Use of Infrared Thermography under Laboratory Conditions

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Abstract: The article deals with the use of thermography for the detection of the course of temperature fields during braking. Substantially higher demands on the reliability and safety of individual parts of the braking system are required with the increasing speed of rail vehicles. The noise parameter is also important in addition to the safety itself. Noise arises due to braking by brake with cast iron blocks. One of the possibilities of reducing noise is the use of composite materials for the production of brake blocks. A higher friction coefficient is a disadvantage of the use of brake blocks made of composite materials. These are much worse heat conductors than cast iron blocks. This causes damage to the tread of the railway wheel. The use of infrared thermography is one way of detecting thermal fields. It is a method that allows a non-contacting way to display, measure and analyze a temperature field on the surface body.

Keywords: Thermography, Thermogram, Thermal Camera, Braking, Brake block, Emissivity

1 Introduction

With the increasing speed of rail vehicles, increasing demands on reliability and especially on the safety of individual parts of the braking system. [1, 2, 3, 4] Braking with used cast iron brakes creates excessive noise. One of the measures is the use of composite materials for the production of brake blocks. The main disadvantage of this solution is that composite brake blocks have a higher friction coefficient and are much worse heat conductors than cast iron brake blocks. This causes damage to the running surface of the wheel. [8, 9, 11, 13] Therefore, the properties of such blocks made of composite materials must be tested and their operation be verified by tests according to standards and regulations. [5, 6, 7, 10, 12, 14, 22] One of the possibilities of testing is to perform tests on brake conditions in laboratories. [15,16,20] The infrared thermography may be used to detect the layout patterns of temperature field. It is a method that allows the contact surface to display, measure and analyze the temperature field on the surface of the body.

2 Infrared termography

Infrared radiation is part of the spectrum of electromagnetic radiation. It has the nature of visible radiation. It is formed by transverse electromagnetic waves which propagate in a homogeneous environment, in vacuum, in gases, in liquids and in solids, in a straight line. Infrared radiation is the invisible part of the electromagnetic spectrum exhibiting thermal effects (Fig. 1). The radiation has a wavelength in the range of about 0.75 μm to 1 mm - the area above the visible portion. Visible radiation corresponding to the spectral sensitivity of the human eye lies within the wavelength range of about 0.38 μm to 0.78 μm.

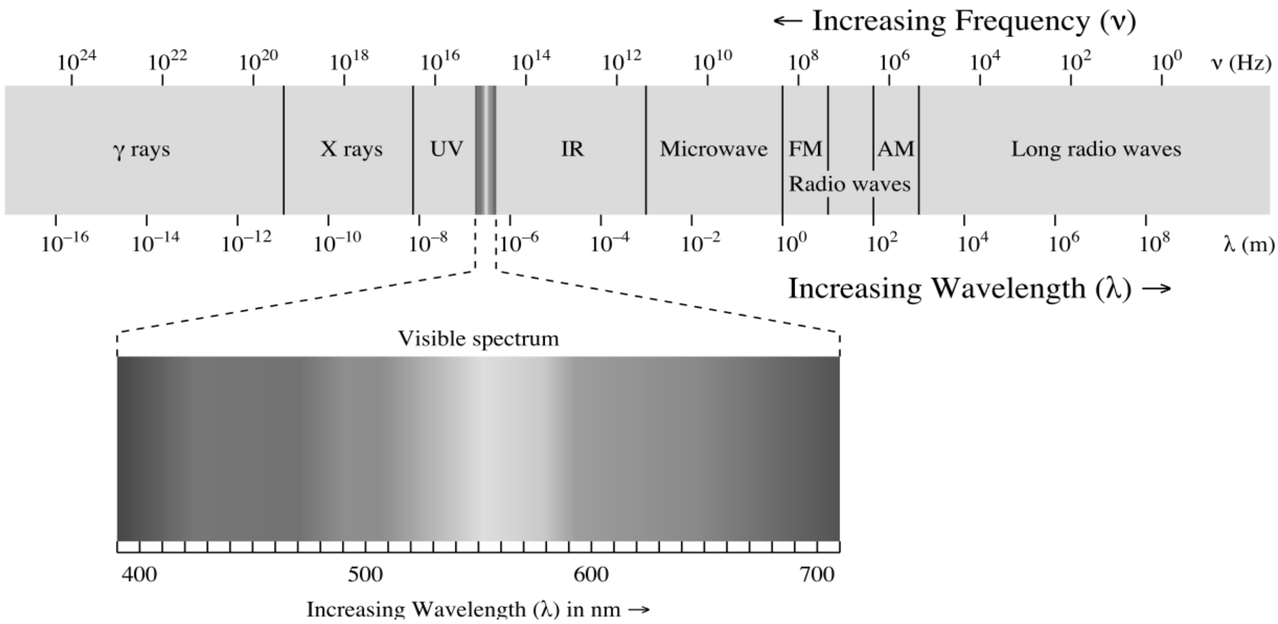


Fig. 1 *Electromagnetic spectrum*

Heat radiation is the radiation that transmits heat energy. Heat radiation is emitted by the surface of all bodies whose temperature is higher than 0 K (-273.5 ° C). The radiated spectrum is continuous.

The term thermography means a method for displaying temperature fields on the surface of the sensed bodies. The surface temperature distribution is represented by the energy and density of the photons emitted from the surface of the sensed body and its evaluation by quantification. Infrared thermography is also a name for a technique that is generally a certain transformation system by which invisible infrared radiation from an object can be displayed to the human eye, depending on its thermal state. In our terms is thermodynamics (thermography) generally referred to as non-contact thermography, respectively, its use infrared imaging systems (also called infra-cameras, thermocouples, thermographic systems, infrared thermographic systems / cameras). [21]

3 The basic principle of thermography

The basic principle of thermography is to detect the energy of radiation emitted from the measured body. This energy represents the temperatures (temperature field) mostly on the surface of the measured body and further the display and quantification (evaluation) of the temperature fields.

Fig. 2 shows a measurement string consisting of the following elements:

1. background, surroundings of the measured body (object),
2. own measured body (object),
3. the atmosphere between the measured body and the measuring system,
4. measuring system.

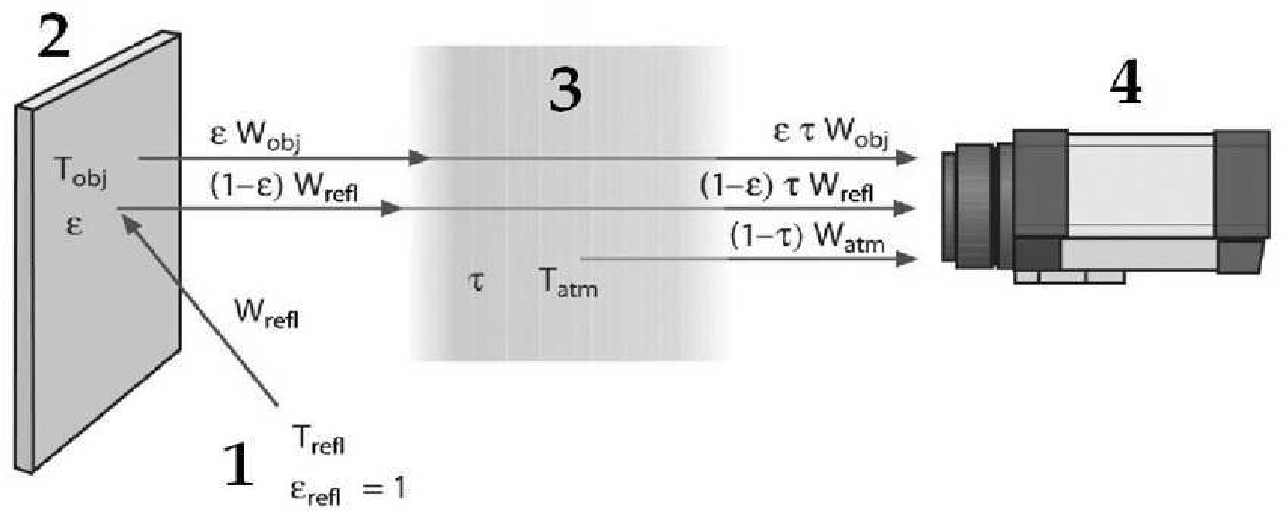
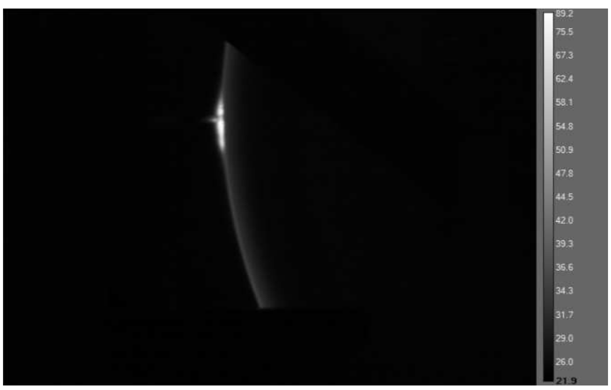


Fig. 2 *Overview of individual flows incident on the detector*

Into the measuring (thermographic) system three radiation flows enter according to the picture:

- the radiation from the measured object, the intensity of which is proportional to the emissivity ε, passes through the atmosphere with the coefficient of throughput τ,
- radiation, resp. Reflecting radiation from the surface of a measured object is called the apparent temperature,
- radiation of the atmosphere. [21]

4 Systems and sensors



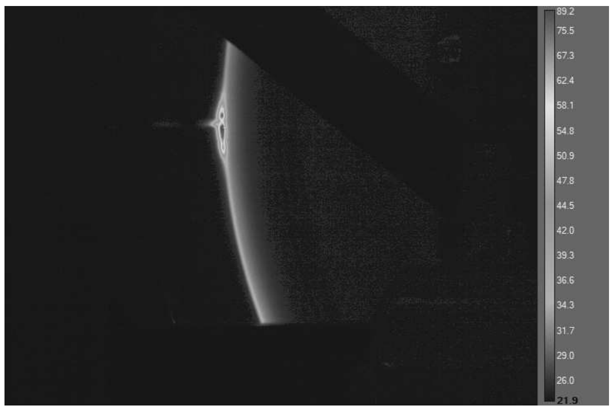


Fig. 3 *Black and white and color termogram*

A typical thermographic system is similar to a camcorder that, unlike a camcorder, displays the thermal radiation of an object (objects) mostly at a standard television picture frequency.

More sophisticated infrared cameras can not only display the temperature field of the object (mostly their surface), but also allow these fields to quantify - to evaluate the temperatures of these fields, for now commonly available systems in the temperature range from - 40 °C to

+ 2000 °C with an image frequency of up to 50 Hz. The actual display of the thermal (temperature) field - the thermogram, can be either black and white or (pseudo) color (Fig. 3).

The basic element of the system is the radiation detector that converts the incident radiation flux into an electrical signal. Infrared radiation detectors used in thermography can be divided into two basic groups:

- Quantum detectors - radiation are converted directly to an electrical signal,
- Heat detectors - radiation detectors heats each detector and evaluates the temperature change.

Photonic detectors have a high sensitivity, they are very stable, they are used for shortwave and longwave zone that interest us in measuring the temperature most, but at the cost of having detectors cool. This can be energy and time consuming. The detector is cooled using liquid nitrogen, or in modern cooled detectors is used the Stirling engine.

Thermal detectors or micro-bolometer detectors are made on a totally different basis and do not need to be cooled. This, however, was a major problem in the past, as the uncooled detectors had a lower sensitivity. Today's micro-bolometers are very close to their sensitivity to cold detectors, but they still have their limits, for example, in speed and the need to check whether all individual pixels measure the same, with the same offset or sensitivity. For this reason, for cold detectors, a "shutter" function is introduced which allows the detector to periodically check the above values.

Today's micro-bolometric fields are usually made on monolithic silicon substrates as common integrated circuits. These miniature bolometers are arranged in the Focal plane array (FPA). Apart from the sensor itself, the chips also contain reader electronics and other auxiliary circuits. The whole chip is located in the evacuated case. The bridge structure provides good thermal insulation between the micro-bolometer and the silicon substrate. The pixel density of micro-bolometers varies from 4 x 4 to 640 x 480 pixels. [21]

5 Detection of temperature during braking with cast iron brake block on the test condition of the braking components RAILBCOT

The measurement was performed during the braking forces setting in the braking unit on the test condition of the RAILBCOT braking components as can be seen in Fig. 4. The FLUKE Ti 400 Thermal Camera (Fig. 5) with bolometer (thermal) detector was used to measure the temperature. [17, 18, 19]

Technical parameters:

- Temperature range (not calibrated below -10 °C) -20 °C to + 1200 °C,
- Accuracy of temperature measurement ± 2 °C or 2% (at 25 °C nominal, whichever is greater)
- on-screen emissivity correction (by number and table),
- on-screen reflection background temperature compensation,
- on - screen transmission correction.

Image performance:

- 9 Hz scanning frequency,
- detector type focal plane beam, uncooled microbolometer, 320 x 240 pixels,
- temperature sensitivity (NETD) - 0.05 °C at 30 °C,
- total pixels 76,800,
- an infrared spectral band of 7.5 to 14 um,
- visual (visible light), industrial camera 5.0 MPx,
- standard infrared lens type,
- field of view 24° x 17°,
- spatial resolution (IFOV) of 1.31 mrad,
- minimum focal length of 15 cm.

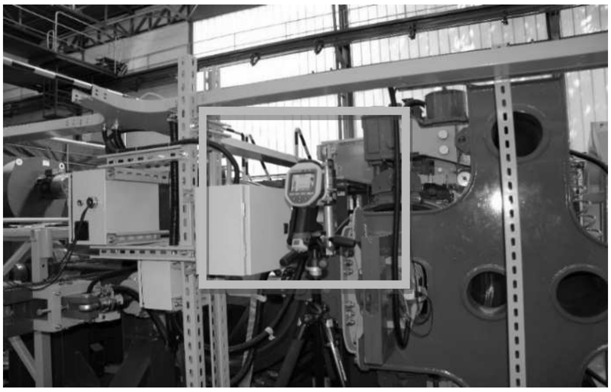


Fig. 4 *Measuring point of Fluke Ti 400*

Fig. 5 *Thermal camera FLUKE Ti 400*

The course of normal force (Fig. 6) in the brake unit that was act to the cast iron brake block is shown in Tab. 1. The ambient temperature was 18 °C. The emissivity value was set to 0.60.

Tab. 1 *Effect of normal force on the brake block*

Effect of normal force on the brake block	
Interval of acting force (s)	**Size of normal force**
0	0
10-20	500
20-30	1000
30-40	1500

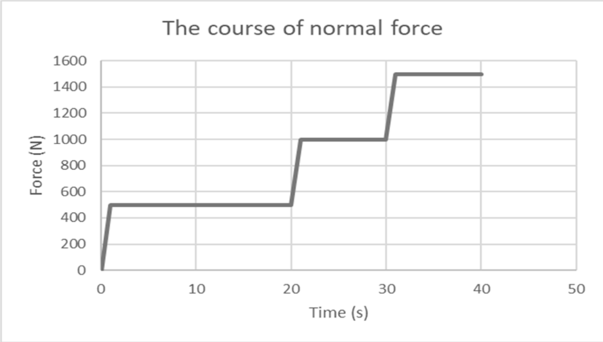


Fig. 6 *Course of normal force*

At the beginning of the braking (Fig. 7), the wheel and the brake block came into contact at the edges of the brake block where two areas were created in which the temperature increased.

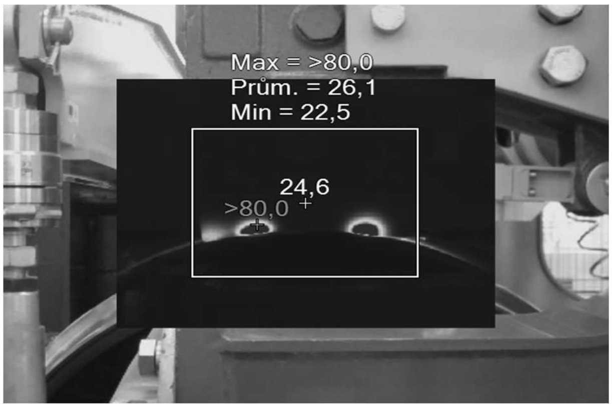


Fig. 7 *Temperatures detected by thermal camera FLUKE at the beginning of braking*

Fig. 8 *Maximum values detected by thermal camera FLUKE*

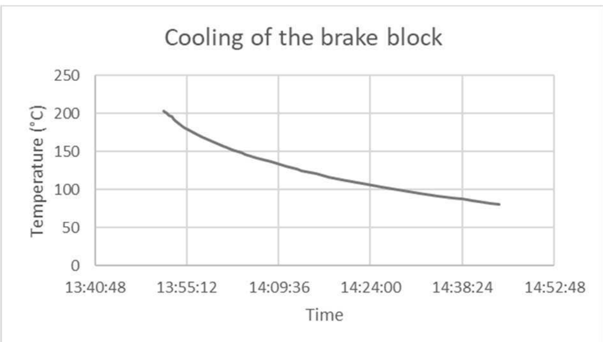


Fig. 9 *Cooling curve*

After a few seconds of braking, the temperature in the brake block has risen above 250°C (Fig. 8).

After the braking, the cooling of the brake block was determined the course. In Fig. 9 it is possible to see the course of cooling which has a decreasing tendency.

After several braking cycle repetitions, it is possible to observe brake block wear (Fig. 10).

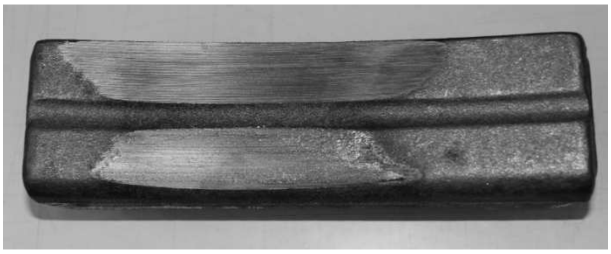


Fig. 10 *Wear on cast iron brake block*

6 Conclusion

The subject of the article is a description of the survey of the temperature fields through the use of infrared thermography. It is a method that uses the non-contact principle of measurement, respectively to find out temperature field course. The advantage is that it is a contactless and relatively fast method. The disadvantages certainly include that the size of the detected signal from all signal sources is influenced by the environment in which the infrared radiation spreads. This means that for the correct measurement we have to ensure optimal conditions. We also need to know, if possible, the correct values of emissivity, the reflected apparent temperature, the distance and the relative humidity of the atmosphere and the temperature of the atmosphere.

The values of the temperature fields for braking by cast iron brake blocks are relative, due to the absence of optimal conditions, but sufficient to detect the heat dissipation in the brake block during braking and its subsequent cooling.

Acknowledgement

The work was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in project No. KEGA 077ŽU-4/2017: Modernization of the Vehicles and engines study program. The work was also supported by the project No. APVV-0842-11: Equivalent railway operation load simulator on the roller rig and VEGA Nr. 1/0927/15: Research of the use of alternative fuels and hybrid drives on traction vehicles with aim to reduce fuel consumption and air pollutants production.

Research-Educational Center of Rail Vehicles (VVCKV)

References

[1] DIŽO, J. (2015). Analysis of a goods wagon running on a railway test track. In: *Manufacturing technology: journal for science, research and production*. ISSN 1213-2489. Vol. 16, no. 4 2016, pp. 667-672.

[2] DIŽO, J., BLATNICKÝ, M. (2016). Computer analysis of the carriage running influence with

wheel-flat on a track. In: *Železničná doprava a logistika*. ISSN 1336-7943. Vol. 12, no. 2 (2016), pp. 15-19.

[3] DIŽO, J., BLATNICKÝ, M., SKOČILASOVÁ, B. (2015). Computational modelling of the rail vehicle multibody system including flexible bodies. In: *Communications: scientific letters of the University of Žilina*. ISSN 1335-4205. Vol. 17, no. 3 2015, pp. 31-36.

[4] GALLIKOVÁ, J., POPROCKÝ, R., (2015). Risks assessment in rail vehicles. In: *PRORAIL 2015 Current problems in rail vehicles*. Žilina, 2015. ISBN 978-80-89276-48-6. pp. 151-158.

[5] GERLICI, J., GORBUNOV, M., KRAVCHENKO, K., KOSTYUCHEVICH, A., NOZHENKO, O., LACK, T., (2008). Experimental rigs for wheel / rail contact research. In: *Manufacturing technology: journal for science, research and production*. ISSN 1213-2489. Vol. 16, no. 5 2016, pp. 909-916.

[6] GERLICI, J., GORBUNOV, M., KRAVCHENKO, K., DOMIN, R., KOVTANETS, M., LACK, T., (2017). Slipping and skidding occurrence probability decreasing by means of the friction controlling in the wheel-braking pad and wheel-rail contacts. In. *Manufacturing technology: journal for science, research and production*. ISSN 1213-2489. Vol. 17, no. 2 2017, pp. 179-186.

[7] GERLICI, J., HLAVŇA, V., ŘEZNÍČEK R. (1994). Simulation of downhill braking with a shoe brake. In: *4.th mini conference on vehicle system dynamic, identification and anomalies*. Technical university of Budapest, 1994.

[8] GERLICI, J., LACK, T., (2009). Railway wheel profile development based on the geometric characteristics shapes. In: *Contact mechanics and wear of rail/wheel systems* = CM2009: 8th international conference: 15th-18th September 2009, Firenze, Italy. 2009. ISBN 978-88-904370-0-7, pp. 961-967.

[9] GERLICI, J., LACK, T., (2003). Rail geometry analysis (from the point of view of wearing in the operation). In: *Communications - scientific letters of the University of Žilina*. ISSN 1335-4205. Vol. 5, No. 1 (2003), (pp. 43-51)

[10] GERLICI, J., LACK, T., (2004). *Contact railway wheelset and track.* University of Žilina. ISBN 80-8070-317-5. (In Slovak)

[11] GERLICI, J., LACK, T., (2011). Railway wheel and rail head profiles development based on the geometric characteristics shapes. In: *Wear*: An international journal on the science and technology of friction, lubrication and wear. ISSN 0043-1648. Vol. 271, No. 1-2 Sp. iss. 2011, pp. 246-258.

[12] GERLICI, J., LACK, T., (2010). Contact geometry influence on the rail / wheel surface stress distribution. In: *Procedia Engineering*. ISSN 1877-7058. Iss. 1 2010, pp. 2249-2257.

[13] GERLICI, J., LACK, T., LACKOVÁ, M., (2004). Calculation of the equivalent conicity function of the railway wheelset tread profile at the Delta R function with a negative slope. In: *Communications - scientific letters of the University of Žilina*. ISSN 1335-4205. Vol. 6, Nr. 2 2004, pp. 49-56

[14] GERLICI, J., ŘEZNÍČEK, R., (1994). Temperature fields in the brake blocks when braking on an incline. In: *XI. International conference "Current problems in rail vehicles"*. (In Slovak), pp. 233-244, Česká Třebová, 13 14. 9. 1994.

[15] HAUSER, V., (2015). Rail-wheel contact of tramways vehicles in arc track. In: *TRANSCOM 2015*: 11-th European conference of young researchers and scientists: Žilina, 2015. ISBN 978-80-554-1048-7. pp. 64-69.

[16] LACK, T., GERLICI, J., (2009). Railway wheel and rail roughness analysis. In: *Communications: Scientific Letters of the University of Žilina*. ISSN 1335-4205. Vol. 11, No. 2 2009, pp. 41-48.

[17] LACK, T., GERLICI, J., (2014). Wheel/rail tangential contact stress evaluation by means of the modified strip method. In: *Communications: scientific letters of the University of Žilina*. ISSN 1335-4205. Vol. 16, no. 3A 2014, pp. 33-39.

[18] LACK, T., GERLICI, J., (2013). Tangential stresses for non-elliptical contact patch computation by means of modified FASTIM method. In: *IAVSD 2013*: 23rd international symposium on dynamics of vehicles on roads and tracks: 19.-23. August 2013, Qingdao, China: proceedings. Chengdu: Southwest Jiaotong University, (p.6).

[19] LACK, T., GERLICI, J., (2013). The FASTSIM method modification in speed up the calculation of tangential contact stresses between wheel and rail. In: *Manufacturing technology: journal for science, research and production*. ISSN 1213-2489. Vol. 13, no. 4 2013, pp. 486-492.

[20] LACK, T., GERLICI, J., (2008). Interational method for railway wheel tread profile design. In: *XVIII konferencja naukova - pojazdy szynowe*: Katowice-Ustroń, 17-19 września 2008: Materialy konferencyjne, pp. 137-149.

[21] PEŤKOVÁ, V., SVOBODA, J., (2016). *The Thermodiagnostics* (In Slovak). Vydavateľstvo Vienala s. r. o., Str. 310. ISBN 978-80-8126-132-9

[22] ŘEZNÍČEK R., GERLICI J., LACK, T., (1993). Stress analysis monoblock wheels braked by FEM (In Slovak). In: *proceedings: ŽELSEM '93, Savings in railway"*, University of Zilina 1993, pp. 155-161, Loučeň, 1993.

10.21062/ujep/131.2018/a/1213-2489/MT/18/3/518