The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 16.1
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.16.1

Thermal Imaging of Wheel-Rail Interface as a Tool for Multipoint Contact Detection

M. Słowiński

Institute of Transport, Poznan University of Technology, Poland

Abstract

The aim of this paper is to present thermal imaging as a tool for detecting multipoint contact between tram wheel and rail under real operation conditions. Firstly, the basic information of the wheel-rail interaction and heat-generating process in the contact patch are introduced. Then the thermography measurement carried out during a tram ride is described. The vehicle and measurement setup are introduced. Next, the analysis of thermograms showing multipoint contact consisting of two, three and four points is presented. Further, the measurement technique, obtained results and the further applications of wheel-rail contact thermal imaging are discussed.

Keywords: thermal imaging, tram vehicle, rail vehicle dynamics, wheel-rail contact, multipoint contact, frictional heating.

1 Introduction

The wheel-rail contact patch is the key area of the interaction between the vehicle and the track since it is where the phenomena that determine ride comfort, ride safety, vibroacoustic emission and wear take place. Two mechanisms providing heat in the interface can be distinguished [1]. First is the difference in velocity between wheel and rail (creepage) which effects in sliding friction heat generation. Creepages may act in 3 directions – longitudinal, lateral, and around the normal axis (spin). Longitudinal creepages arise during acceleration and braking, lateral creepages - during curve negotiations. The spin creepage is generated mainly by wheel conicity and wheelset yaw velocity. The second mechanism is a local plastic deformation, which occurs due to the high normal and shear stresses in the contact patch. However, it is stated that heating due to plastification results in a small contribution to the total temperature rise, due to the relatively small strain [1]. Those mechanisms, which cause local temperature rises, are the factors that make wheel-rail contact detectable by infrared thermography.

There are 3 basic types of contact between the wheel and the rail: single-point contact, multipoint contact and conformal contact [2]. Typically, single-point contact occurs during straight section passing, multipoint contact during curving or due to the poor technical condition of wheels and rails. Conformal wheel-rail contact is caused often by worn wheel and rail profiles or in well designed (dedicated) wheel-rail pairs. While each of these types of wheel-rail contact could negatively affect the interaction of the vehicle and the track, multipoint contact is the most undesirable one, because contact points on the wheel have different linear velocities. This results in creepages between wheel and rail, which give rise to frictional energy dissipation resulting in local temperature rises at the wheel-rail interface.

The aim of this paper is to present thermal imaging as a tool for detecting multipoint contact between wheel and rail in real-operating conditions. As described above, local plastic deformation and creepages generated by multipoint contact between wheel and rail, cause local temperature rises. These temperature rises can be detected by thermal imaging measurements and enable to study of wheel-rail interaction via an alternative way. The most common methods used for wheel-rail interface monitoring are roller rigs and numerical simulations. However, thermography measurement unlike those methods creates the possibility for identifying multipoint contact between wheel and rail in a given infrastructure, weather and real operation conditions context.

2 Methods

There are only two papers, which focus on the thermal imaging of wheel-rail contact under real operation conditions. The pioneering work in this field was presented by Burstow et al. [3], which described the measurement of the local temperature rise in rail surface. Yamamoto [4] proposed the improvement of Burstow's method by adding the possibility of the exact localisation of the contact patch. However, these two research are based on experimental measurements carried out on rail vehicles. For this reason, the author of the following paper noticed a research gap, therefore the main goal was to investigate the tram vehicle. The measured vehicle was Tramino S105p driving on the Poznań tram system. It is a 3-bogie tram with a trailer bogie in the middle. The nominal wheel diameter is 620 mm, however, a diameter of a worn profile may be as low as 510 mm. PST profile was adopted for the vehicle wheels. In the Poznań tram system there are mainly two types of rail – 49E1 and grooved type rail 60R2.

With the aim of achieving accurate and reliable wheel-rail contact area monitoring, the measurement system presented in Figure 1 was used. FLIR E60 thermal imaging camera was placed behind the left wheel of the trailing wheelset of the first bogie, with the lens positioned perpendicularly to the railhead surface. Under the camera, there was a mirror tilted at an angle of 45° allowing observation of the contact of the wheel with the rail. In addition, by placing a camera at the front of the vehicle and synchronising it with a thermal camera, it was possible to link the thermal data with the specific infrastructure section.

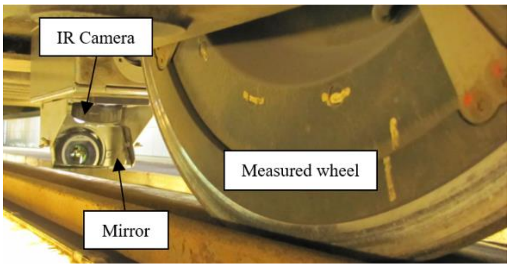

Figure 1: Thermography measurement system setup.

The tram was operated on a track during a dry summer night so as to minimize the influence of atmospheric factors that could negatively affect the results. The vehicle rode without passengers at operating speeds based on section restrictions. There was no wheel flange lubrication during the journey. The routes containing straight sections, crossings and numerous curves were chosen in order to investigate the behaviour of the wheelsets under potentially adverse conditions.

3 Results

The results of the thermal imaging measurement are thermograms showing the wheel-rail interaction on which it was possible to identify local temperature increases. It was remarked that during negotiating the track sections, where theoretically there should be no creepages (e.g. single-point contact on the straight section in good technical condition), no significant increase in temperature was noticed (Figure 2). It means that wheel-rail contact principles are obtained, i.e. there is no temperature rise during one-point contact between wheel and rail on a straight track section.

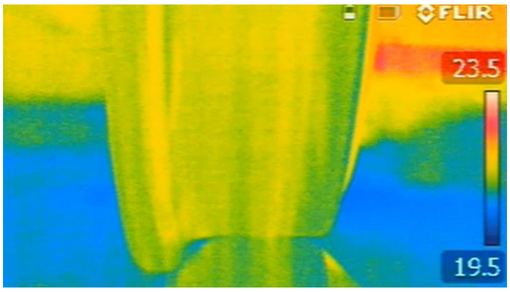

Figure 2: Thermogram of a single-point contact during straight section negotiating.

Multipoint contacts, which led to creepages between the wheel and the rail and consequent local temperature increases, were identified on the thermal images. The situations in which multipoint contact between wheel and rail were obtained from thermal imaging measurements are:

- curve negotiating,
- driving through straight section (backflange contact),
- driving through railway crossings.

Two-point contact was most often observed when the investigated wheel was an inner wheel in a curve. The additional contact occurred between the wheel flange and the rail (Figure 3).

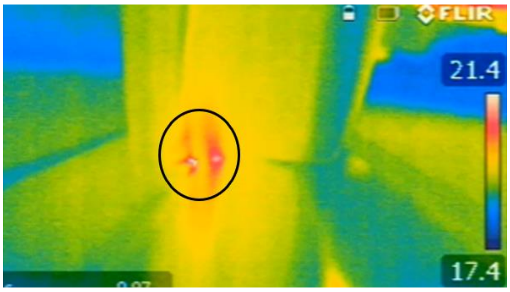

Figure 3: Thermogram of a multipoint contact between wheel and rail during curve negotiation.

During thermograms analysis, contacts between the wheel flange root and the rail head were also found showing three or four points (Figure 4). They appeared when the vehicle was driving through a tight curve to the left when the observed wheel was the inner wheel of the wheelset. The occurrence of multi-point contact, in this case, may be caused by poor technical condition of the track, e.g. lateral wear of the rail head.

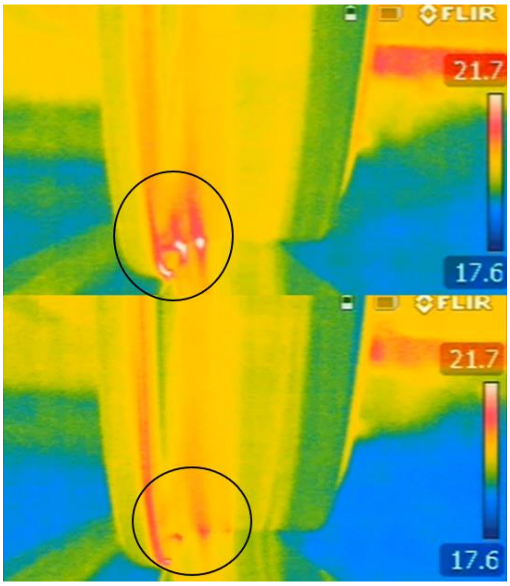

Figure 4: Thermograms of multipoint contact.

Two-point contact was also noted when traversing a tangent track section. This phenomenon is specific for light rail vehicles dynamics and is called backflange contact. It is caused by the irregularity of rails and consequent wheelset lateral displacement within available gauge clearance. It resulted in additional contact between the flange and the guard rail (Figure 5).

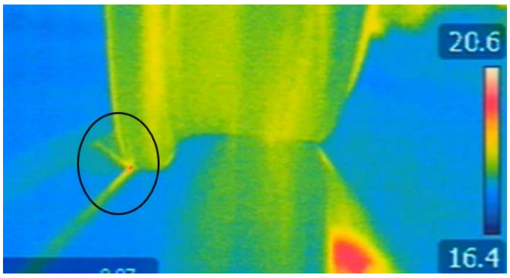

Figure 5: Thermogram of multipoint contact
on a tangent track section.

Another situation when two-point contact was detected, was rail crossing passing. Due to the lateral displacement of the wheelset, the wheel contacted the crossing's guard rail with its flange (Figure 6). Normally, one-point contact between the wheel flange and the crossing base occurs.

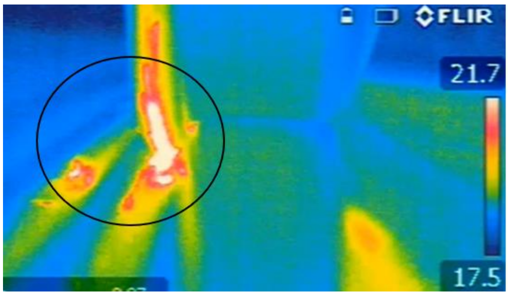

Figure 6: Thermogram of multipoint contact
during rail crossing passing.

4 Conclusions and Contributions

The study shows that thermography images of wheel-rail contact are an effective tool for multipoint contact detection. Moreover, this kind of measurement, thanks to its non-invasiveness nature, enables to take into consideration real operation aspects of rail vehicles dynamics. In the literature, there are papers on thermal imaging at the wheel-rail contact, but they describe a study on a railway vehicle. Research presented in this paper is focused on a tram vehicle. That kind of vehicle accelerates and decelerates more frequent and intense than rail vehicles and rides on the tracks with a radius of curves below 50 m. Those factors imply that intense and undesirable phenomena occur between the tram wheel and the rail, especially multipoint contacts, which cause high creepages and, in consequence, temperature rise in the interface. It was observed, that during curve negotiation and railway crossing passing, the multipoint contact between wheel and rail may occur. In addition, even for the straight sections of the track, some two-point contacts were observed. The reason for it was the poor technical condition of the track or wheel. It was experimentally proved that the multipoint contact causes a local temperature rise in the wheel-rail contact.

The carried out measurements, as well as the analysis performed on their basis, are an alternative form of assessing the wheel-rail interaction in comparison with commonly used MBS simulations. Thermal imaging may also be a supplement to simulations and calculations as a validation of computed results. For this reason, further work on thermal imaging of the wheel-rail contact area is planned to be carried out in the direction of a quantitative analysis, which will determine the temperatures prevailing in this area and the precise location of the contact point between the wheel and the rail. In addition, simultaneously thermal imaging of two wheels can be conducted in order to compare their behaviour during the run. Another important step of improving the application of thermal imaging to wheel-rail interface monitoring can be artificial intelligence technologies for image processing to find relationships between temperature generated at wheel-rail interface and interaction characteristics.

Acknowledgements

All the presented work has been realized within the research project "A measuring system for identifying the wheel-rail pair wear intensity using imaging in the range of visible and infrared light" (LIDER/35/0182/L-12/20/NCBR/2021), financed by the National Centre for Research and Development (LIDER XII initiative).

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