacent steady arms: \(-R_1+R_2 \) (shown as the red line) and \(-R_2+R_3 \) (shown as the blue line). Figure 5 indicates that static force \( F_s \) can be estimated more accurately by operation of the subtraction, in particular, when the static force is exerted near the center of the span between two supporting points. Therefore, the differences in axial forces between adjacent pull-off arms can also be calculated using this method.

It was also confirmed that a vertical load applied to the contact wire does not affect the ratio \( R_i \). It means that the axial force acting on steady arms does not change if vertical force is applied to the contact wire by the pantograph.

![Fig. 4 Configuration of the contact line (top-view). Strain gauges were affixed to each steady arm No.1-No.3](image)

![Fig. 5 Measurement result of the ratio \( R_i \) of axial force \( F_{pi} \) generated in each steady arm No.1 to static load \( F_s \)](image)

In other words, false detection which means that a normal pantograph is judged as an abnormal one can be prevented no matter how large the contact force applied is, by a passing normal pantograph.

According to the above results, the configuration of the detection system was determined as follows. Steady arms with sensors such as strain gauges should be installed at least at three adjacent supporting points in order to detect step-shaped wear formed at any position on the pantograph head. In addition, step-shaped wear on contact strips can be detected with high accuracy not only by measuring the axial force acting on each steady arm but also by calculating the differences in the axial force between adjacent steady arms. The system can be applied easily to lines in operation since no need for sensors to be installed on the contact wire, the catenary wire, or droppers.

### 3.2 Running test

In order to grasp the characteristics of the axial force of steady arms caused by a passing pantograph with step-shaped wear, running tests were carried out using current collection testing equipment of RTRI (Fig. 6). This equipment is composed of a 500 m-long track and a carriage capable of running at a maximum speed of 200 km/h on which a real pantograph can be mounted. The mechanical interaction between an overhead contact line and a pantograph can be investigated by the equipment.
In these tests, the configuration of the contact line was the same as in Fig. 4, and contact strips with and without artificial groove-shaped wear were examined. Artificial groove-shaped wear with a depth of 2 mm and widths of 30 mm or 15 mm, were used in these tests. Figure 7 shows the axial force fluctuation acting on each steady arm measured in the tests. The red line shows the results of test runs using a pantograph with artificial groove-shaped wear; black, for pantographs with normal contact strips. Figure 7 (a) show the test results for pantograph runs at 130 km/h; and (b) pantograph runs at 4 km/h. These figures show some important characteristics. In case of pantographs with step-shaped wear, large axial forces were observed, especially at high speed. This characteristic indicates that detection of a large force demonstrates that the contact strip on the pantograph has step-shaped wear. On the other hand, the maximum value of the axial force observed on pantographs with normal contact strip running at 130 km/h (black line in Fig. 7 (a)) was almost the same as that observed on pantographs with the contact strips that had artificial groove-shaped wear running at 4 km/h (red line in Fig. 7 (b)). This means that it is difficult to determine whether the pantograph is normal or abnormal using only the maximum value. However, a saw-tooth waveform such as the red line in Fig. 7 (b) was observed on a pantograph with step-shaped wear running at low-speed. A low-pass filter can extract clear saw-tooth waveforms from raw data. Figure 8 shows that pantographs with step-shaped wear can be easily detected by using filtered waveforms, since both filtered waveforms can be clearly distinguished. This means then that the detection process uses not only the original waveforms but also low-pass filtered waveforms in order to detect step-shaped wear regardless of train speed.
3.3 Algorithm of the detection method

Based on the above mentioned characteristics, the authors devised an algorithm for the detection method.

The algorithm was composed of two steps (Fig. 9). Raw waveforms of the axial forces acting on the steady arms were provided for the first step: low-pass filtered waveforms, provided for the second step. In both steps, if either of the following conditions were satisfied, it was deemed that the train had a contact strip with step-shaped wear.

- Either of the absolute values of $F_{\text{max},i}$ or $F_{\text{min},i}$ is greater than the threshold value $V_t$.
- Either of the differences between $F_{\text{max},i}$ and $F_{\text{min},i}$, that is, $F_{\text{max},2} - F_{\text{min},1}$ or $F_{\text{max},3} - F_{\text{min},2}$ is greater than the threshold value $V_s$.

Where $j$ is the number of detection step ($j=1, 2$), the maximum and minimum value of the axial force of the pull-off arm No.$i$. These threshold values $V_t$ and $V_s$ ($j=1, 2$) are determined by the values of the axial forces on passing of a normal pantograph. Figure 9 shows the flowchart of the algorithm.

3.4 Results of verification tests

The authors carried out verification tests to confirm the accuracy of the detection method by using current collection testing equipment. In these tests, a pantograph ran at 4 to 130 km/h, contact strips with and without step-shaped wear were used. The location of step-shaped wear on the pantograph heads was varied. Results of the tests for step-shaped wear placed at 23 mm away from the center of the pantograph head, are shown in Fig. 10. A total of 86 tests were carried out. Figure 10 (a) shows the detection results from step one of the detection algorithm; Fig. 10 (b), from step two. It was confirmed that a pantograph running at high-speed can be checked using the first step in the algorithm, and at low-speed can be checked using the second step. Consequently, pantographs running at any speed can be accurately examined for the presence of step-shaped wear on contact strips using the detection algorithm.

4. New telemeter which includes dynamic strain amplifier

Currently-used data acquisition systems installed on the contact line are generally heavy because large batteries are necessary. The step-shaped wear detection system with such heavy data acquisition equipment can be installed at limited on a confined location because the system has to be installed on a rigid structure. Therefore, the authors also developed a compact, light-weight and power-saving telemeter with a dynamic strain amplifier. Figure 11 shows a picture of the transmitter of the telemeter, and Table 1 shows its specifications. Since the system is com-
pact, light-weight and power-saving, it can be installed in various locations without heavy batteries. Although this transmitter can only send signals on one channel, this is not a problem for application of the detection method. It is because only one measurement item (axial force acting on a steady arm) is necessary for each supporting point.

5. Conclusions

The authors developed a method for detecting step-shaped wear on contact strips by measuring axial forces acting on steady arms, which can enhance railway safety and reliability. The system based on this method can be applied easily in practice to operational lines since no sensor has to be installed on the contact wire, the catenary wire, or droppers, and can detect step-shaped wear regardless of train speed and location of the step-shaped wear on the contact strips. In addition, the authors also developed a compact, light-weight and power-saving telemeter include a dynamic strain amplifier in order to implement the detection method.

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Table 1 Specifications of the developed telemeter

| Weight, g       | 20                                       |
|-----------------|------------------------------------------|
| Dimensions of the transmitter, mm | 52(W) x 30(H) x 12(D)                      |
| Number of input channels, ch       | 1                                        |
| Transmission frequency band, GHz   | 2.4                                      |
| Maximum transmittable distance, m  | 200                                      |
| Power consumption of the transmitter, mW | During measurement: 230 mW During standby: 7 mW |