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Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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PASSIVE AND ACTIVE INFRARED THERMOGRAPHY SURVEY IN THE RAILWAY TRANSPORT FIELD

Anna Stoynova, Nencho Nenov, Borislav Bonev
Technical University of Sofia, Bulgaria

Abstract

Structural degradation of many components of a railway system leads to many rail failures on rail networks. Therefore, there is an obvious need to use more innovative approaches by applying efficient remote survey technologies, data analysis and fast decision making. Thermography is an advanced NDT technique based on the detection of infrared radiation. This thermal technique for test and diagnostic, provides a fast, 2D and real-time inspection as well as a non-destructive testing. Unlike the passive thermography, the active thermography is a technique requiring external thermal excitation of the tested object. The two modes of thermography are based on infrared waves generated from the surface of the specimen captured by thermal imager. Effective approaches by using thermography technology for successfully studying of hidden defects in materials as well as in electrical and mechanical units of railway systems is developed. The main features of passive and different actives modes of the infrared thermography technique, important for application in railway transport field are discussed in the paper. The requirements of thermography survey of railway transport, including on components of the rolling stock and the infrastructure, the safety of railway systems and transport as well as the preventive maintenance are analysed. Experimental results from infrared monitoring of some electrical and mechanical units of railway systems are presented. Thermal imaging and innovative thermal data analysis of problem areas in catenaries connection, hidden crack detection in rail and some components of the rolling stock are shown and discussed.

Keywords: railway, infrared thermography, failure inspection, remote condition monitoring, innovative data analysis

1 Introduction

An effective solving the tasks for diagnostics of electrical equipment, mechanical parts, materials and structures of the rail transport, modern diagnostic methods and technical means for control is required. A large number of inspection tasks in rail transport can be carried out by infrared thermography. Infrared Thermography (IRT) belongs to the methods of thermal non-destructive control. They are based on the analysis of temperature fields using thermograms, obtained from portable thermal imagers [1-3]. An expert decision is needed about object status. IRT survey of an object allows with minimum financial losses and short time to verify the reliability, to detect defects, to reduce maintenance losses. The infrared camera, generally is a noncontact high-sensitivity thermometer with low accuracy (associated with a relatively high error of ± 2% ÷ ± 1%), which fast measures the object's thermal (infrared) radiation. However, the sensitivity of the method is more important than the accuracy of temperature measurement for the thermal detection of defects in materials and constructions, since hidden defects are detected by thermal anomalies. In thermal diagnostics of electrical

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and mechanical equipment in rail transport, where the thresholds are used as norms, there is no point in ensuring an error below 1 ÷ 3 °C [4].
Thermographic diagnostics is increasingly needed as a means for controlling and diagnosing various components (electrical, mechanical, materials and constructions) in the various subsystems of the railway system: Rolling Stock Subsystem, Energy subsystem, Infrastructure subsystem. Usually up to 80% of the various defects in electrical equipment and up to 30% in the machines can be detected and diagnosed by a thermographic method. In this sense, infrared thermography survey can successfully supplement other non-destructive control methods and early diagnostic.
At present, during the thermographic study, the main tasks are to identify the areas of local overheating caused by potential defects, and when discovered, the task is assumed to be completed. This limits the scope of the thermographic survey and does not allow the full use of infrared technology. The conversion of the thermographic test into a mature tool for technical diagnostics can be achieved by using new mathematical methods and computer technologies to process test results.
The task of predicting the equipment work based on a thermographic survey is practically not yet fully resolved. This state is related to the imperfect system of thermographic monitoring, in which the thermographic survey is carried out without accumulation and analysis of data, no algorithms and techniques for collecting and statistical processing of the results from thermography survey, no efficient diagnostic models allowing prediction of the complex equipment behaviour.
In the work, the potential and peculiarities of full and effective use of thermographic techniques in rail transport are analysed. Experimental results from the performed thermographic survey on different rail transport objects are presented. An innovative technology for thermographic monitoring in order to improve the quality and reliability of thermal studies focused on the field of rail transport is proposed.

2 Basic procedures of the infrared thermography in railway

Applications in railway transport find the both approaches for thermographic control: passive and active.
The passive approach is conducted without the use of additional (external) sources of temperature influence on the subject. For the diagnosis of the electrical equipment of rolling stock (locomotives and wagons), electrical power substations equipment, electrical installations of traction substations and the contact network (power transformers, switchgear, measuring transformers, valves, surge suppressors, capacitors, etc.), safety installations in the stations (switches, relays, etc.) the passive approach is used because a sufficient thermal field arises when the mentioned objects operate.
The active approach is based on the thermal impact deliberately applied to the object and a subsequent analysis of the object's structure variation due to the heating (or cooling) induced. This approach is used for objects that are not subjected to heat load. Therefore, the object is subjected to energy excitation to induct temperature variation. Optical, convective, ultrasound, electromagnetic, electrical and mechanical stimulation can be used to excite a dynamic thermal process in the controlled object. The effectiveness of detecting available hidden defects is associated with providing the necessary energy and time, as well as the application of special processing of the sequences of thermograms.
The most commonly used active thermography approaches are: modulated (lock-in), pulse and pulse phase thermography [5].

3 Active infrared thermography application

3.1 Cracks detection on railway tracks

The rail derailments frequently can be caused by broken rail. Implementing integrated thermography survey of material degradation and cracks can successfully support characterising the structural integrity and safety of railway infrastructure. The task of crack detection and evaluation as shown in recent research can be successfully resolved by active thermography [6]. It is known that cracks can occur in rails such as: rail gauge corner cracking, shelling, transverse rail defects and squats. Over the last five years, a series of research have been carried out to improve the detection of cracks of different orientation (e.g. inductive excitation) [7-9]. Promising results have been received for detection of natural and artificial cracks. For example, in [8] is reported that the dimensions of detected cracks start from 80 μm crack depth for a slanted crack with a length of a few millimeters.
Rail squats are cracks growing below the surface of the head of a rail due to surface depressing. In [10] is researched the presence and location of rail squats. It is reported that rail squats with diameter more than 8 mm and depth ranging 0.5 ÷ 6 mm are characterised by LT.

3.2 Cracks detection on railway axles and wheels

Studies of fatigue cracks across the axles have been carried out due to electrical arcing, corrosion and stress corrosion cracking [11]. It is shown that active thermography offers opportunities for regular crack observations. This may give useful information to update the design of axes. It is reported that a wayside continuous monitoring system prototype for inspection of hotspots on wheel rim and axle bearing box is developed [12].
Recently, investigations have been carried out to assess the effect of corrosion upon fatigue properties of railway axles. The corrosion and crack propagation relationship, particularly at the crack initiation stage are studied by active thermography [13-16]. Corrosion fatigue racks from 0.7 ÷ 4 mm deep and 20 mm long are detected. It was observed that the crack growth occurred in specific stages that could be identified and related to the sample lifetime.

3.3 Other application in railway transport

Active thermography is also applied for survey of various concrete and composite railroad bridge and railroad structural components. A study is focuses mainly on thermography for detecting debonds in timber railroad bridges wrapped with GFRP composites [17, 18]. Also application of IRT technique for debond detection in composite railroad ties is presented.

4 Passive infrared thermography application

Most of unplanned repairs of locomotives (over 50 %) are carried out due to electrical equipment failures. Statistics show that 12-13 % of the total number of failures of diesel locomotives are due to failures in the thermal equipment. The infrared thermography is increasingly used In order to obtain minimal losses in servicing the locomotives, [19-21].
IRT can be applied to maintenance, repair and diagnostics of electrical equipment and mechanical equipment of electric and diesel locomotives, as well as for energy audits of buildings and facilities that are part of locomotive depots for the detection of thermal leakages from the cabs of locomotive drivers, wagons, etc.
Results from thermography non-destructive survey are presented [22, 23]. Diagnostic has been performed to detect nonvisible voids of a railroad tunnel in operation (a box type tunnel excavated by cut and cover method) [22]. The influence of the depth and thermal measurements include the surface temperature of the sound and defected concrete parts and the

tunnel air temperatures. In such a study, both passive and active thermography may be used [23]. The influence of the depth and orientation angle of the void with respect to the concrete surface has been investigated in [23]. In the damaged concrete void depths between 19 cm and 30 cm are detected. Checking the water ingress through walls and drainage problems in tunnel systems can also be surveyed by thermography methods.
By passive thermography may detect, people walking in tunnels, trespassers, stopped cars on tracks, people falling from platforms on tracks etc.
In research [24] the contact pantograph – catenary quality is studied with infrared techniques. It is argues that the thermographic images are more informative than standard camera images. In the case of traction power systems, thermography can be applied throughout the distribution and consumption cycle: from traction substations to electrical equipment of rolling stock. Thermography transformation into a mature method of technical diagnosis can only be done when developing mathematical methods and computer technologies to process research results [25].
The power supply system in the catenary, transformer boxes and traction substations in railway systems can also precise monitored for the goals of maintenance by IRT [26]. By infrared camera can survey many elements of traction substations (transformers, fuses, circuit breakers, distribution lines, connectors, reflow lines and other equipment) and on this way avoiding damage for excessive temperature [27]. Using infrared camera can help in finding troubles of the connector, casing, and three-phase unbalance and other risks.

5 Experimental results

Experimental research has been carried out on various railway transport-related objects. A modular thermographic system has been used, including: infrared camera FLIR ThermaCam SC640, equipped with different type lenses (25°, 45°, 7° and close up 50 μm); IRX-box USB-interface electronics between camera, software and excitation sources; software – ResearchIR, MatLab, Flotherm, Ansys, ThermoVision SDK, LabView and self-developed software; different kinds of excitation sources. Thermographic measurements were performed the both in laboratory and outdoors. This is related to the implementation of additional procedures to compensate of external influences, which is not commented in the present paper, as well as the algorithms for specific processing, mathematical models and analyses in the specific situations [28].
The thermogram on Fig. 1 shows a potential failure in the electrical equipment of a locomotive due to a loose ground connection. On Fig. 2 the temperature profile of bearing area (marked on the shown thermogram in Fig. 3) is presented. On Fig. 3 a thermogram of locomotive bearing at train speed 10 km/h is given.

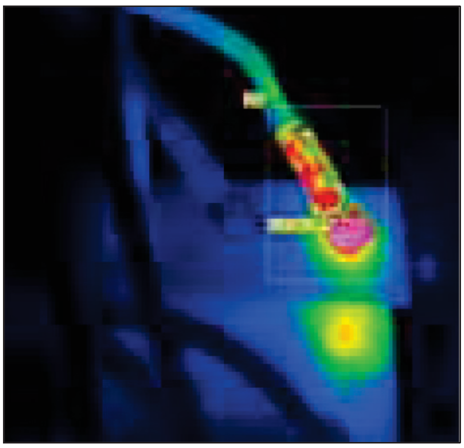

Figure 1 Thermogram of weakened bolting for connection to ground

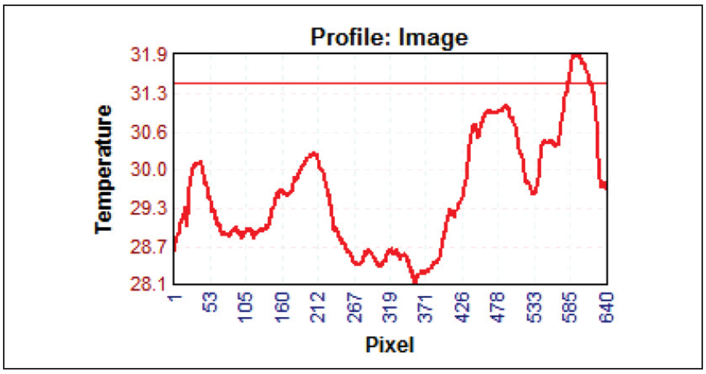

Figure 2 Temperature profile for the bearing – marked area on Fig. 3

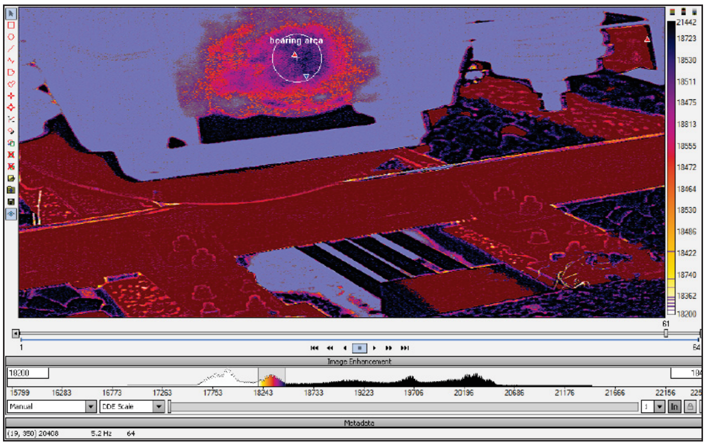

Figure 3 Thermogram of one bearing for locomotive captured at 10 km/h

The both sides of the locomotive must be monitored to capture all the bearings. An additional thermography camera is required when an adaptation could not found. When we use only one infrared camera we should positioning the camera at 45° angle to the rail tracks. A thermography system can be built for continuous monitoring of hot spots on axle bearing boxes as well on wheel rims of the locomotives and wagons.

IRT study of wear of contacts during long commutation of electro-mechanical relays used for signalling and switching systems of railway automation is conducted [29]. On Fig. 4 two thermograms are shown for open contact (a) and for closed contact (b). The temperature on the contact area is an important factor for their commutation quality and long life. Induction thermography corrosion studies have been performed. The results can be used to characterize bolts and other metal parts used in railway tracks. On Fig. 5 is shown thermograms of samples with artificial defects of corrosion in two different materials and corrosion levels.

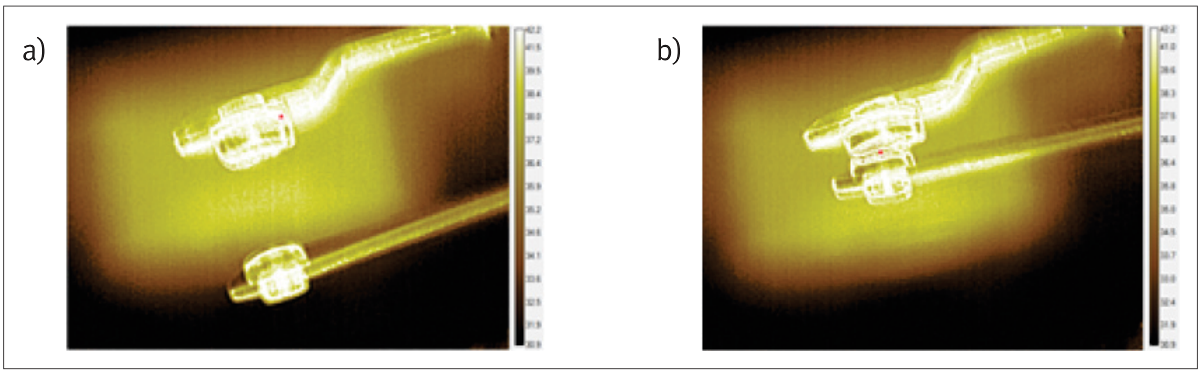

Figure 4 Thermograms of contact areas for relays used in railway automation: a) open contact, b) closed contact)

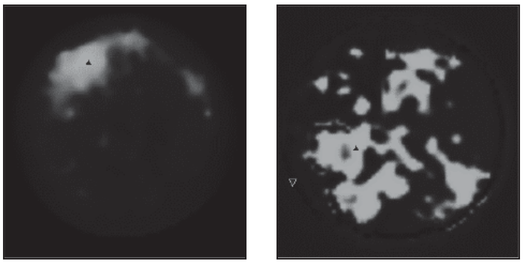

Figure 5 Thermograms of samples with different corrosion level (corroded areas are light)

A thermographic examination of the electric point machine used in the railway infrastructure was carried out. When performing periodic diagnostics, loose mechanical connections are detected. On Fig. 6 is shown two working states of the study of such machine in real working conditions.
A thermographic preventive diagnosis is conducted to detect loose bolts along the railway track. On Fig. 7 is shown thermogram of such case, marked with red. The blue marked area points to checking for presence of a crack. The black-marked area is a case of a tightened bolt.

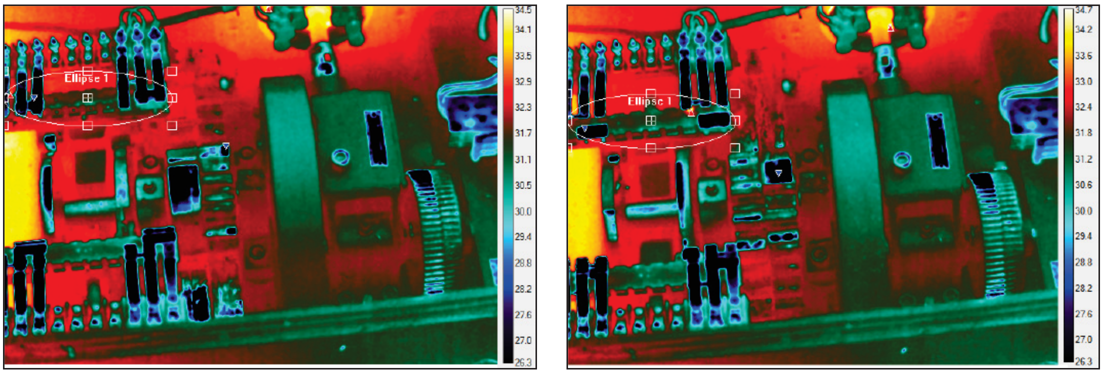

Figure 6 Thermographic study of the switching of electric point machine in real working conditions

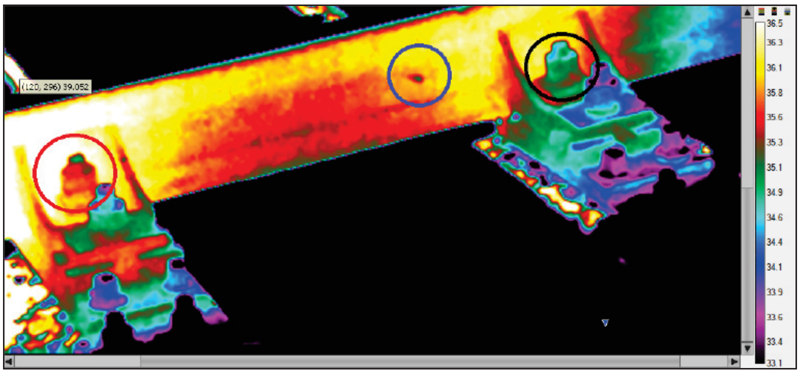

Figure 7 Thermogram from preventive diagnosis of loose bolts along the railway track

6 System approach to the management of thermographic monitoring in railway transport

A thermographic monitoring system used in railway transport must meet the following requirements and capabilities:
- data storing and analysing;
- creating algorithms and technology for collecting and statistically processing the results of thermographic surveys;
- creating diagnostic models to predict the behaviour of sophisticated equipment.

Fig. 8 shows a schematic block diagram of a thermographic monitoring management system. The proposed system consists of four main blocks: preliminary preparation, working preparation, thermography monitoring, and mathematical processing. The results from mathematical processing of previous surveys during the preliminary preparation phase are analysed and the predictions for the level of defectiveness is estimated. Effective solving of the task of thermographic survey managing at this stage requires the use of modern mathematical methods and computer technologies. A coefficient of defectiveness K_d can be introduced as a measure for evaluation of the defectiveness:

$$K_d = \Delta T_{increased} / \Delta T_{normal} \tag{1}$$

where $\Delta T_{increased}$ is the measured increased object temperature, and ΔT_{normal} is the measured (or mathematically simulated) normal object temperature.

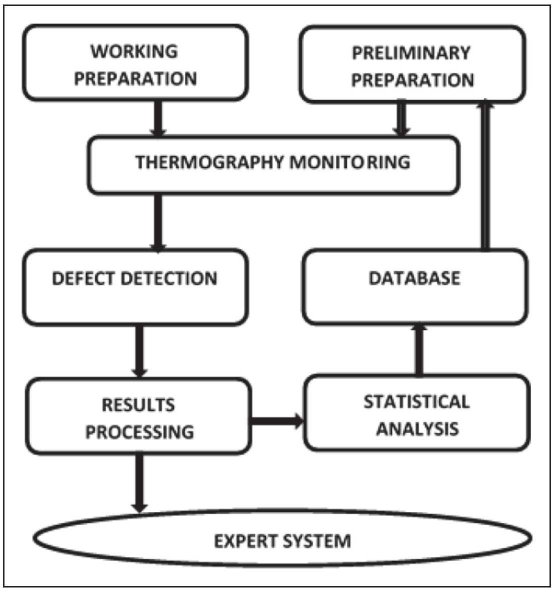

Figure 8 Block diagram of a thermographic monitoring management system

The cluster analysis procedures are very appropriate for this stage. For example, data classification with k-means clustering algorithm or fuzzy classification procedures may be used. The second tool is more effective in finding unambiguous clustering of problem areas in solving poorly structured tasks as they are the typical cases for railway transport objects. Multiple regression analysis can be used to determine the factors on which the number of defects depends. Possible influence factors can be selected: mean residual life, the number of registered defects in the past, etc. depending on the specifics of the surveyed objects. The working preparation stage takes place directly on the object under investigation. A status or working mode characterization is performed here, and imitative modelling can be applied to data from relevant information systems. During the third stage, a direct thermographic survey using the results from the previous two stages and special recommendations depending on the specifics of the objects is carried out. In the final stage, the treatment, visualization and storage of the thermograms from the survey are carried out. Here, tables to distribute defects, graphs, and histograms as a result of mathematical processing can be used.

7 Conclusions

At present, the thermographic approach for research and diagnostics is a high-tech field of applied research that combines the theories of heat transfer, infrared technology and computer processing of experimental data. The interest and intensive research in the thermographic methods application in for railway transport is due to the universal character, high productivity, safety of the usage of the infrared equipment and the illustrating results. The conducted experiments and the obtained results show that in the case of monitoring's systemic management, infrared thermography can effectively complement other non-destructive testing and diagnostic methods used in rail transport.

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