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A Measuring System for Identifying the Wheel-Rail Pair Wear Intensity using Visible and Infrared Imaging

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Abstract

It is currently not possible to experimentally identify specific operating conditions or sections of infrastructure for which certain values of the wear intensity of wheels and rails occur during rail vehicle driving.This paper shows the development of a new approach to characterize the wheel-rail wear by the means of visible and infrared light range imaging. The main assumptions of the undertaking, adopted methods, preliminary and anticipated results are demonstrated. On the basis of the results of preliminary tests in real operation conditions and on a tribological machine, it has been proved that the presented method can be implemented while monitoring the wheel-rail interaction. The issues that need to be solved in order to ensure the appropriate quality of measurement are emphasized, e.g. low emissivity of metal surfaces, difficult access to the wheelset of the vehicle and the presence of contaminants and third bodies in the wheel-rail contact. The utimate goal of the described undertaking is the development and experimental verification of a prototype of a measuring system to identify the wear intensity of the wheel-rail pair. The implementation of the method will contribute to the expansion of research

possibilities in the field of the analysis of wheel-rail contact and to deepening the knowledge about its behavior in various operating conditions.

Keywords: railway engineering, wheel-rail, rolling contact, wear, thermal imaging

1 Introduction

Despite the fundamental role of the wheel-rail contact in determination of ride safety, it is still very difficult to determine its shape and position in real-life operation conditions. One of the methods of monitoring the wheel-rail interaction is to measure normal and tangential forces in the contact area, which have a significant impact on the wear intensity of the friction pairs [1]. Direct measurement of these forces while driving is problematic due to high values of contact stress, difficult access and its complex movement. Common methods of measuring forces in the area of wheel-rail contact are based primarily on the use of strain gauges placed circumferentially on the wheel rim [2]. Other methods of estimating contact forces are based on the analysis of vibration accelerations as input data to inverse mathematical models [3] or on the deformation of the wheel measured by distance transducers [4].

The described methods enable us to determine the forces between the wheel and rail, but without their distribution in the contact area, which results in the impossibility of reading the instantaneous wear intensity. However, wear intensity can be defined as the volume of material removed (Archard's law) on a roller stand. Wear is closely related to the slip in the wheel-rail interface, which was recorded in infrared by Gallardo-Hernandez et al. [5]. Burstow et al. [6] described the use of infrared light imaging for monitoring wheel-rail contact under regular operation conditions. The authors found that the measurable thermal trace of the contact area visible on the rolling surfaces allows us to recognize its transverse location. The described method was further developed by Yamamoto [7] in terms of localization of the wheel-rail contact area. The author noticed great potential of the method in wear analysis of traction vehicle wheels.

However, none of the mentioned works presents any approach to measure the instantaneous intensity of wear or its classification under regular operation conditions. Therefore, it is currently not possible to experimentally identify specific operating conditions or sections of infrastructure for which certain values of the wear intensity of wheand rails occur during rail vehicle driving.

The problem will be investigated within the project titled “A measuring system for identifying the wheel-rail pair wear intensity using imaging in the range of visible and infrared light”. This paper describes the main assumptions of the undertaking, adopted methods and anticipated results.

2 Methods

The contact area between the wheel and rail is impossible to be directly observed on a moving rail vehicle. The concept of the measuring system for the identification of wear intensity assumes the use of thermal and visible imaging. This will enable us to identify the distribution of thermal fields on the tested elements in real time. Thanks to this, it will be possible to locate the contact areas, determine their type and estimate the instantaneous intensity of wear. The schematic diagram of the system is shown in Figure 1. The identification will be performed using supervised machine learning techniques.

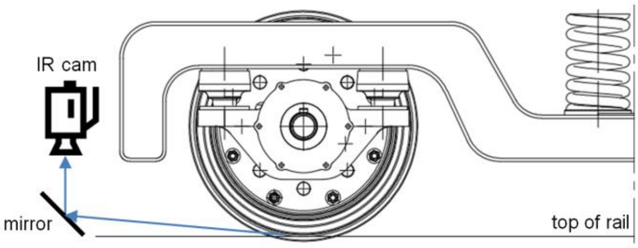

Figure 1: Schematic diagram of the measurement system (imaging).

The first, laboratory version of the measurement system will be developed using a 1:2 scaled roller rig. Preliminary experimental tests in real operation will be a base to determine the measurement conditions. Obviously, it is necessary to know the emissivity of the tested surfaces, which is variable, among others, depending on the surface condition. The variable value of the emissivity coefficient ε results from the changing share of pollutants, the presence of oxides, traces after repairs or the surface topography [8]. Additionally, it should be remembered that the smooth metal surfaces of the wheel are characterized by low emissivity (less than 0.30). Therefore, techniques aiming to increase the emissivity value should be developed.
The target measurement system will be designed to be mounted on a tram, on an attacking wheelset. Cameras will observe the wheel surfaces leaving the contact. Figure 2 shows inputs and outputs of the identification algorithm. The main functions of the algorithm are set on the right side. The system will make it possible not only to determine the instantaneous intensity of wear, but also to relate it to various operating conditions (driving speed, weather conditions, type and location of contact, location in the track system).

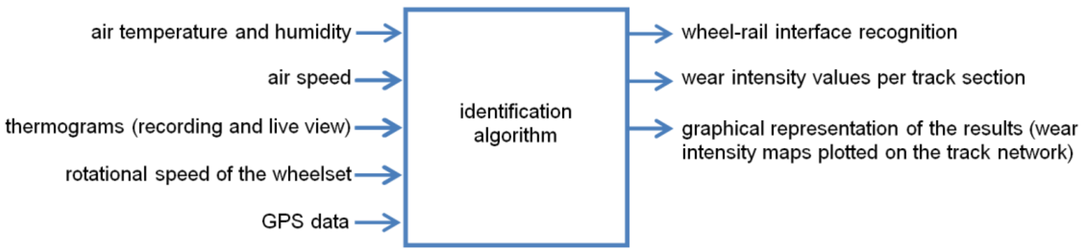

Figure 2: Inputs and outputs of the identification algorithm.

At each stage of the work, it is necessary to verify the obtained data. During the tests on a roller rig, validation will be performed with reference to the friction work. The results of the tests in real operation conditions will be verified on the basis of the measured state of rail wear and the MBS simulation.

3 Results

The possibility of application of the method was confirmed on the Amsler tribological machine, with rolling 50 mm diameter cylindrical samples (Figure 3). It has been shown that it is possible to measure the temperature rise close to the contact point of the rolling kinematic pair (with a low emissivity coefficient) using thermal imaging. Figure 4 shows the temperature time history during the test on the Amsler machine. In the time range 13:10–13:50 there was a noticeable increase in temperature in the contact area. Despite the constant load (1000 N), the temperature increase was non-asymptotic and the steady state was not reached. The factor influencing such a course of temperature values could be the emissivity coefficient, which varied as a function of temperature. However, it is also probable that the contact pressure of the kinematic pair increased slightly together with the thermal expansion of the machine elements, which in turn led to an exponential increase in measured temperature.

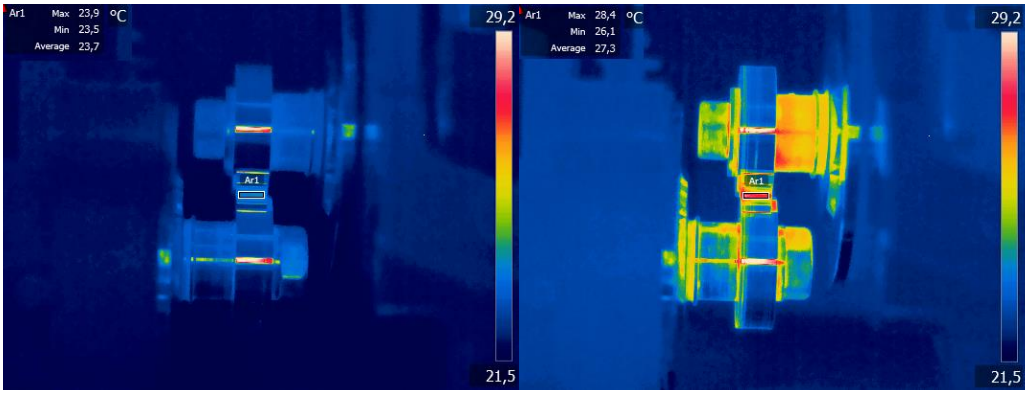

Figure 2: Thermograms from Amsler machine (a – before the measurement, b – end of the test).

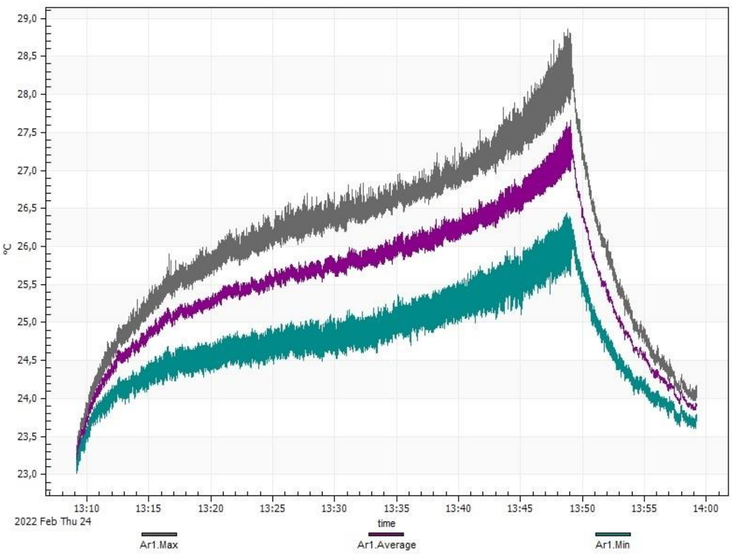

Figure 3: Temperature at the contact point of the tribological machine rollers.

On the basis of the tests carried out in real operation conditions, it has been proved that the presented method can be implemented while monitoring the wheel-rail interaction (Figure 5).

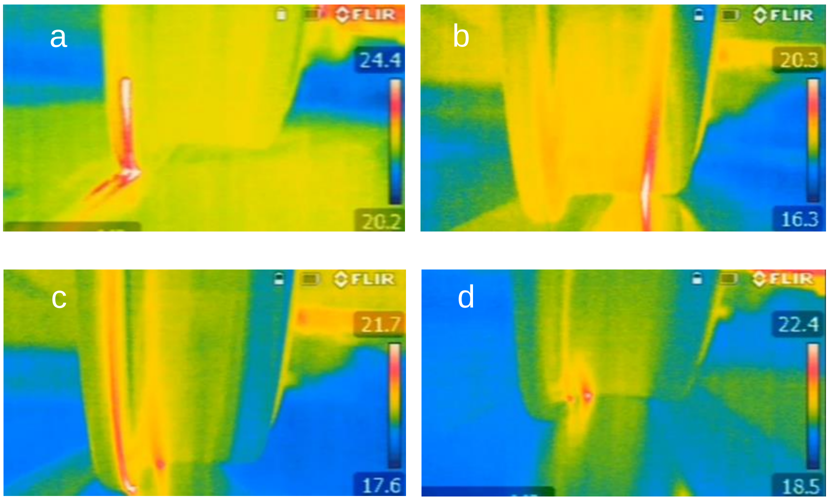

Figure 4: Thermograms from real operation conditions (a – shallow-grooved frog, b – outer wheel in a curve, c – inner wheel in a curve, d – two-point contact).

The temperature in the wheel-rail contact area was also examined in the laboratory. This area demonstrated the features of a blackbody or a cavity with a relatively high emissivity. In order to achieve an established emissivity value the samples of wheel and rail were heated in a furnace to a temperature close to 100°C. The cross-sections were painted black (ε = 0.93÷0.95) for reference. Based on the known temperature of the wheel-rail pair elements (measured with a thermocouple), it was possible to determine the emissivity on raw surfaces close to the contact (Figure 6).

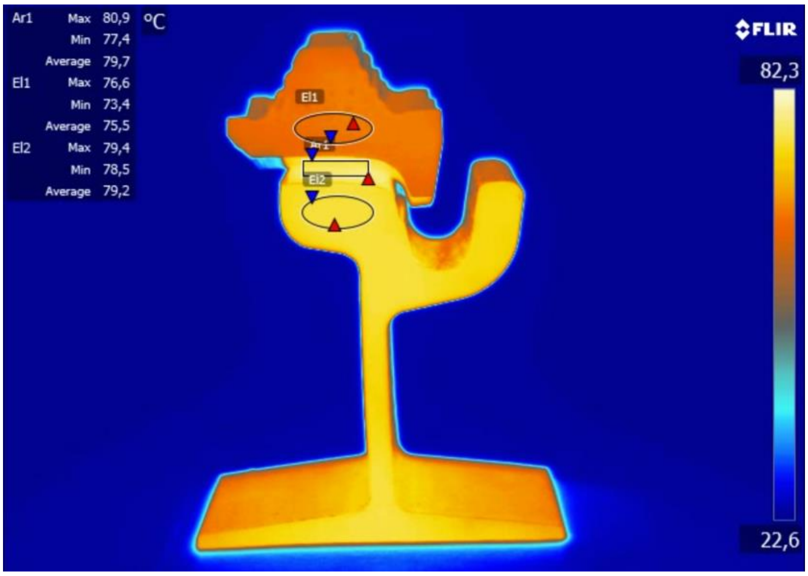

Figure 6: Test object with marked measurement areas.

This experiment was carried out for the unprepared surfaces – oxidized and contaminated, as well as for the surface cleaned and polished, to imitate operation conditions. This study allowed us to determine the effective emissivity value in the measurement area in the range of 0.80÷0.90, regardless of the type of surface treatment.

4 Conclusions and Contributions

The proposed method is innovative due to the original use of the measurement technique as well as the measured quantities and observation conditions. Thermovision has not been used so far as a tool for measuring the wheel-rail wear intensity in real operation conditions, giving the possibility of assigning it to individual driving conditions. Alternatively, strain gauge sets can be used to measure the wear intensity – however, once placed on the rolling surface, it would be quickly damaged due to repeated high loads, not to mention the introduction of disturbances caused by the presence of third bodies. Another way is to use strain gauges on the wheel surfaces not involved in contact, after appropriate calibration of the measuring system. This means calculation of the wear on a basis of incomplete information like contaminants in the interface, variable friction coefficient and so on. Another problem is the simultaneous occurrence of adhesion and slip in the contact area. So far, we are unable to distinguish them in real operating conditions. The solution to this problem may be the recording of the friction effects, but not its causes i.e. heat.

Another advantage of the measuring system that has been being developed is the potential unlimited range of operating conditions for the wheel-rail pair in which the measurement can be performed. Wear in the rolling contact area occurs in every contact operation conditions. The project focuses on real rolling contact subjected to complex motion conditions (actual operation), which should be the most desirable research material in application research.

The implementation of the project will contribute to the expansion of research possibilities in the field of the analysis of cooperating surfaces in the area of wheel-rail contact and to deepening the knowledge about its behavior in various operating conditions. The obtained results will fill the gap concerning the methods of identification and classification of the intensity of wear in the conditions of real operation. Until now, such information is being obtained by recreating real conditions using numerical models and laboratory test stands. The possibility of obtaining results from such a system certainly will be valuable in terms of validating numerical models.

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