



## The use of thermal imaging studies in the diagnosis of railroad infrastructure elements

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*The article presents selected results of thermovision measurements of EOR elements used for heating railway turnouts under the BRIK2/0036/2022 project. The tests were carried out for various types of railway turnouts (ordinary). The results made it possible to observe the temperature distribution for different construction solutions of turnouts. Further work is focused on preparing assumptions and criteria for developing an application supporting the interpretation of thermo-grams, which can be a tool supporting the diagnostics of EOR devices. The creation of a simple diagnostic tool that allows the evaluation and interpretation of the obtained thermogram may enable maintenance services to make the right decisions in the field of operation.*

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## 1. Introduction

The transportation tasks currently facing rail transportation make it necessary to constantly develop and improve the construction and diagnostics of railroads. These tasks are mainly due to changes in operating conditions, such as the need to increase maximum train speeds, increase permissible axle loads or increase capacity. An important element is the operational reliability that determines the economy and safety of rail transportation. Also, recently increased environmental requirements are imposing further criteria to which modern technologies in railroad construction must be adapted. Ensuring the possibility of the railway junction at the station especially during winter periods with snowfall requires the use of solutions to maintain the full efficiency of the railroad turnout enabling its repositioning regardless of weather conditions. Electric turnout heating (ETH), which has been in use for several decades, is one of the most effective solutions for ensuring that trains can pass the railway junction. An important element during operation is the diagnosis of both the turnout elements and the equipment used to heat the turnouts, including

both power and control systems. Conducting diagnostics on these elements and devices allows to avoid emergency situations that prevent normal operation to ensure turnouts are passable. Another important element may also be the use of innovative turnout heating systems that reduce the Infrastructure Manager's electricity consumption. Work related to optimization (construction of a new control system) of the ETH reducing the demand for electricity used in turnout heating is being carried out within the framework of the BRIK2/0036/2022 project titled: "Energy Efficient Electric Turnout Heating System with Adaptive Heating Power Distribution".

## 2. Research problem – literature review

Diagnostic testing is an integral part of technical infrastructure maintenance. Also in the case of railroad turnouts, there are numerous instructions for maintaining railroad turnouts [4–6, 9, 18] or operating and maintaining ETH systems [7]. Thermal imaging cameras are playing an increasingly important role in diagnostics, as they enable carrying out some inspection of thermal aspects without interfering with the device

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in question. Such tools can also be used to diagnose rail defects or in turnout heating systems. Thermal imaging cameras are devices that capture infrared radiation emitted by objects whose temperature is above absolute zero. This type of camera was originally developed as a night vision and observation tool for the military. The use of this type of detector in vision systems for monitoring the condition of rails or turnouts eliminates the lighting problems that occur with normal grayscale and RGB cameras – Red, Green, Blue). The use of thermal imaging studies like energy efficiency analysis of electric heating of railroad turnouts has been the subject of numerous scientific papers [1, 3, 4, 17, 19]. The paper considers the contribution of the various heat transfer mechanisms to the course of the heating phenomenon in the turnout space. A rather interesting take on the use of thermal imaging cameras to detect irregularities in rails can be found in paper [12], where an experiment was performed on real objects. The study looked for a method to detect the phenomenon of "rolling" which is impossible to detect by profile inspection or visual inspection. The authors demonstrate that the use of thermography makes it possible to detect this phenomenon, despite the fact that the only method known so far to detect this type of defect is complex inspection systems based on eddy currents. An analysis of recent research points to the need to use thermal imaging to investigate metal damage, where the test piece is heated by a short induced pulse of electric current, and a thermal imaging camera records – during and after the pulse – the temperature distribution on the surface [7]. In the indicated work, finite element simulations were performed to investigate how the phase contrast depends on parameters such as excitation frequency, pulse duration, material parameters, crack depth and crack angle. Based on these results, generalized functions for the dependence of the phase difference on all these parameters were derived. The author posits that these functions can serve as guidelines for optimizing measurement parameters for a given material so that cracks can be detected, and their depth estimated. What is more common is that this technology is used in railroad technology, among other things, by infrastructure managers in assessing the broad technical condition of equipment in which thermal processes occur. Observation and monitoring of these processes, including with the use of IT tools according to the authors is not the future, but a necessary present resulting from the implementation of new technologies. Visual inspection, thermal imaging measurements in the process of operation of electrical or power equipment, control or monitoring of "hot axles" are becoming standard. Referring to rail vehicles, thermal imaging can be used in the diagnosis of

welded bearings or brake discs, railway wheels in terms of thermal loads. One can mention here, among others: the following publications, which include thermal imaging measurements when examining rail vehicles or their components [8, 11, 13–16]. Thermal imaging-related technologies enable operator-safe, non-contact, direct measurement of temperature on the surface of the tested object. The result of this measurement, properly interpreted, allows to decide whether the device or element is operational, working or requires replacement/repair. Interpretation of the technical condition should be objective; this objectivity is provided by properly designed and properly used IT tools. The thermogram analyzed by the operator is burdened with his subjective judgment resulting from his knowledge of the device under test, his knowledge of the processes taking place in the device under test, as well as his ability to operate the device at the stage of taking the measurement and interpreting the result of that measurement. It is important to use during the measurement the appropriate tools defined, implemented in the thermal imaging camera and software at the stage of analysis and interpretation of the result. The need to carry out diagnostics of railroad turnouts with particular attention to the problem of diagnostic imaging was noted in paper [9], which discusses the principles of correctly taken photography of the examined pavement element, which, in addition to the verbal record, is particularly useful in the process of diagnosis and evaluation of changes occurring over time. As indicated in the aforementioned work, a railroad turnout is one of the more complicated elements of a railway track. During its operation, special attention should be paid to problems related to its proper maintenance. To this end, it is necessary to conduct ongoing and periodic inspections that will allow early detection and correction of defects, thereby extending the life of railroad turnouts. During the conducted inspections, particularly including visual inspection of the elements of the railroad turnout, the detected defects should be archived in the form of photographs or thermograms. The documentation produced in this way can be used in subsequent periodic reviews to analyze the changes taking place. The considerations outlined above show that early detection of damage to railroad infrastructure elements (such as rails and railroad turnout elements) is an indispensable part of ensuring a high level of safety and reliability in rail traffic. For this reason, too, tools should be developed for reading thermograms, as well as for preliminary interpretation of the results obtained, which will allow the diagnostician to make a diagnosis or take action. This probably requires the preparation of an appropriate supporting application using, for example, artificial intelligence, which, based on the thermograms

taken and implemented into the program, will interpret the results obtained, enable the identification and management of hazardous situations in rail transportation infrastructure.

### 3. Experimental studies

Thermographic studies of heat distribution on turnouts of railroad ETH systems were carried out at two locations on the PKP PLK S.A. network. The thermographic tests were conducted on ordinary turnouts made of two types of 60E1 and 49E1 rails. In order to obtain as much data and information as possible on the performance of ETH systems, the following types of turnouts were studied: Rz-49E1-190-1:9; Rz-49E1-300-1:9; Rz-60E1-190-1:9; Rz-60E1-300-1:9; Rz-60E1-500-1:12 and Rz-60E1-1200-1:18.5. The tests were performed for the turnout in a cold state (without ETH attached), as well as during attached heating. The tests took into account aspects of turnout design such as:

- the position of the switch blade (point with blade straight or diverging)
- varying distances of the switch blade from the saver for point with diverging blade
- varying stroke of the switch blade along its length
- varying cross-section and mass of the switch blade along its length.

In addition, the heating time was taken into account, as well as the process of its warming up of the turnout. Figure 1 shows the turnout heating zones considered during the conducted tests.



Fig. 1. Switch-point saver heating work area, for right and left point

Figures 2–7 show example thermograms with the distribution of apparent temperature in the studied railroad turnout.

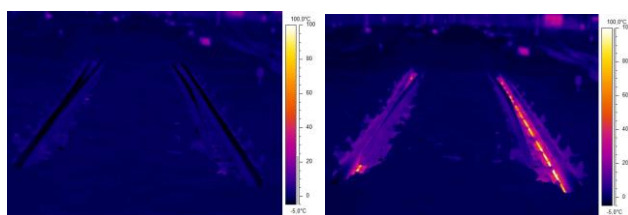


Fig. 2. Thermograms showing sections of the track system presenting track heaters of the turnout electric heating system, (right) cold state, (left) heated state for turnout Rz-49E1-190-1:9

The thermograms presented in Fig. 2–5 were taken at the dates and weather conditions described in Table 1. The turnout area was covered with a layer of snow (10 to 20 centimeters). The cold condition was the so-called “as-is condition” after a period of heavy snowfall, in which the installed ETH equipment operated. The melting process was not recorded; the condition after the snow had already melted was recorded. The thermograms in the heated state show an even temperature distribution for all visible heaters (radiators) for each heating zone. The heating zones defined for each turnout area are described in detail in publication [1].

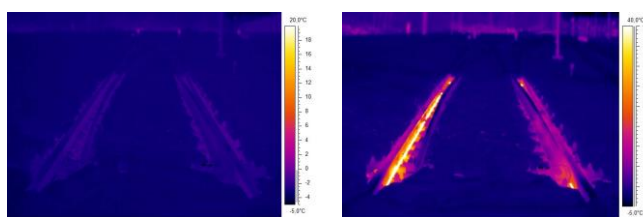


Fig. 3. Thermograms showing sections of the track system presenting track heaters of the turnout electric heating system, (right) cold state, (left) heated state for turnout Rz-49E1-300-1:9

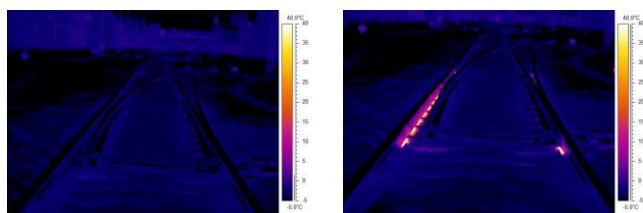


Fig. 4. Thermograms showing sections of the track system presenting track heaters of the turnout electric heating system, (right) cold state, (left) heated state for turnout Rz-60E1-190-1:9

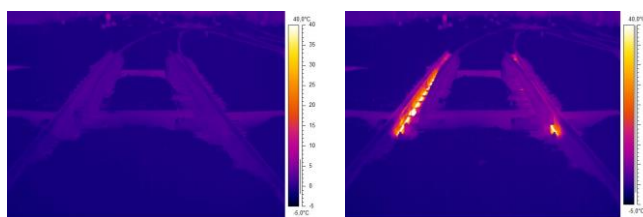


Fig. 5. Thermograms showing sections of the track system presenting track heaters of the turnout electric heating system, (right) cold state, (left) heated state for turnout Rz-60E1-300-1:9

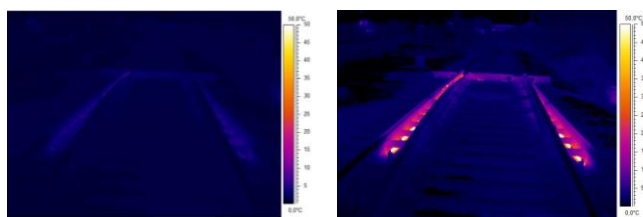


Fig. 6. Thermograms showing sections of the track system presenting track heaters of the turnout electric heating system, (right) cold state, (left) heated state for turnout Rz-60E1-500-1:12

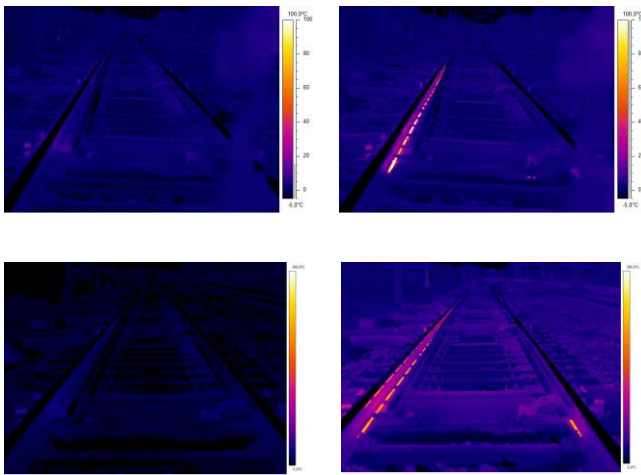


Fig. 7. Thermograms showing parts of the track system showing track heaters of the turnout electric heating system, (right) cold state, (left) heated state for turnout Rz-60E1-1200-1:18.5 taken with two types of thermal imaging cameras (640×480 – 45° and 1024×768 – 28°, bottom thermograms)

The thermograms shown in Fig. 6 and 7 were taken for turnouts not covered with snow. No snow melting process was observed for these turnouts. Thermograms for turnout Rz-60E1-1200-1:18.5 were taken using thermal imaging cameras with a resolution of 640×480 with a lens of 45° and 1024×768, lens 28°. In the latter case, a much more detailed picture of the apparent temperature distribution on the surface of the turnout area was obtained. The thermograms presented here are only a small percentage of the images taken and have been selected to present the possibilities of thermal imaging applications. Detailed analysis and interpretation of individual photos will allow us to

assess the effectiveness of turnout heating, the temperature distribution in those turnout elements responsible for possibility of the railway junction. Analysis of thermographic images can also allow the development of criteria for evaluating the solution used, as well as assessing its energy efficiency. A summary of selected parameters describing weather conditions on the days of the survey is presented in Table 1. The source of weather data is the daily weather reports of the Institute of Meteorology and Water Management of the National Research Institute (IMGW-PIB) [10]. On the days of the thermal imaging inspection, there was no rainfall or snowfall buildup. A uniform image composition was maintained during the measurements. The thermal imaging camera was set on a tripod at a height of 1.2 meters from the level of the sleepers and at a distance of 10 meters from the base point, which was the end of the spire in the direction towards the blade. Maintaining a uniform composition was expedient due to the use of software tools for analyzing and interpreting thermal images using machine learning, neural networks and artificial intelligence. These tools modelled in a diagnostic tool formula are currently being tested.

The thermograms presented in Fig. 2–7 were recorded in the automatic mode of camera operation. In the subsequent analysis and interpretation of the thermograms using the camera manufacturer's dedicated software, an emissivity correction was made in selected areas of the turnout due to the variation in materials. Emissivity is a key parameter affecting the value of the apparent temperature seen in thermograms.

Table 1. Selected parameters describing weather conditions

Date	Time	Temperature [°C]	Forecast	Pressure [hPa]	Wind [km/h]	Humidity [%]	Type of turnout
24.01.2023	10:00	0.1	Totally cloudy	1039.5	8.7	100	Rz-60E1-500-1:12
	11:00	0.5	Totally cloudy	1039.8	8.6	100	
	12:00	0.8	Totally cloudy	1039.9	8.5	99.0	
14.02.2023	10:00	1.0	Totally cloudy	1037.6	1.4	91.4	Rz-60E1-300-1:9
	11:00	1.5	Mostly cloudy	1037.5	2.9	86.2	
	12:00	1.9	Partly cloudy	1037.0	2.5	84.8	
15.02.2023	10:00	1.4	Cloudless	1032.5	5.4	89.1	Rz-60E1-190-1:9
	11:00	2.7	Cloudless	1032.2	2.2	77.7	
	12:00	3.8	Cloudless	1031.6	0.7	71.2	
16.02.2023	10:00	0.9	Totally cloudy	1028.1	4.3	85.0	Rz-49E1-300-1:9
	11:00	2.4	Totally cloudy	1027.7	4	79.9	
	12:00	3	Totally cloudy	1027.2	4.7	72.7	
08.03.2023	10:00	1.4	Sunny	996.0	23	85.0	Rz-60E1-1200-1:18,5
	11:00	2.0	Sunny	996.3	22	83.0	
	12:00	2.6	Sunny	997.0	23	82.4	

When recording the thermograms, the emissivity coefficient  $\varepsilon = 0.95$  was assumed due to the material and surface diversity of objects in the turnout area. The basic principle was followed: the assumed (for the factory, default camera settings) high emissivity coefficient "does not distort" the value of the apparent temperature on the surface of the tested object. The measurements were performed in automatic mode, in which the camera automatically selects and adjusts the level and span of the temperature scale (the so-called minimum and maximum temperature scale), and the focus of the digital camera is set automatically along with automatic tuning of the thermal image. During the field tests, the temperature was also recorded using the thermoelectric method. Using, among others, the M-3860M digital multimeter from METEX, temperature measurement, range from  $-40\text{ C}$  to  $+1200\text{ }^\circ\text{C}$ , accuracy  $\pm 3\%$ , raster  $1\text{ }^\circ\text{C}$ . When recording the thermograms, the emissivity coefficient  $\varepsilon = 0.95$  and the distance from the object were taken into account (for the image composition, in the scope of the entire turnout, the distance was 5 m from the end of the turnout spire).

An iron-type colour palette was chosen to visualize the thermograms. The turnout heating was recorded for a period of one hour, starting from the cold state to heated turnout state. In the presented set of thermograms, a correction of the spread and temperature level was made – uniform for the cold and heated state of the turnout. In parallel with the recording of the apparent temperature distribution using a thermal imaging camera, the thermographic method was also used to record the temperature at selected points of the turnout with a recorder using thermoelectric temperature sensors, so-called thermocouples. These measurements are subject to analysis and are not discussed in this publication.

#### 4. Diagnostic tool

In the longer term, it is planned to build a diagnostic tool to assist services dealing with, among other things: maintenance of ETH systems on the basis of thermograms taken at specific locations. The assumptions for the diagnostic tool are outlined below:

- **development of the architecture of a demonstrator** for thermal imaging diagnostics of selected elements of rail transportation infrastructure including ETH
- **development of thermal imaging patterns** for selected elements of rail transportation infrastructure. The patterns will be described by the characteristics of the images, which will be determined based on the created database containing thermograms of objects and devices

- **development of a database architecture** that will be used to collect selected information on turnouts equipped with ETH
- **development of guidelines describing the principles of application of the developed method** of thermal imaging diagnostics of selected elements of the track infrastructure of rail transport
- recommendations on practical aspects of measurements, such as thermal imaging inspection of the object under study, camera settings, image composition and the possibility of using diagnostic tools with which the thermal imaging camera is equipped
- a method of thermal imaging diagnostics of selected elements of rail transportation infrastructure, including, but not limited to:
  - analytical reports that take into account the current state of rail transportation infrastructure equipment from an operational aspect related to thermal processes
  - report on the assessment of energy efficiency and the impact of these systems on the so-called carbon footprint
  - evaluation report on the ergonomics of the demonstrator's HMIs
  - experimental research database
  - database for managing operational processes.

The method is to combine the functionality of a stationary station with control, inspection and visual inspection during track inspection, including electrical turnout heating devices. The authors of the proposed method assume that the user should be aware of the basics of thermal imaging in the field of thermogram registration. During the inspection, a trained employee of the infrastructure manager will record a thermogram with a camera with defined minimum hardware requirements, including a defined image composition. This is the subject of current research carried out as part of the research project. The goal is to automate the operation of turnout electric heating devices, their diagnostics and an objective assessment of the operation of these devices, supported by the user with computer tools. The thermogram will be analyzed and interpreted using computer-aided tools. On this basis, an opinion (diagnosis) will be issued based on the adopted criteria.

#### 5. Conclusion

The thermal imaging tests presented in the article, performed on various types of turnouts most typically used on the PKP PLK S.A. network with built-in ETH devices, show that thermal imaging can be an important element in maintenance and diagnostics. The

creation of a simple diagnostic tool to evaluate and interpret the obtained thermogram can enable maintenance services to make the right operational decisions. The procedure itself, the place where the measurements are taken, the camera settings as well as the evaluation tool should not be complicated, facilitating the user's quick diagnostic action. Ultimately, the tool can also be used for more complex activities like analysis, analytical reports taking into account the current state of rail transport infrastructure equipment in the operational aspect related to thermal processes. The performed thermal imaging measurements, in conjunction with the applied modern ETH control systems, can provide a valuable basis for optimization of energy consumption as well as further development of technological solutions in this area.

The thermal imaging camera will be used in the qualitative assessment of the effect of the electric turnout heating system. The obtained measurement results are intended to indicate areas in the vicinity of the heater-rail system in which factors that may influence the incorrect operation of the turnout, such as snow or icing of structural elements enabling the

change of the turnout position, are effectively eliminated. As a result of the research and thermal visual inspection of the turnouts, areas were noticed and the range of heat distribution and energy radiated in the heater-rail system to the surroundings were defined. In many areas, the authors believe that this coverage is too extensive. Such intensive heating of certain areas of the turnout is not required and justified. This causes excessive electricity consumption. This observation is a reason to optimally manage and control the turnout heating process, and thus actively reduce energy consumption.

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#### Nomenclature

ETH Electric Turnout Heating System  
BRIK Badania i Rozwój w Infrastrukturze Kolejowej  
(Research and Development in Railway  
Infrastructure)

Rz Rozjazd zwyczajny (Standard railway turnout)

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