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THE USE OF THERMAL VISION IN TESTING THE TENSION OF STEEL ROPES

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Abstract:
The article presents the results of experimental thermal imaging measurements of steel ropes as a basic structural element of handling and transport equipment. Based on the measurements, we can conclude that at an average value of the load of the tested ropes of 49.5%, the temperature in the critical point begins to rise significantly due to plastic deformation. When the set limit is exceeded in terms of Hooke's law, which expresses the relationship between the deformation of a solid body caused by the action of stress and the magnitude of this stress, plastic deformation (non-linear increase) occurs. Up to these values, the increase is linear and the deformation is directly proportional to the stress of the material. It is assumed that if the rope were damaged, the temperature could rise more sharply even with a smaller load on the rope. The presented results of the laboratory experiments and the course of the experiments themselves revealed the necessity of very accurate temperature targeting.

Key words:
Infrared thermography, tests, defectoscopy, steel rope

1 INTRODUCTION

Infrared thermography (IRT) is a reliable, fast, cost-effective and non-destructive testing (NDT) measurement that allows the measurement of the surface temperature of materials in real time (Sarawade and Charniva, 2018). The IRT method can be applied to monitor the condition of equipment elements and at the same time as an element of predictive or preventive maintenance in various sectors of industry (Sarawade and Charniva, 2018). The sensitivity of the method and the quality of the IRT measurement is decreased with the depth of the location and with the reduction of the size of the examined defect (Popow and Gurka, 2019). IRT interprets the temperature field of the body of the device under investigation and is basically based on the difference in the thermotechnical properties of the internal structure of the object and the defects found in it (Usamentiaga et.al., 2014). The growing demands for IRT capabilities focus current research on improving the performance of devices, scanning larger areas and the ability to work at higher temperatures, on the other hand, the goal is to develop cheaper and easier-to-operate IRT detectors (Rogalski,2003). Thermographic data is difficult to process, due to the fact that heat conduction is short-range and exhibits a poor signal-to-noise ratio (Higuera et.al., 2019).

The goal of the research was to determine the tension in the technical elements of transport machines and equipment through the use of infrared technology. Drbul et.al, 2014 dealt with mechanical engineering metrology and the quality of surfaces created by machining technologies. Contingency related to production and other novelties in the second revision of the standard "Maintenance Terminology" is addressed (Grenčík, 2018). The research was aimed at determining the possibilities of the IRT methodology to predict damage to steel ropes and subsequently to use the knowledge gained in the maintenance of ropes in operation. The main research problems included: - choice of appropriate technology and sensitivity of the sensing device, - determination of the effect of ambient temperature on the measurement process, - determination of the functional dependence between the internal voltage in the component and the temperature that was radiated from the component, - determination of the critical threshold of plastic deformation caused by internal stress in the part.

In general, the field of thermography and thus also the technique of thermal imaging cameras itself, is very comprehensive and is closely connected with the very application of the use of thermal cameras. In general, we divide thermal imaging technology into:

- SWIR cameras - cameras (modules) of the French company NIT (New Imaging Technologies) work in the wave range of 0.9 to 1.7 μm and are characterized by a dynamic range of 120dB, i.e. without image oversaturation in extreme exposures. In terms of application, these cameras are used for Machine Vision and measurement in ironworks (temperatures around 1000°C and more), automotive, defense applications, etc.
- MWIR cameras - medium-wave thermal cameras of the German company Infratec are used primarily in the areas of R&D, scientific applications and as high-speed (tens of kHz). Their temperature sensitivity is very high, which can be further increased by the methods and procedures of the so-called active thermography (up to mK units). These systems enable spectral filtering (measurement on the surface of transparent materials or, conversely, measurement through ordinary non-transparent materials) and also microscopic applications thanks to macro lenses, expanding rings of ordinary lenses or macro caps.
- LWIR cameras - long-wave thermal cameras are the most widespread type of thermal cameras for most applications (predictive maintenance, construction, partly also R&D). Cameras are portable (handheld) or stationary (fixed). Similarly, it is possible to connect to the next level of the so-called systems. active thermography (Heinz et.al, 2022), which is a branch of NDT for the detection of internal defects in materials.

2 METHODS AND METHODOLOGY

The SKF TKTI 21 thermal camera (Fig. 1) was used for the measurements. It is a durable, hand-held digital camera with advanced thermal sensing capabilities. It is suitable for use as a tool for NDT tests and predictive maintenance. The thermal camera has a large 3.5-inch color screen that provides a clear and sharp image using any of eleven color palettes (Ruddock, 2013). It is designed for easy operation, for measuring multiple temperatures and displaying temperature differences. Images can be saved as radiometric data and digital images on a micro SD card. It also includes powerful computer software for further image processing and analysis.

Fig.1 *Thermal camera SKF TKTI 21*
Source: (Authors)

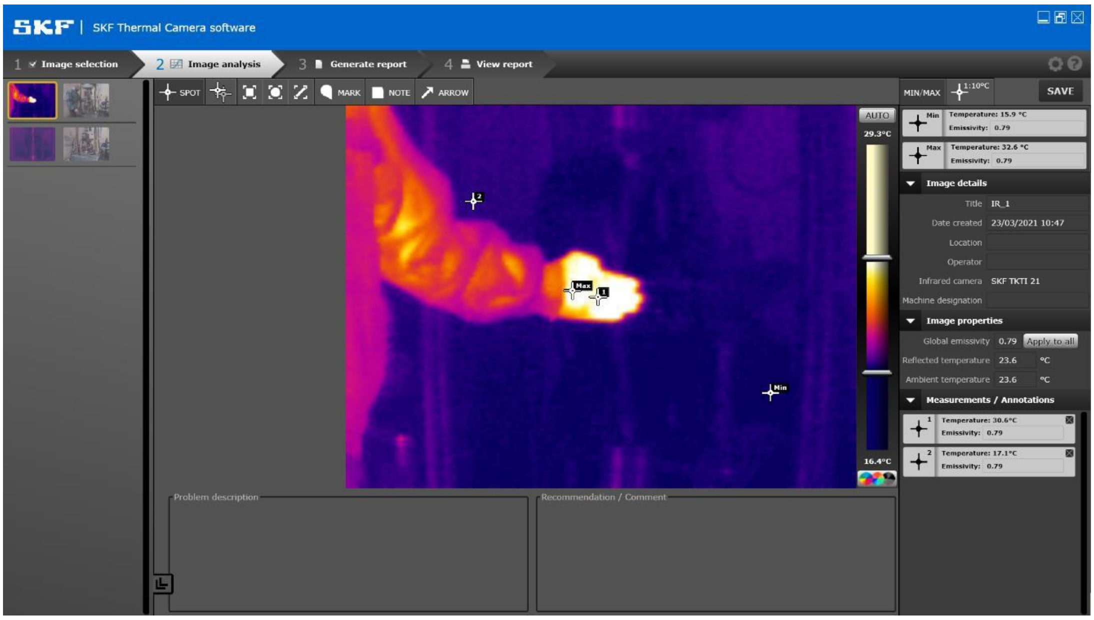

Fig.2 *The software environment SKF TKTI*
Source: SKF TKTI 21&31_manuál

The experiments were carried out on two blasting devices allowing the tensioning of short lengths of steel ropes in different lengths: - WPM 300 blasting machine (Fig. 3A) for determining the strength of metals, - breaking machine Krepet BME 2500 – MDV (Fig. 3B) for determining the strength of ropes.

Fig.3 *Test machines*
A - tearing machine WPM 300; B - blasting machine Krepet BME 2500 – MDV

2.1 Methodology of measuring the tension of steel ropes using infrared technology

Individual measurements were evaluated using thermograms and graphs of the dependence of temperature on the load force of the steel rope. A thermogram is a picture of a sample with a marked place (a point with a number) where the biggest temperature differences occur. The given place has the appropriate coloring compared to the surroundings (Fig. 5 - Fig. 8). The emissivity value for steel was set to 0.79 for the purposes of the experiments.

2.2 Technical parameters of the tested ropes

During the experimental thermal imaging measurements, steel ropes with the construction 22.4 6x19S FC 1570 U sZ were tested, respectively. 22.4 6x19S FC 1770 U zZDue to the high thermal conductivity of the material, the temperature difference decreases very quickly (Oswald-Tranta and Wally, 2005).The technical parameters of the tested steel ropes are:

- Steel rope: 6 - strand, 114 wires;
- Nominal rope diameter: 22.4 mm;
- Construction: 6 (1 + 9 + 9) + v;
- Winding of rope/wires: parallel;
- Nominal wire diameter: strand core 2.24 mm, first layer 1 mm, second layer 1.8 mm;
- Nominal load-bearing cross-section of the rope: 203.5 mm2; • Nominal weight of 1 m of rope: 1.87 kg;
- Nominal strength of the wires: 1570 MPa, or 1770;
- Nominal load capacity: 319.5 kN (1570MPa), or 360.2 kN (1770MPa).

The ropes were cast from both sides into conical ends and inserted into the jaws of the tearing machine (Fig. 4). Clamped samples of steel ropes were gradually stretched with a force corresponding to one division of the scale of the WPM 300 tearing machine (300N) for a time interval of 5 seconds. The loading speed was chosen with regard to the most accurate determination of the threshold of plastic deformation of the material of the tested samples.

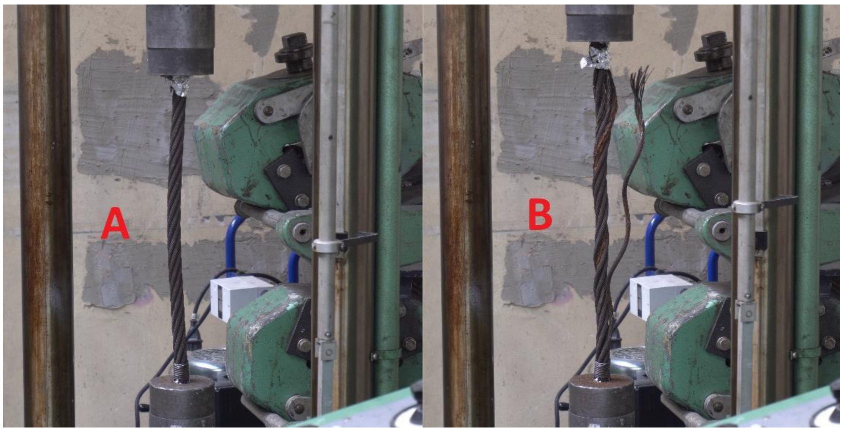

Fig.4 *Sample No. 1 of steel rope; A - beginning of measurement, B - after damage*

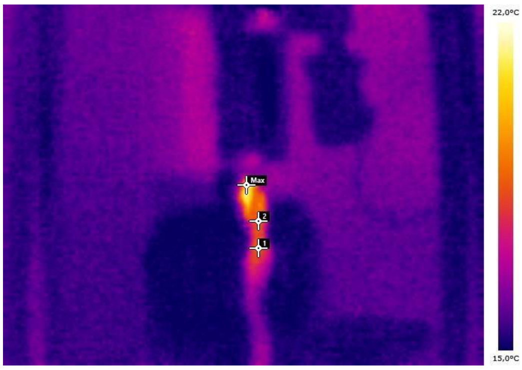

Fig.5 *Thermogram - beginning, t = 16,3 °C*

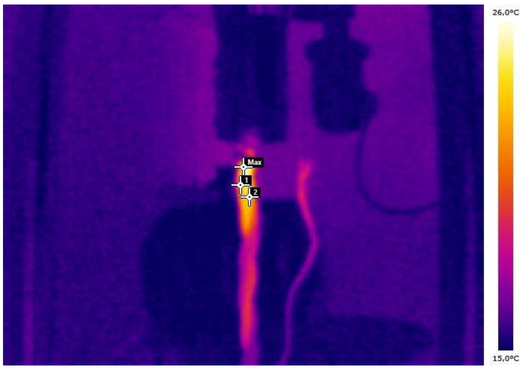

Fig. 6 *Thermogram – test, t =17,2 °C*

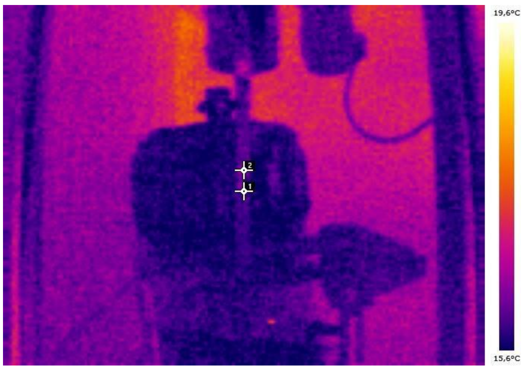

Fig. 7 *Thermogram - test, t = 21,7 °C*

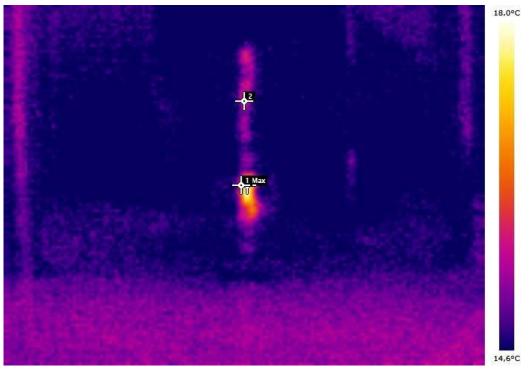

Fig.8 *Thermogram – end, t = 25,7 °C*

3 RESULTS

The presented measurement results were obtained from experiments on three samples of steel ropes:

test sample no. 1 rope 22.4 6x19 FC 1570 U zZ,
test sample no. 2 rope 22.4 6x19 FC 1770 U zZ,
test sample no. 3 rope 22.4 6x19 FC 1570 U zZ.

By measuring samples of steel ropes, the dependence between the increase in temperature and the increase in strength or voltage. The thermal stress was captured by an SKF TKTI 21 thermal camera, and the external load course was captured by a WPM 300 specimen tensile testing device. During the measurement, the thermal camera automatically calibrated, recorded, and evaluated the parameters of the reflected temperature, ambient temperature, and sample temperature. Before the measurement, it was necessary to enter the emissivity value of the material surface and the distance from the sample to the thermal camera. By means of images, the places on the samples where thermal stress occurred were captured. During stress, these places appeared on the thermal camera with the appropriate color. Recorded temperature differences in critical locations showed a slight increase in temperature. Temperature increase for steel rope sample no. 1 is presented in Table no. 1. The initial damage to the sample in the form of breakage of the rope wires occurred at a temperature of 22.0 °C. The read value represents an increase in temperature from the temperature aimed at the beginning of the measurement by 5.7°C. After this damage, sample no. 1 stretched until its complete rupture. In the case of complete rupture, there was an additional temperature increase of 3.7 °C compared to the temperature recorded when part of the sample was torn. The difference in the temperature of the sample at the beginning and at the end of the measurement represents a value of 9.4 °C. From the values listed in the table, a graphical dependence of the temperature on the force of loading the sample was made (Figure 9).

Tab. 1 *Course of temperature and force during stressing of steel rope sample no. 1*

Force [kN]	**t_{max} [°C]**	**The course of the stretching process**
0	16,3	Start of measurement
4,75	16,6	It rises with increasing strength temperature
21,78	17,2	
39,33	17,8	
58,36	19,4	
90,76	20,2	
157,61	21,7	
211,67	22,0	Partial rope damage
231,26	23,9	-
242,80	24,6	
253,81	25,3	
254,17	25,7	Total rope damage

From the course of the curve on the graphical dependence (Fig. 9), it can be seen that a greater increase in temperature occurs before the partial damage of the sample from a temperature of 20.2 °C to 21.7 °C and after it from a temperature of 22.0 °C to 23, 9 °C. The correlation dependence of the temperature on the force constructed in the graphic dependence (Fig. 9) is satisfactory and its linear dependence describes the course of the measurement and the dependence of the temperature on the force. Based on the calculated regression model, whose value of the correlation coefficient is 0.98, we consider this graphic dependence satisfactory. We consider statistical functional dependencies satisfactory if the value of the correlation coefficient [r]>0.7.

For a more accurate display of the relationship between the temperature and the external load on the rope, a graphic dependence was constructed between the induced tension and the sensed temperature (Figure 10). The figure also takes into account the correlation function describing the relationship between the sensed temperature and the induced voltage.

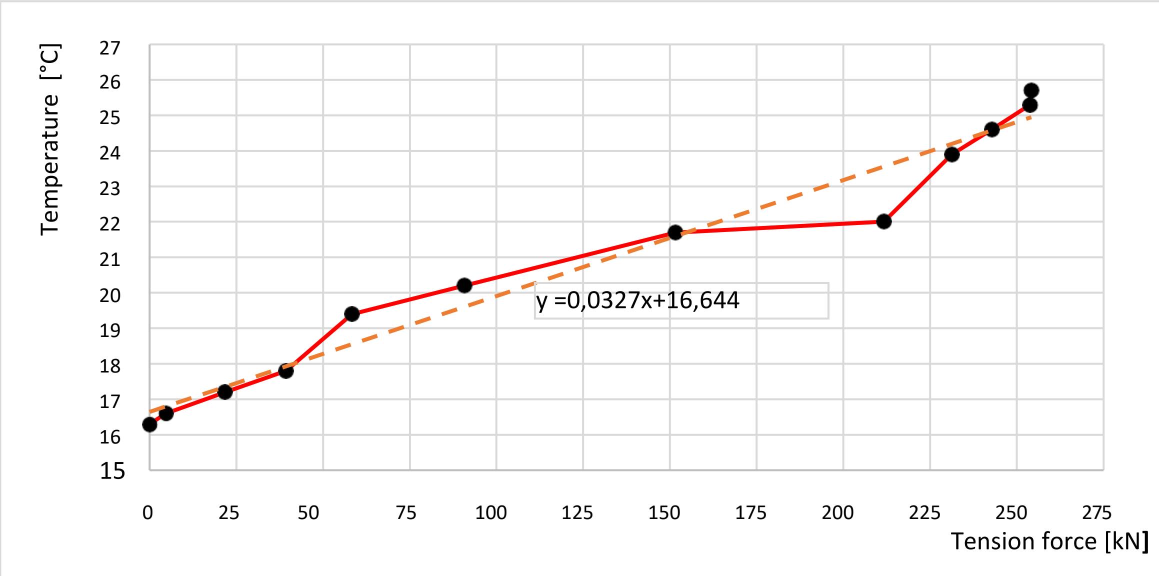

Fig. 9 *Graphical dependence of temperature and tension force during tensioning of steel rope sample no.1*

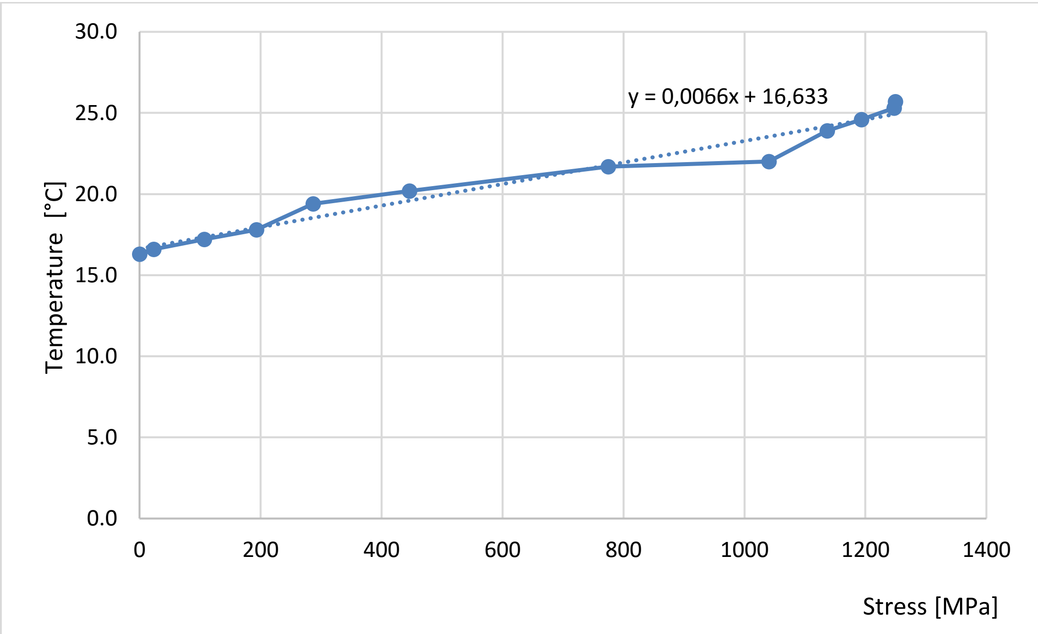

Fig. 10 *Graphical dependence of temperature change on tension in steel rope sample no.1*

4 DISCUSSION

During the experiments, the measured values were evaluated by the thermal camera software in the form of thermograms, which accurately determined the values of the temperature differences. The temperature differences were subsequently evaluated using graphical dependences of temperature on the tension of the sample for steel rope no. 1, for steel rope no. 2 and for steel rope no. 3. For the comparison of individual steel ropes, a common graphic dependence was created (Fig. 11), on which the dependence of temperature on the internal tension in the rope can be seen.

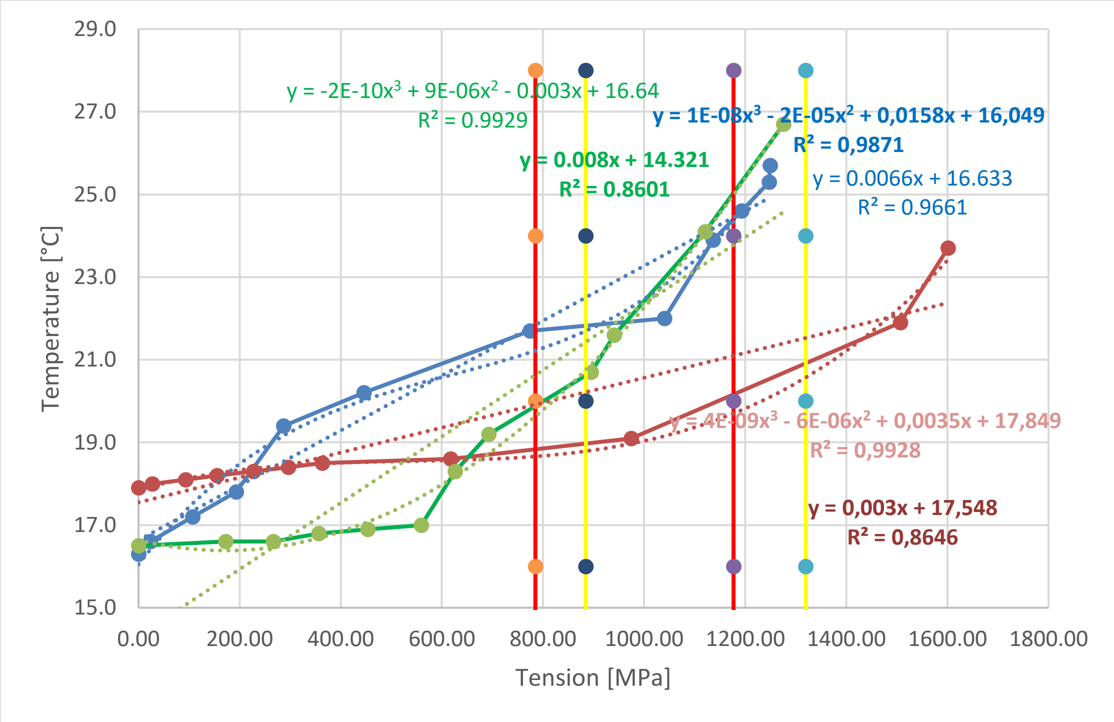

Fig. 11 *Graph showing the dependence of temperature values on tension in tested rope samples no. 1, no. 2 and no. 3.*

According to the graphic dependence (Fig. 11), we can conclude that the rate of temperature increase is significantly dependent on the temperature of the surrounding environment. Due to the dependence on the ambient temperature, the dependence curve shifts upwards, or down. The temperature rise is a function of the rate of increase of the external load on the sample. The mechanical-deformation energy inside the rope samples is converted into thermal energy, which was manifested by an increase in temperature. The temperature of steel rope sample no. 1 begins to increase more sharply at a value of 49.33% of the nominal tension of the rope wires. For steel rope sample no. 2 the temperature started to rise more rapidly at a value of 55.05% of the nominal tension of the rope wires. For steel rope sample no. 3 the temperature rises more sharply at 44.10% of the nominal tension of the rope wires. Samples where there was a sharper increase in temperature in the range of 44% to 50% of the nominal tension of the wires of the rope were ropes made of wires of strength class 1570 MPa (sample no. 1 and 3). For sample no. 3 made of rope with wires of strength class 1770 MPa, a sharp rise in temperature began only at a tension greater than 55%. When applying Hooke's law, which expresses the relationship between the deformation of a solid body caused by the action of stress and the magnitude of this stress, we can state that above the above-mentioned limit value of the load, plastic deformation occurs, which causes a non-linear increase in the emitting temperature. Up to these values, the increase is linear and the deformation is directly proportional to the stress of the material. It is assumed that if the rope were damaged, the temperature could increase more rapidly with less load on the rope.

5 CONCLUSION

Based on the experiments, the following conclusions can be drawn: - the facts found indicate that, as part of further research, it is necessary to focus on the relationship between the nominal mechanical strength of the tested sample and the radiated thermal energy captured by the thermal imaging system, - the rate of temperature increase is significantly dependent on the temperature of the surrounding environment, - means of thermography are another option for monitoring the stress of steel ropes, and temperature can be used as an NDT tool.

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