Improvement of Method for Locating Position of Wheel / Rail Contact by Means of Thermal Imaging

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Estimation of vehicle dynamic characteristics depends on sufficiently accurate locating of the wheel/rail contact point. However, since it is not possible to place a camera on a truck close enough to the rail head level, locating the wheel/rail contact point while a vehicle is running was not possible in previous studies. To solve this problem, this study proposes a new method for digitalizing the contact point based on the method presented in the study by Burstow et al., which uses thermal imaging. An experiment to locate the contact position was carried out using an actual vehicle on the RTRI test line. The test results confirmed that the contact position between the wheel and the rail could be identified accurately while the vehicle was running in conditions suitable for using a thermography camera. In addition, this paper describes how this proposal could be applied to a derailment experiment.

Keywords: wheel/rail, contact position, thermographic camera, flash temperature, frictional heat, visualization

1. Introduction

Determining railway vehicle dynamic characteristics in detail depends significantly on being able to understand the tangential force acting between the wheel and the rail (creep force), and obtain proper evaluation of the wheel/rail contact position and shape of the corresponding contact patch [1]. Thus, the contact characteristics of the wheel / rail interface were examined through numerical analysis and laboratory experiments while concentrating on the shape of the contact patch. Based on the results obtained in the laboratory tests, the shape, even presenting slight unevenness, which most reduced lateral force when running through curves was identified through actual vehicle running tests [2]. Following this, the focus was placed on locating the position of the contact patch on the wheel/rail interface. In experiments to measure the tangential force generated at the wheel/rail interface using a twin-disk sliding-frictional rolling machine, which has an actual sized wheel and a roller-rig, it is not difficult to detect the location of the contact patch on the wheel/rail interface because a charged-coupled device (CCD) camera can be installed near the contact position in the longitudinal direction of the rail (see Fig. 1(a)). This is not possible for running tests on commercial lines, given the risk of the CCD camera colliding with track structures. In previous running experiments using actual vehicles, to verify wheel/rail contact, a CCD camera was mounted above rail head level, i.e. behind the life guard on the bogie, to avoid any negative impact on running safety. From this position of course, it is not possible to locate the contact position on the rail (see Fig. 1(b)).

The work by Burstow et al. on this subject is therefore of particular interest. Specifically, because in their paper they present a method for visualizing the wheel/rail point of contact of a vehicle as it runs through curves and switches by means of a thermography camera mounted on the car body, and experimental results from tests applying this method to an actual vehicle [3].

By improving the visualization method presented in the Burstow’s study, this paper proposes a new technique for locating the wheel/rail contact point more precisely, i.e. by installing a thermographic camera under the truck frame close to the rail head, and locating the contact point on thermal images through computed analysis. Running tests with an actual vehicle were performed on the RTRI tests track to verify the proposed technique. This paper describes the new locating technique and results from location of contact position.

Fig. 1 Difference of view of the contact point between wheel and rail

2. Visualization technique of the contact position between the wheel and the rail

2.1 Burstow et al. experiment for detecting wheel/rail contact position

Burstow et al. installed a thermal imaging camera which detects thermal radiation infrared rays emitted by an object and described the technique they developed, which in the thermal imaging confirms the rise in temperature due to frictional heat generated between the wheel and the rail, i.e. the flash temperature indicates the wheel/
rail contact position on the monitor. They then verified the validity of this method in running tests with an actual vehicle. According to the literature [3], the flash temperature at the contact point on the wheel tread is about two degrees Centigrade above the surrounding non-contact area. The interface contact points in curved sections (for a curve radius of 1400 m) and in turnouts were confirmed by what was displayed on the monitor. The paper however also reported pseudo thermal images caused by specular reflection and contamination or inactivation of the rail head surface.

2.2 Performance confirmation by preliminary experiment

In reference to the literature [3], a thermographic camera with a similar performance to the one used by Burstow et al. was used, and the effectiveness of Burstow’s method was confirmed. That is to say, the thermographic camera was mounted under the car body above rail head level, and the contact position of wheel/rail was recorded as a thermal image taken from the rear toward the running direction. This confirmed the wheel/rail temperature rise in the afterimages displayed on the monitor, and that thermal images considered to be the wheel/rail contact point shown in Fig. 2(a) could be obtained. At the same time however, pseudo thermal images generated by the reflection on the rail head were also detected, even when the vehicles were immobile and no slipping was taking place (see Fig. 2(b)).

Furthermore, when a bogie vehicle runs through a curved section, a relative yaw angle occurs between the car body and the truck. This means that if the wheel/rail contact point is located with a thermographic camera mounted under the car body, a method for correcting the viewing angle is necessary.

Based on the findings of these preliminary experiments, in this study, in order to decrease erroneous results due to pseudo thermal images, and in order to locate the contact position of wheel/rail accurately with a simple measurement device, the thermographic camera was mounted under one of the cross beams of the truck frame, close to the rail head, and viewing the target wheel from behind. Depending on the type of the axle box suspension, the running wheelset can be displaced in the yawing direction due to bending of the axle spring, however, since this displacement is very small, it can be ignored.

3. Experiment for locating the wheel/rail contact position using newly configured device

3.1 Overview of running test in RTRI

A running experiment in which a diesel locomotive pulled a railway car was carried out on the RTRI test line as shown in Fig. 3. The running tests were carried out at three speeds: 10 km/h, 20 km/h, and 30 km/h in the direction of the red arrow in Fig. 3. Hereinafter, the left side rail and the right side rail mean the inside rail and the outside rail respectively, because there was no right curve in the test set up. The target wheel filmed with the thermographic camera was the front wheel of the car, and the thermal images recorded the wheel/rail contact point from behind, facing the direction of travel. The wheel tread brake of the coach was not used to avoid the surface temperature of the wheel tread becoming too high due to braking. Weather conditions during the running experiment were either sunny or cloudy, and the air temperature was between 9.3 to 22.8 degrees Centigrade.

3.2 Thermographic camera

The thermographic camera mounted under the cross beam of the truck frame is shown in Fig. 4. As the space for installing the camera under the truck frame was small, the compact and light-weight "AIR32 Professional" made by IR System Co., Ltd., was used. To make it easier to measure the frictional temperature of the wheel/rail, the measurement range of this thermographic camera was customized to be from 20 to 40 degrees Centigrade. For reference, the
Table 1 Specifications of thermographic camera

|                     | The thermographic camera used in this study | The thermographic camera presented in the literature [3] |
|---------------------|--------------------------------------------|--------------------------------------------------------|
| Pixel number, pic   | 320 × 240                                  | 320 × 240                                              |
| Thermal range of measurement, degrees C. | 20 ~ 40                                    | -20 ~ 120 (Estimation)                                 |
| Temperature precision, degrees C.          | ± 0.5                                      | ± 2 (or ± 2%)                                          |
| Available environmental temperature, degrees C. | 5 ~ 40                                   | -15 ~ 50                                                |
| Mass, kg            | About 0.25                                 | About 0.7                                              |
| Dimension, millimeters | 53 × 81 × 60                          | 170 × 70 × 70                                          |
| Frame rate, Hz      | 20 (Maximum)                               | 60 (Maximum)                                           |
| Vibration resistance, shock resistance     | Nothing                                    | 2G(IEC68-2-29), 25G(IEC68-2-29)                        |
| Dust proof and drip proof resistance       | Nothing                                    | IP40, IEC529                                           |

The major specifications of this thermographic camera are shown in Table 1 in comparison with those presented in the literature [3]. The goal in this experiment was to use the thermographic camera as a tool to measure and clarify wheel/rail interaction phenomena, and should therefore be used at low velocity and in dry conditions. This means that other measurements, i.e. vibration resistance, shock resistance, dust proof and drip proof resistance, were not considered.

3.3 Confirming accuracy of wheel/rail contact position located by thermographic camera

In order to confirm that the wheel/rail contact point recorded by the thermal imaging camera was identical to the actual contact position, first, the thermographic images close to the contact position of wheel/rail at low running speed, i.e. about 10 km/h, were recorded by the thermographic camera. Second, the car was made to stop once at the place where the thermal images were recorded, and photographs of the contact position of wheel/rail were taken by digital camera. Finally, the thermal images were compared with the photographs. The left wheel and right wheel were compared, and the results shown in Fig. 5(a)(b) and in Fig. 5(c)(d) respectively.

A comparison of the contact position on the left wheel shown in Fig. 5(a)(b), shows that both contact positions on the wheel tread, and the contact position located through thermal imaging were almost identical to the position in the photograph. For the right wheel shown in Fig. 5(c), there was no contact between the wheel tread and the rail head due to a difference in rolling radius between the right and left wheels of the vehicle running through the sharp curved section, whereas the inside surface of the flange was touching the rail gauge corner. As shown in Fig. 5(d), the flash temperature was also confirmed at the position close to the center of the inside of the wheel flange, which is almost identical to the position shown in Fig. 5(c).

Based on the above, it is considered that the wheel/rail contact point recorded by the thermographic camera was identical to the actual contact position.

Fig. 5  Comparison of the contact positions of wheel/rail by the thermal image with those of the photograph

3.4 Digitization of contact position

In order to locate the wheel/rail contact point with accuracy, the thermal images recorded by the thermographic camera were digitized after proofing. A metal gauge in the form of a metal comb with teeth spaced at 5 millimeter intervals was made and used for this study. Before the running tests, the vehicle was first made to stop on a straight section. The metal gauge was placed at the edge of the outside surface of the wheel and was photographed with the thermal imaging camera. Next was the digitization process using the relationship between the thermal image and the size of the actual intervals between the teeth of the comb.

3.5 Search area for contact point

3.5.1 Search area for wheel/rail contact point on left wheel

The area set for searching for the wheel/rail contact point on the left wheel is shown in Fig. 6. The search area was set close to the wheel/rail contact zone. Eight points were determined by dividing a 40 millimeter-wide band measured from the outside face of the wheel at 5 millimeter-intervals, with one extra point to determine whether the wheel flange was in contact with the rail gauge corner or not.

Changes in strength of sunlight must also be taken into account when using a thermographic camera in the daytime. Therefore, a referential search point, of about 40 millimeters in width was set just above the eight points. In order to make adjustments to decrease the influence of the sunlight the average temperature value for the points in this referential search area was subtracted from the maximum temperature among the eight search points, which
was obtained from measurements made while the vehicle was running. The wheel/rail contact point on the left wheel was defined as the position having the highest temperature among the eight points. When minor slipping occurred, i.e., when the vehicle was running in the straight section etc., the wheel/rail contact point could not be located accurately because it was not possible to determine the difference in surface temperature between each of the 8 search points. If the point with the highest temperature was one degree Centigrade or more over the average for the eight points, this was taken as the correct result for the analysis, and the output for the other points was zero.

### 3.5.2 Search area for wheel/rail contact point on right wheel

The search area for the wheel/rail contact point on the right wheel is shown in Fig. 7. In this section, in order to understand the motion of a wheelset, only two search points were set: one on the wheel flange and the other on the tread close to the outside rim. In this case, the aim was not to locate the contact position with the same accuracy as on the left wheel which had more search points. As such, no temperature correction was carried out either.

3.6 Results of running tests on RTRI test line

#### 3.6.1 Location of wheel/rail contact point on left wheel

The results for locating the wheel/rail contact point on the left wheel when the vehicle was running at a maximum speed of 30km/h, are shown in Fig. 8 (a). The vertical axis is the contact point in the horizontal direction of the wheel tread which corresponds to the position on the wheel tread in the horizontal direction shown in Fig. 8 (b). The horizontal axis in Fig. 8(a) shows time. In Fig. 8(a), the blue line and the green line mean the contact position on the wheel tread and the wheel flange, respectively.

At the start of the test, the vehicle was run along a straight section for a while. There was only minimal wheel slip on the straight section so the contact position could not be located with the thermographic camera. However, when the wheelset moved in the horizontal and lateral direction due to track irregularity, namely between about 18 sec. and 33 sec. as shown in Fig. 8(a), the left wheel flange clearly touched the gauge corner of the rail several times. Following this, the wheel/rail contact point on the left wheel shifted significantly by about -35 millimeters on the wheel tread, as shown in Fig. 8(b) in the horizontal direction (see Fig. 9(a)). This was because the wheelset entered a facing #10 turnout (point A in Fig. 8(a)), and exited on the tongue rail and the lead rail which are considered to have a curved alignment. After passing the #10 turnout, (point B in Fig. 8(a)), the wheelset was displaced momentarily to the left, and the wheel flange on the left wheel touched the rail (see Fig. 9(b)). Then, after running through a short straight section, the contact position of the wheelset shifted significantly by about -55 millimeters on the wheel tread, to a point close to edge of the wheel tread, on the transition curve on the entry side of a curved section with R160m (see point C in Fig. 8(a) and Fig. 9(c)). This is because the height of the rail head on the outside was comparatively higher than on the inside due to wear of the rail head on the inside. These results suggest that it may be possible to investigate sections where cross-sectional shape of the rail head is heavily affected by wear, by installing a device based on the proposed technique in this paper, on vehicles running on commercial lines. This application could lead to measures that save on track maintenance.

Next, in both the R160m and R100m curved sections, slight vibration occurred when the wheel/rail contact point was around -37 millimeters on the wheel tread in the horizontal direction (see point D in Fig. 8(a) and Fig. 9(d)). The reason why the wheel/rail contact point on the left wheel in both curves were almost the same despite the difference in curve radius was that the height of the rail head on the outside was comparatively higher than on the inside due to wear of the rail head on the inside.
in curve radius was that the cross-sectional shape of the rail head and slack were almost the same for both curves, and as the radius of each curve was small, the difference in the rolling radius between the right and the left wheel was insufficient and the wheel flange of the right wheel ran pressed to the gauge corner of rail. Therefore, it was assumed that the wheel/rail contact point was almost the same on each curve. This same tendency was observed for all running conditions during the experiment.

The technique proposed in this paper cannot be used to locate the contact point stably in all environmental conditions. If the surface temperature of the target object is high, or there are large temperature fluctuations, it may not be possible to locate the wheel/rail contact point because the contrast between touching and non-touching parts becomes tenuous. Incorrect results, for example detection of the contact point on the straight section between 120 seconds to the end, as shown in Fig. 8(a), occurred because even though the conditions made it hard for the thermographic camera to measure the flash temperature, the surface temperature of the earth influenced the temperature of the thermographic camera search point due to vibration of the wheelset and the track. Therefore, in order to measure the contact point accurately, it is important to have suitable environmental conditions for photographing, and to ensure that no other thermal objects other than the flash temperature due to the contact between the wheel/rail, influence the temperature of the search points. As such, to use the proposed technique properly, it is necessary to have minimum control over environmental conditions, i.e. performing test runs at night when temperatures are low and do not fluctuate much.

To conclude, the above results indicate that it is possible to use the proposed technique to locate the wheel/rail contact point accurately if the photographing is done in suitable environmental conditions.

### 3.6.2 Locating of wheel/rail contact point on right wheel

Figure. 10 shows the wheel/rail flash temperatures on the right wheel when the maximum vehicle running speed was 30 km/h. The green and blue lines show the flash temperatures on the wheel flange and the wheel tread respectively which indicate whether or not the wheel was touching the rail in the various curved sections.

Since the vehicles were run for a while on a piece of straight section at the beginning of the running tests, there was no confirmation of the change in flash temperature of the wheel flange and the wheel tread as for the search points on the left wheel. The flash temperature of the wheel flange suddenly increased to about 30 degrees Centigrade near turnout #10 (cf. point E shown in Fig. 10). This was because after the right-hand wheel on the vehicle passed through the tongue rail to the lead rail (see Fig. 11(a)), some slipping occurred due to the difference in rolling radius between the right and left wheels. At the crossing of the same turnout (cf. point F in Fig. 10), although the surface temperature was low, the flash temperature of the wheel tread was confirmed. This was because the contact point on the tread shifted suddenly from the wheel flange side to the edge of the wheel tread near the turnout crossing (see Fig. 11(b)). In the R160m and R100m curved sections, there is little difference in the rolling radius between the right

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**Fig. 9 Wheel/rail contact on left wheel in various positions**

(a) Contact at point A  (b) Contact at point B  
(c) Contact at point C  (d) Contact at point D

**Fig. 10 Change in wheel/rail contact point flash temperature on the right side during running tests**

(a) Contact at point E  (b) Contact at point F  
(c) Contact at point G  (d) Contact at point H

**Fig. 11 Various wheel/rail contact points on right side**
and left wheel, so the wheel flange is constantly touching the gauge corner of the rail. The large change in flash temperature of the wheel flange occurred because the yawing amplitude of the wheelset was small (see in Fig. 11(c)(d)). When contact was observed between the wheel flange and the gauge corner of the rail on the monitor in the cabin, this confirmed synchronization of the yawing motion of the wheelset and the shift in the contact point from the base of the wheel flange to the center of the inside of the wheel flange. These results indicate that with the right environmental conditions for photographing, the proposed technique can be used to clarify the motion of the right-hand wheel on both curved and straight sections of track with irregularity, without digitizing the contact point in detail, as for the wheel/rail contact point on the left-hand rail.

Here, the contact point between the backside of the wheel and the guard angle could not be located using the flash temperature when the vehicle was running through the turnout, because there were only two search points on the right-hand wheel. If the search point is set on the backside of the wheel, however, the contact point on the backside of the wheel can be located.

4. Case study - running experiment for wheel flange climb derailment

The performance of the proposed technique was verified in a running test for wheel flange climb derailment. The running experiment was carried out using a vehicle made to have significant wheel load imbalance, on a RTRI test line. The results of this test are shown in Fig. 12. Note that the installation angle of the thermographic camera was different from that described in the experiments in Chapter 3, whilst the mounting location was almost the same, and the wheel/rail contact point on the right side of the front wheelset was photographed from the rear in the vehicle running direction. Insight into wheel motion was obtained as follows: thermal images were not digitized using the metal proofreading scale. The search points were set close to the wheel flange, and divided into 7 points, while insight into the motion of the wheelset was obtained by defining the point where maximum temperature was reached. The vehicle was running through the exit transition curve from a R100m curved section. It is understood that the wheel on the right side climbed onto the rail head after about 4 sec., and the wheel flange-top kept running on the rail head for about 3 sec., the wheel flange slid down from the rail head, and the wheel tread came into contact with the rail head. When the wheel flange on the right side climbed up the rail head, the rolling-sliding frictional force between the wheel and the rail peaked because the difference grew in the rolling radius of the wheel on the right side and the left. Therefore, when the top of wheel flange ran on the rail head, the flash temperature increased, and it was easier to locate the wheel/rail contact point on the thermal images.

These results show that the proposed technique can be used to gain much more detailed insight than previous methods using a CCD camera.

5. Conclusions

In this study, a new technique for accurately locating the wheel/rail contact point using a thermographic camera is proposed based on the visualization method presented in the Burstow study. Running tests were carried out to verify the validity of the proposed technique on the RTRI test line. The following insight was gained:

(1) In order to understand wheelset motion, two techniques were proposed. One technique was to digitize thermal images based on the relationship between a metal comb type scale and the number of pixels, after which the wheel/rail contact point could be accurately located through calculation. Another technique was to understand wheelset motion by setting two search points: one on the wheel flange and the other on the edge of the wheel tread touching the outside face of the wheel.

(2) In order to verify the validity of the proposed technique, vehicle running tests for locating the wheel/rail contact point were carried out using an actual vehicle. As a result, when the experiment was carried out under the following three conditions: (a) minimal influence from direct sunlight, (b) low surface temperatures of the earth, track facilities, and wheel/rail interface, and little fluctuation in temperature, and (c) high wheel/rail flash temperature, the wheel/rail contact point could be accurately located and insight could also be gained.
into wheelset motion.

(3) This proposed technique was then applied in running tests for rail climb derailment. Results showed that the contact point between the flange and the gauge corner of the rail could be accurately located as the wheel climbed the rail head. This suggests that the proposed technique can be used to gain more detailed insight than conventional methods using CCD camera.

The results presented here suggest that the proposed technique can be utilized in many experiments relating to wheel/rail contact problems as a useful tool in the right environmental conditions for photographing. For example, if the research target is the powered axle of a power car, it would be possible to understand more about the frictional heat generated on the wheel/rail interface during significant wheel slipping and braking. This means that the technique could be used to devise techniques to investigate wheel/rail wear tendencies.

This technique will be used to confirm results from tests to validate solutions to various wheel/rail contact problems.

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