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USE OF INFRARED TECHNOLOGY IN BELT TRANSPORT TO ENSURE ITS FLUIDITY - DESIGN OF MEASUREMENT METHODOLOGY

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Abstract:
Infrared Thermography can be defined as the collection, imaging, storage, and evaluation of electromagnetic radiation in the infrared bandwidth of the electromagnetic spectrum using an electronic imaging device. Within this, heat transfer is important. The way it spreads can be by conduction, flow and radiation. Infrared thermography is widely used in the field of non-destructive testing. The article describes the measurement methodology performed on a conveyor belt using the thermal camera. The dependence between the increase in temperature and the increase in force (tension) was recorded using a thermal camera. The individual results were displayed by means of thermograms and histograms as well as graphs of the dependence of temperature on the load force. Based on this, conclusions were drawn on the use of this method in measuring conveyor belts.

Key words:
Infrared thermography, heat transfer, conveyor belt, tension

INTRODUCTION

Infrared thermography is a science that uses electro-optical systems to detect and measure thermal radiation and its "transfer" to surface temperature. Radiation is the movement of heat that occurs when energy (electromagnetic waves) is radiated into space without the required direct medium to transfer it. Modern infrared thermography uses electro-optical devices to detect and measure radiation and its transmission to the surface temperature of buildings and measured objects. Thermal displays work on the basis of infrared thermography. The thermal imager is used as an effective tool for fault investigation, maintenance, and inspection of electrical systems, mechanical systems, and buildings [1]. Thermal cameras are passive sensors that capture infrared radiation emitted by all objects with a temperature above absolute zero. This type of camera was originally developed as a surveillance and night vision tool for the military, but recently the price has dropped, significantly opening up a wider field of applications. The use of this type of sensor in visual systems eliminates problems with the illumination of common grayscale and RGB cameras [2]. Currently, research in the field of infrared detectors is focused on improving the performance of single-element devices, large electronically sensed fields, and higher operating temperatures. Another important goal is to make IR detectors cheaper and more convenient [3]. Heat flux thermography is a non - destructive testing method that offers a number of advantages. These include relatively fast inspection of larger areas, easy interpretation of results, and the absence of potential risks such as ionizing radiation. The disadvantage is, depending on the application, its limited penetration depth [4].

Photothermal radiometry allows remote measurement of local harmonic heat transfer, where the phase angle (between remote storage of optical energy and the resulting temperature modulation) is sensitive to subsurface properties or disturbances. Phase-sensitive modulation thermography combines the advantages of photothermal radiometry with the fast infrared imaging technique, revealing hidden errors in a short time. Although this blocking thermography is based on remote optical heating of the whole area of interest, defects can be selectively heated by modulated ultrasound, which is converted to heat by the action of a mechanical loss angle, which is amplified in the faulty areas [5]. Infrared thermography (IRT) is widely used in the field of non-destructive testing (NDT) for inspection, monitoring, and basic research. In addition to NDT, thermography has been widely used in many areas in recent years, for example in determining thermophysical parameters, agriculture, medicine, biology. Recently, IRT has been successfully used to indirectly identify sectors with a high concentration of current density in planar microwave devices. Developments in quantum detector technology have increased the accuracy of temperature measurements over a few millikelvin [6].

1 THEORY/CALCULATION

CONVEYOR BELT

The conveyor belt is a very important part of conveyor systems. It is a traction element, which represents the transmission of traction force from the drive drum to the conveyor belt. There is surface friction between the belt and the drive drum. The belt should fulfil several functions - traction, support, and protection. It must be sufficiently flexible and strong when filled with transported material. When optimizing resistances and shipping costs, it should have high resistance to stress and the lowest possible weight. In the operation of these devices, the belts are designed according to the purpose of transport and the type of transported material [7, 8].

The basic division of belts according to the type of carcass:

- rubber-textile;
- steel cords;
- and other.

The conveyor belt consists of an upper and a lower cover layer. The upper cover layer provides protection of the carcass and is a contact surface with the transported material. The lower part of the conveyor belt is formed by the lower cover layer. This layer ensures contact with the support and guide rollers of the roller stand. The rubber protective edge prevents damage from the sides. The task of the adhesive mixture is to form a firm connection between the individual layers. When transporting materials with a large piece, there is a risk of puncture, aramid fibres or cords are vulcanized into the structure, ensuring the protective function of the carcass (bumper). Another part is the skeleton, which ensures the transmission of tensile forces.

The most commonly used belts in practice are the rubber - textile belts. The longitudinal frame is made of polyester canvas. The belts are impact and corrosion resistant with high adhesion and tensile strength. The belts are manufactured in various widths and strength classes. They are used to transport material over medium and long distances.

Steel cord belts - in practice they are used for long transport distances under the action of large axial forces in the conveyor belt. The steel cords that form the belt carcass are longitudinally embedded in the rubber core. In practice, less used belts due to their mechanical properties.

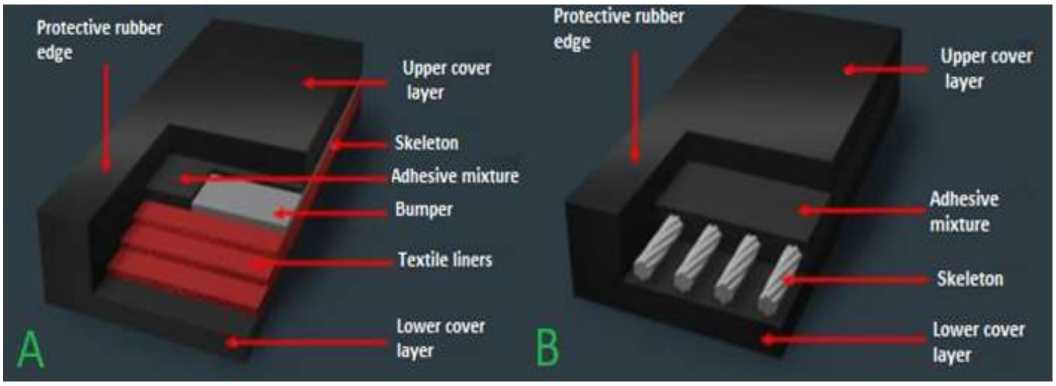

Fig. 1 *Composition of the: A - rubber-textile belt, B - steel cord belts [9]*

The conveyor belts gaps are formed by the penetration of a hard sharp-edged material or a foreign body through the cover layer and the carcass of the belt. There is insufficient resistance of the belt as well as the support system to the impact force of the incident material. The gap in the rubber-textile and steel cord strips has a different character due to their cohesiveness and strength. In the case of rubber-textile conveyor belts, the occurrence of punctures is much higher due to the large damage to the carcass and the possibility of separation and subsequent rupture of the belt. In the case of a steel cord conveyor belt, the cuts present a lower risk of reducing the strength of the carcass due to the arrangement of the cords, but there is an increase in the possibility of longitudinal cutting along the entire length of the belt [7, 8].

Tensile strength:

$$f_s = \frac{F_r}{b_t} \quad [N / mm] \qquad (1)$$

where: f_s - tensile strength [N / mm],

F_r - maximum force [N],
b_t - body width [mm].

Tensibility:

$$\varepsilon_r = \frac{100 \cdot (L_2 - L_1)}{L_1} \quad [\%] \qquad (2)$$

where: ε_r - tensibility [%],
L_1 - initial length [mm],
L_2 - length at failure of the test piece [mm].
Elongation at reference load:

$$\varepsilon_r = \frac{100 \cdot (L_A - L_1)}{L_1} \quad [\%] \qquad (3)$$

where: ε_t - tensibility [%],
L_1 - initial length, ie. distance between reference marks [mm],
L_A - length at reference body load [mm] [10].

Emissivity

For the accuracy of measurements with a thermal imager, it is necessary to define the emissivity. Emissivity is the speed at which an object emits energy compared to the speed of a black body at a certain temperature and wavelength. Without knowledge of the emissivity of the object of interest, it is not possible to make any assumptions about this object, as can be seen in the infrared image, in relation to its temperature or the actual thermal properties.[11].

The emissivity of an object is given by five characteristics:
1. Material of the object;
2. Surface condition of the object;
3. Object temperature;
4. Object of wavelength;
5. Geometry of the displayed area.

The two main properties that determine emissivity are the material and the condition of the surface

All radiometric infrared cameras are equipped with an on-board computer or microprocessor, which allows you to calculate the temperature value from the area or place on the building. The Stefan-Boltzmann formula is used to calculate this temperature. The camera measures the amount of infrared energy radiated from a certain area. The correct emission value and the amount of radiated background energy must be entered to take into account the energy resulting from the reflection. Reflection or reflected temperature is any thermal radiation originating from other objects that reflects off the target you are measuring. The computer then determines the temperature using the relationship between the emitted energy and the temperature defined according to the Stefan-Boltzmann formula.

There are two ways to determine emissivity. It can be determined using a search graph or by measuring with an infrared camera. In general, these graphs are good for a number of non-metal materials. Since most metals are subject to oxidation, the surface condition changes, which in turn changes the emissivity. This effect on emissivity cannot be effectively assessed by visual assessment. It is always best to perform an emissivity test on a metal sample to determine the temperature before performing an infrared check and calculating the temperature.

Stefan - Boltzmann's law:

$$Q = 5{,}67 \cdot 10^{-8} \cdot T \qquad (4)$$

where: Q - total amount of radiated energy,
5.67. 10^{-8} - Stefan-Boltzmann constant,
T - temperature in degrees Kelvin [11].

Heat transfer

Heat transfer is important in thermography. Heat transfer is the transfer of thermal energy from a warmer building to a colder one. Thermal processes, e.g. heating, cooling, condensation and evaporation are governed by the laws of heat transfer, which are described in more detail in the literature on thermodynamics. When designing technical equipment, this knowledge shall be applied to the extent and in the manner required for a particular type of equipment. The processed material must be heated to the required temperature, the reaction heat must be supplied or removed, the heat of vaporization must be supplied during the evaporation of liquids, or vice versa, the heat of vaporization must be removed during vapor condensation, etc. Very often it is required in other cases, on the contrary, the heat exchange with the surroundings must be kept to a minimum [12].

Methods of spread heat

1. Conduction: conduction of heat is characterized by the transfer of energy at the microscopic level, that is, between the atoms and molecules of the system. Heat conduction is used mainly in rigid bodies, the different parts of which have different temperatures. Heat is also dissipated by conduction in liquids and gases, where, however, heat transfer by convection is also used.

Fourier's law:

$$q'' = -k \cdot \frac{\Delta T}{d} \qquad (5)$$

Where: q'' - heat flux density,
k - thermal conductivity coefficient,
ΔT - temperature difference,
D -material thickness.

2. Flow (convection): flow occurs in fluids and represents the transfer of energy at the macroscopic level, t. j. between fluid particles containing a large number of molecules or atoms. It is always accompanied by heat conduction and the relative proportion of both depends on the hydrodynamic conditions. Heat transfer by convection is significantly faster than heat conduction in fluids.

The formula for calculating convection is:

$$q = h \cdot (T_s - T_\infty) \qquad (6)$$

where:
h is the convection coefficient of heat transfer. The second part of this formula is the temperature difference between the surface temperature of the object and the infinite temperature of the convection stream. Convection is usually easily identifiable with infrared thermography due to its very specific thermal structure.

3. Radiation: The heat transfer by radiation is fundamentally different from previous methods. During radiation, heat is propagated in the form of electromagnetic waves and does not require a material environment to pass from one body to another.

If thermal radiation hits the body $\dot{Q}$, part of the radiation $\dot{Q}_A$ is absorbed, part of the radiation $\dot{Q}_R$ is reflected and part of the radiation $\dot{Q}_D$ passes through the body by:

$$\dot{Q} = \dot{Q}_A + \dot{Q}_R + \dot{Q}_D \qquad (7)$$

or:

$$\begin{aligned} 1 &= \dot{Q}_A / \dot{Q} + \dot{Q}_R / \dot{Q} + \dot{Q}_D / \dot{Q} \\ 1 &= A + R + D \end{aligned} \qquad (8)$$

where: A - thermal conductivity (absorptivity),
R - thermal reflectivity (reflexivity),
D - warmth (diathermicity).

It is important to emphasize that all three heat transfer mechanisms work together. Usually one of them either predominates or does not appear at all. The environment determines which mechanism manifests itself or will be predominant. In solids, heat is spread only by conduction. In vacuum only by radiation. However, gases absorb radiation very poorly, usually only at certain wavelengths. For example, ozone absorbs only ultraviolet radiation. Liquids absorb radiation very well. Thus, all three mechanisms can be applied in gas and liquid. Which of the mechanisms will predominate depends on temperatures and hydrodynamic conditions.

Heat transfer by conduction and convection

The driving force of heat transfer by conduction and flow is the temperature difference between different places of the system (solid, liquid, gas), ie the temperature gradient. Heat is propagated at the molecular level by transferring energy between molecules. The following division is also suitable for convection:

- free convection occurs by the effect of gravity and the direction of heat transfer has a vertical direction. The heat rises because the warmer parts of liquids and gases have a lower density,
- forced convection occurs when the flow is forced (for example by a fan in a room), then the direction of heat transfer depends on the direction of fluid flow.

Heat transfer by radiation

A special case is heat transfer by radiation, when neither convection nor conduction is applied. Radiation can also dissipate heat through the vacuum. The intensity of thermal radiation depends on a certain power of the temperature of the radiated body. Radiation transfers, for example, energy from the Sun to the Earth, part of the heat is removed from the Earth by its own radiation. Each of these three modes of heat transfer can be:

- steady (stationary) transfer - is characterized by the fact that at different places of the heat exchange surface the temperatures may be different, but they do not change over time. Such a process takes place in continuously operating heat exchangers during heat transfer using gaseous or liquid substances,
- unsteady (non - stationary) transfer - in technical practice it occurs very often, especially in the periodic operation of heating or cooling apparatuses and vessels,

during heating, cooling or freezing of solid substances, etc. This type of heat transfer is characterized by the fact that temperatures at any point in the participating system change over time [12].

2 METHODOLOGY OF MEASURING THE CONVEYOR BELT WITH A THERMOCAMERA

This section lists the instruments and devices used for the measurement. Measurements of conveyor belt samples were performed using a ZWICK ROELL Z030 tearing machine using a testo 882 thermal camera (Figure 2). The measured material stresses were torn by the tearing machine. The temperature of the sample was monitored with a thermal camera.

The ZWICK ROELL Z030 tearing machine is designed for bending, pressure, and tensile tests of conveyor belt samples. It allows pulsating, smooth, and also cyclic loading of the respective test sample. The first step is to prepare the sample, condition it and then carry out the test itself. The course of the test was recorded by a thermal camera by means of images at individual time points.

During the test, it is necessary to ensure a symmetrical attachment of the test body so that the direction of the tensile force and the centerline of the jaws coincide. The main output of the tensile test is the tensile strength, elongation at break, stress at a given deformation, elongation at given stress, stress, and elongation at yield strength. The STN ISO 283 standard specifies the entire course of the test. For each performed test, it is necessary to measure the thickness of the test body using a thickness gauge. The test specimens are cut in the direction of the axis (warp) of the conveyor belt or perpendicular to it (attack). The cut sides of the strip samples must be perpendicular.

The testo 882 thermal camera, which measures the temperature in the conveyor belt, belongs to the category of thermal cameras intended for professional thermography, both in industrial maintenance and in construction. In the field of industry, it can be used to detect e.g. transient resistances in the electrical switchboard, control bearings. In the field of construction, it can be used to detect thermal bridges, building structures, fillings, etc. [13].

The technical parameters of the testo 882 thermal camera are:

- 76,800 temperature measuring pixels. (infrared resolution 320x240 pixels.), the possibility of extending the quality to a resolution of 640x480 pixels;
- Temperature sensitivity lower than 50 mK, which represents 0.05 ° C;
- Temperature range between -20 and + 350 ° C divided into two ranges:
- -20 to + 100 ° C and 0 to + 350 ° C;
- The operating temperature of the device -15 to + 40 ° C;
- Lens with a viewing angle of 32 ° x 23 °;
- Automatic hot and cold spot detection for direct display of critical temperature conditions;
- Integrated digital camera with LED lights;
- IRSoft computer software [13].

Fig. 2 *Devices used for measuring conveyor belt;*
A - Shredder ZWICK ROELL Z030; B - testo 882 thermal camera

The measurement was performed on a sample of the conveyor belt type EP 630/4 800 4 + 2 Y. The material forming the carcass of the belt after warp is polyester (synthetic fiber, high strength, good tensile properties) and the carcass material in the weft is made of polyamide (synthetic fiber, considerable extension). The nominal strength of the belt is 630 $N.mm^{-1}$ with the number of belt inserts 4. The thickness of the upper cover layer of the belt is 4mm and the thickness of the lower cover layer is 2mm. Coating category Y is specified for slightly abrasive, granular, and loose material. A sample of this strip was prepared on a hydraulic press ATOM SE 25 (Figure 3), where it was cut to the appropriate size and shape using a cutting tool. The tool together with the conveyor belt is placed on the working place of the machine so that the upper edge is on the upper cover layer and the appropriate parameters of the cutting process are set.

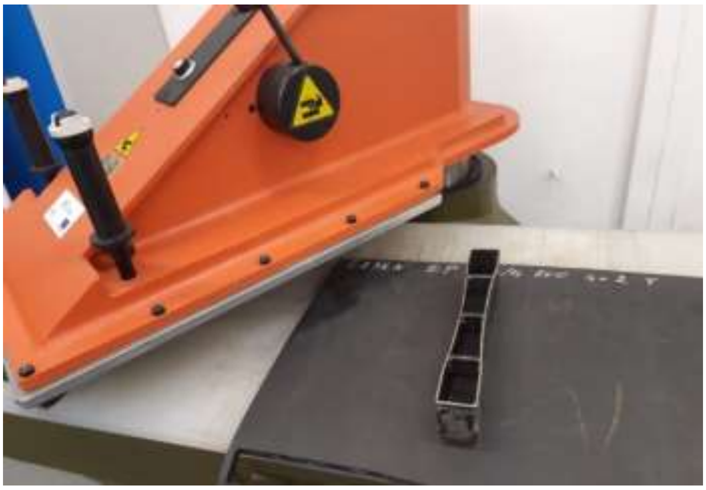

Fig. 3 *Hydraulic press ATOM SE 25 - sample preparation of the conveyor belt*

The sample of the conveyor belt (Figure 4), inserted into the jaws of the tearing machine, was tension at a speed v = 100 mm / min according to the standard STN ISO 283. During the measurement, the temperature of the sample was recorded by a thermal camera. The created images were evaluated by thermogram and histogram using IRSoft software. The entire course of the test was also recorded by a tensile diagram by the appropriate shredder software. The diagram shows the magnitude and course of the force at which the belt sample is stressed. The sample is gradually elongated until it ruptures at a certain force.

Fig. 4 *Conveyor belt sample EP 630/4 800 4 + 2 Y; A - before rupture; B - after rupture*

3 RESULTS

When creating the thermogram, the places on the sample where the temperature changes during the stretching of the sample were marked. This represents the places where the temperature rises. At the same time, a histogram was created, which, based on the marked place on the thermogram image, evaluates the course of the temperature increase as a percentage.

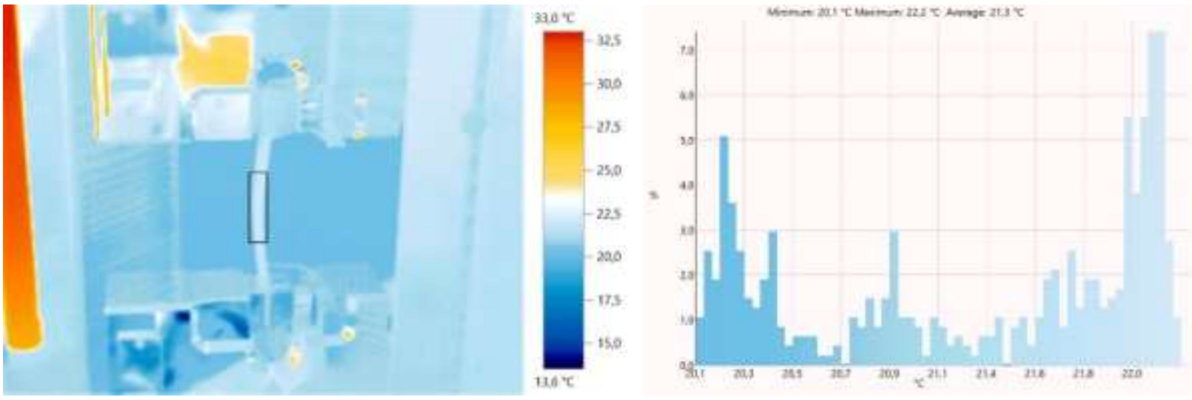

Fig. 5 *Thermogram with histogram - start of measurement, t = 22,2 °C*

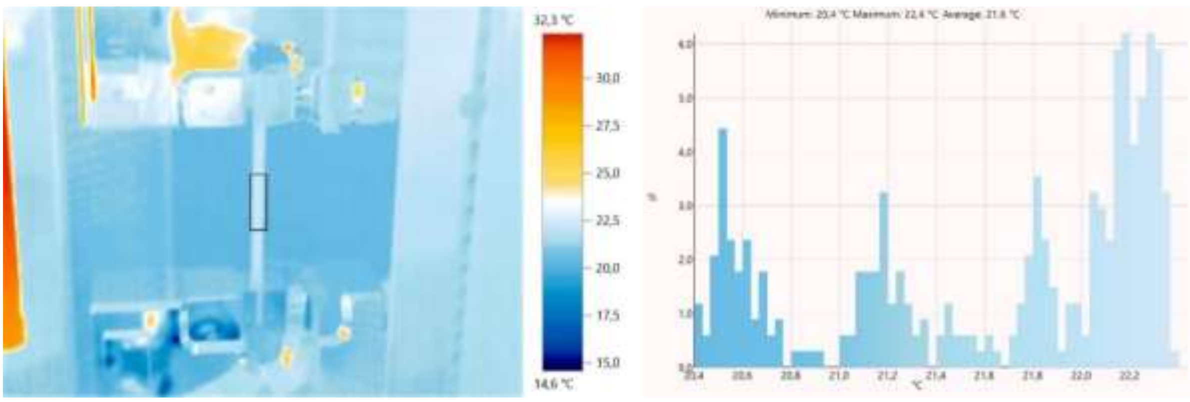

Fig. 6 *Thermogram with histogram - belt tensioning process, t = 22,4 °C*

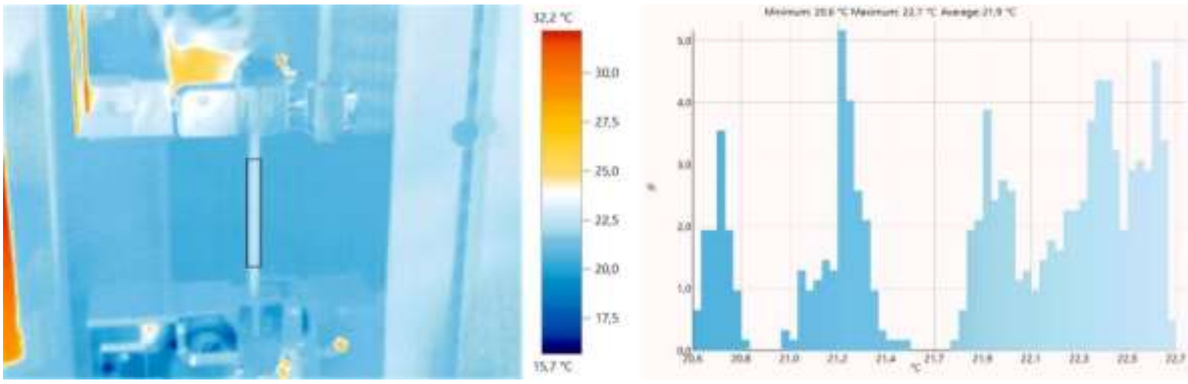

Fig. 7 *Thermogram with histogram - belt tensioning process, t = 22,7 °C*

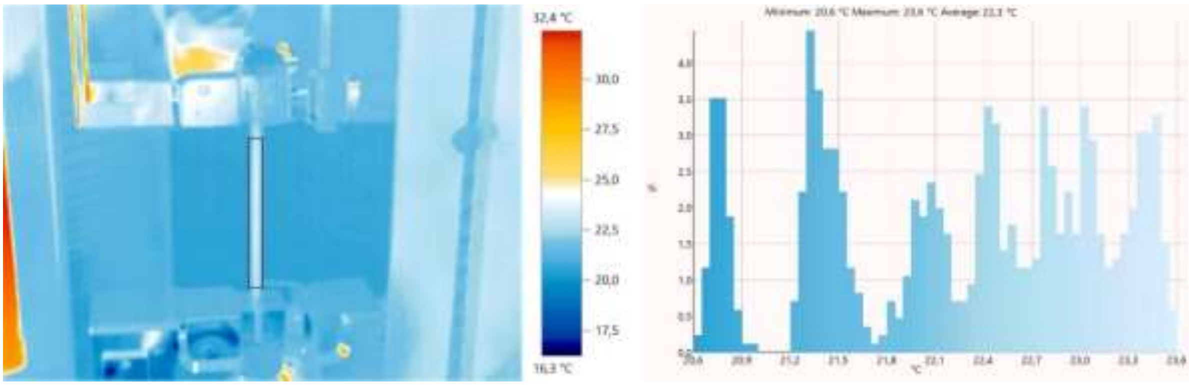

Fig. 8 *Thermogram with histogram - belt tensioning process, t = 23,6 °C*

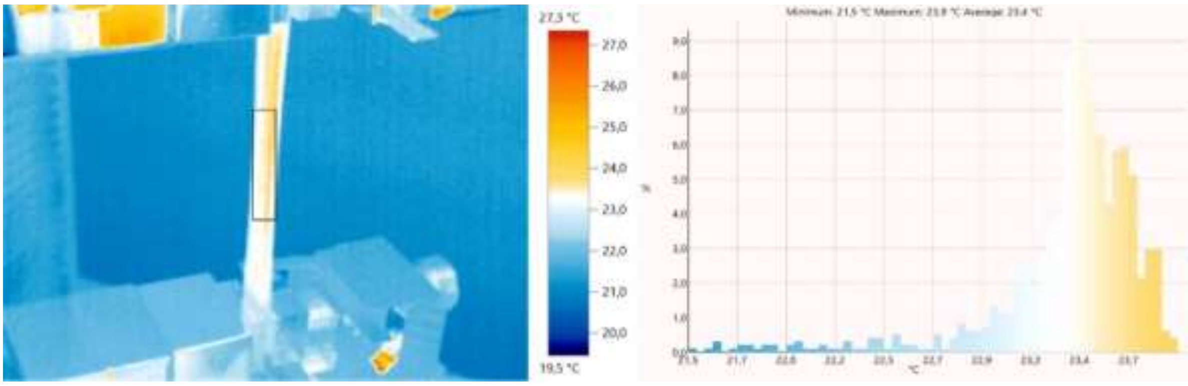

Fig. 9 *Thermogram with histogram - belt tensioning process, t = 23,9 °C*

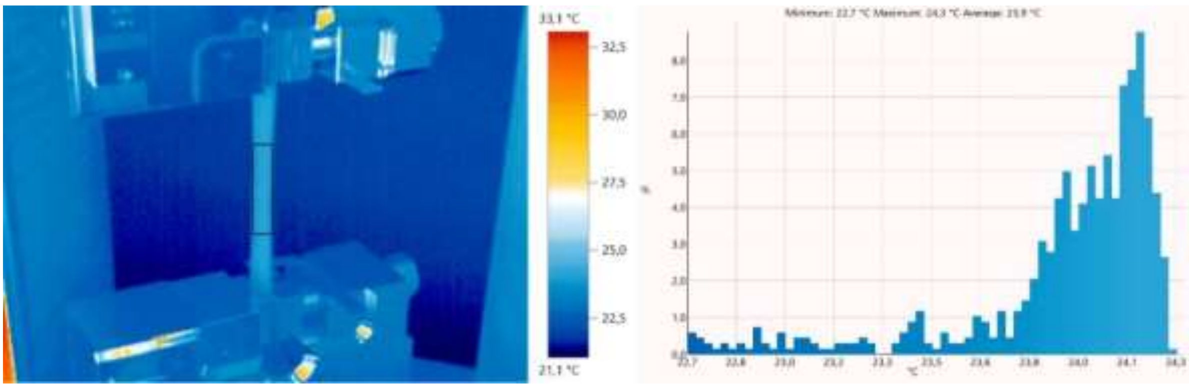

Fig. 10 *Thermogram with histogram - belt tensioning process, t = 24,3 °C*

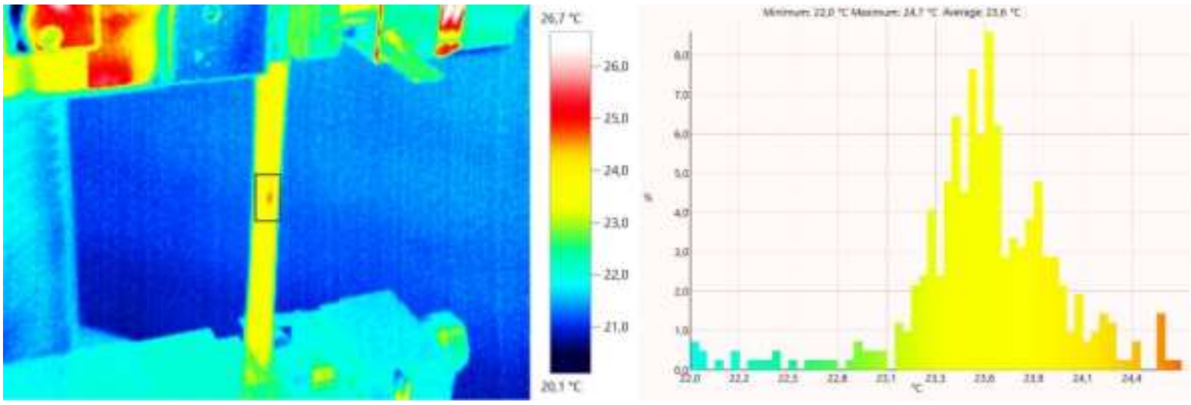

Fig. 11 *Thermogram with histogram - belt tensioning process, t = 24,7 °C*

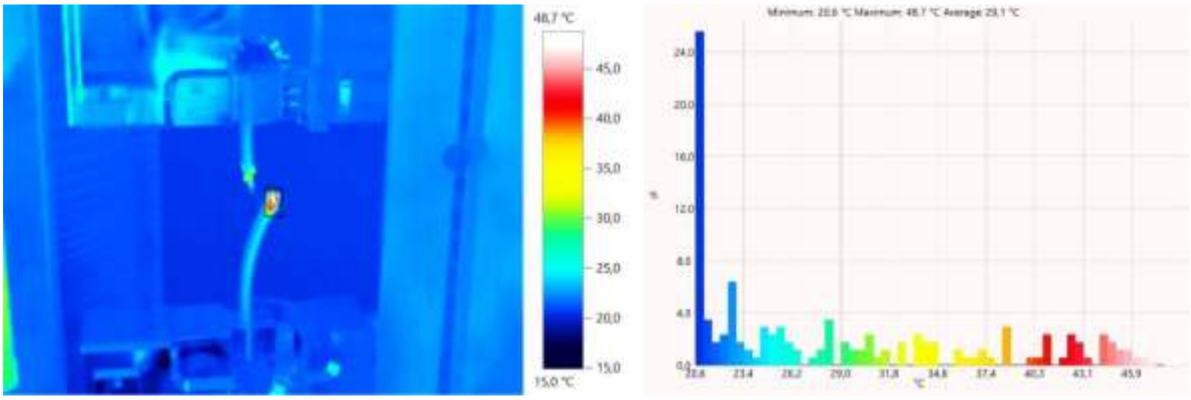

Fig. 12 *Thermogram with histogram - rupture of the belt sample, t = 48,7 °C*

The results of the thermograms and histograms show that small increases in temperature occur when the strip sample is stressed. Temperature differences ranged from 0.1 to 0.6 ° C. The sample was measured by setting the parameters of the thermal imager and evaluated by the software at a reflection temperature t = 22 ° C, which was equal to the ambient temperature. The outside temperature was - 5 ° C and the emissivity of the surface of the rubber material was set to 0.94. After rupture of the belt sample (Figure 12), the belt skeleton reached a temperature of 48.7 ° C. In table no. 1 shows the measured values of force and temperature during the test of the subject belt sample.

Tab. 1 *The course of temperature and force during the strain of the conveyor belt sample*

Figure	Force[N]	t_{max} [°C]	The course of strain
6	2000	22,2	The temperature rises with increasing force
7	7 000	22,4	
8	10 000	22,7	
9	13 000	23,6	
10	14 000	23,9	
11	15 500	24,3	
12	16 500	24,7	Partial damage to the belt sample
13	17 000	48,7	Damage to the belt sample

From the table values, a graphical dependence of the temperature on the loading force of the sample was made. From the course of the curve on the graph (Figure 13), it is clear that a large increase in temperature occurs just before the sample is interrupted. In the graph in Figure 13, the measured values are translated by a linear correlation curve. From the display of the graphical curve of the dependence and the correlation curve of temperature on force and the correlation coefficient, it is clear that the correlation is low and the linear dependence does not reliably capture the course of measurement and the dependence of temperature on force. Based on the calculated regression model, whose value of the correlation coefficient in the case of Figure 13 is 0.48, we consider this graphical dependence to be expressed. The expressed trend is considered to be the one if [r]> 0.4. Because the linear correlation is unsatisfactory, the measured values were divided into two sets. After the division, the dependences were shown for both sets (Figure 14 and 15) and the best correlation function was found to capture the relationship between temperature and load force.

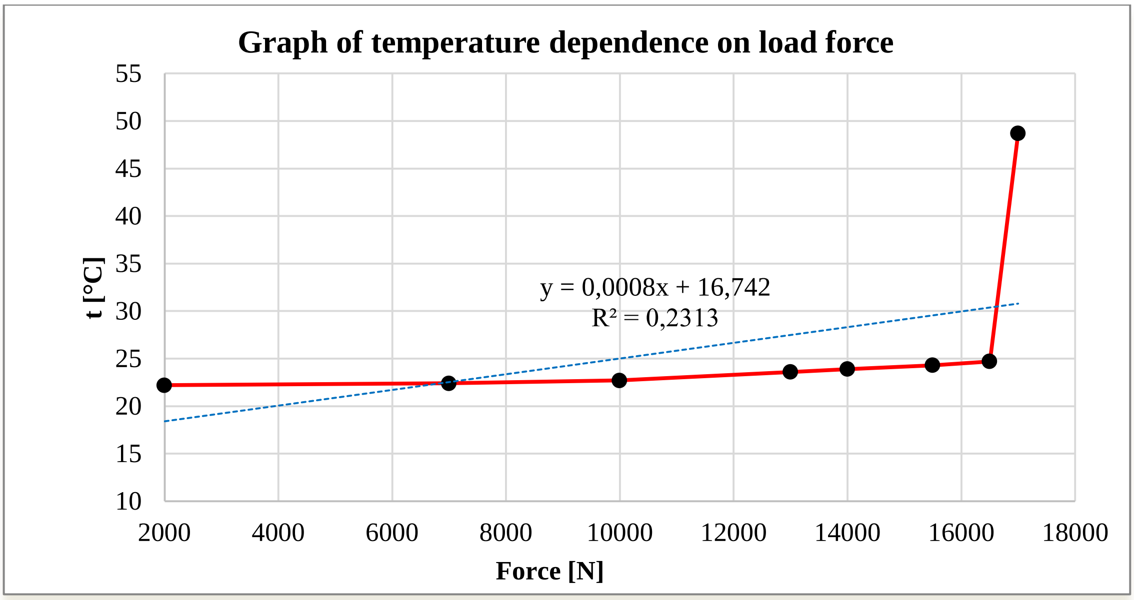

Fig. 13 *Graph showing the dependence of the extreme values of temperature on the force during the tensioning of the belt sample*

The set of measured values was divided into the first set of values for force values from 2000 N to 13,000 N with temperature values from 22.2 ° C to 23.6 ° C. The second set of values for force was in the range from 13000 N to 17000 N with a temperature range from 23.9 ° C to 48.7 ° C according to Table 1. Correlation curves were processed for both files. From the graph in Figure 14 it is clear that the direction of the first set is very small and the temperature values increased very only by 1.4 ° C in the force range 2000 N to 13000 N. The correlation function direction has a value of 0.0001. This means that the temperature curve is actually a horizontal line. In the second set of values, it can be seen that the temperature did not rise very sharply, the enormous increase in temperature is between the penultimate and the last value of the force at which the sample was destroyed.

The temperature rise between the two forces is 24 ° C and the direction of the linear correlation function on the force interval is 0.0041. This directive value is 40 times greater than the directive value in the force set in the range 2000 N to 13000 N. For comparison with the linear dependence, a graph was created showing the exponential increase in temperature (Figure 15). The course of the test itself is also described by the creation of a tensile diagram

(Figure 16), which shows the elongation of the belt sample during its loading on the machine. This means that the sample was extended by 42.9 mm, which represents a value of 15% in the diagram.

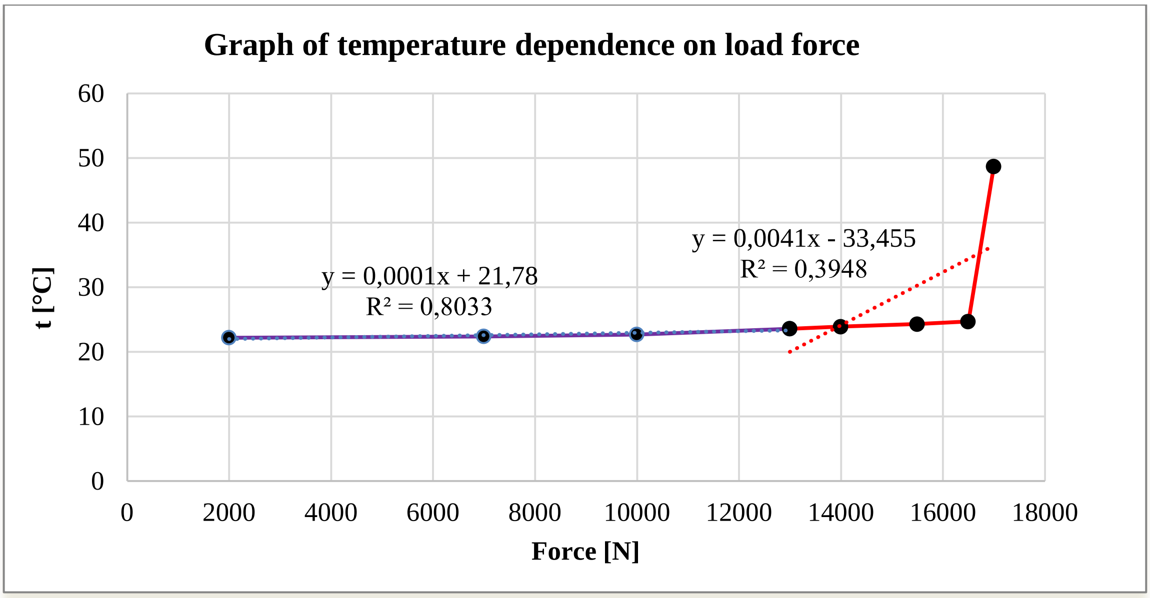

Fig. 14 *Graphical dependence of temperature change on load force*

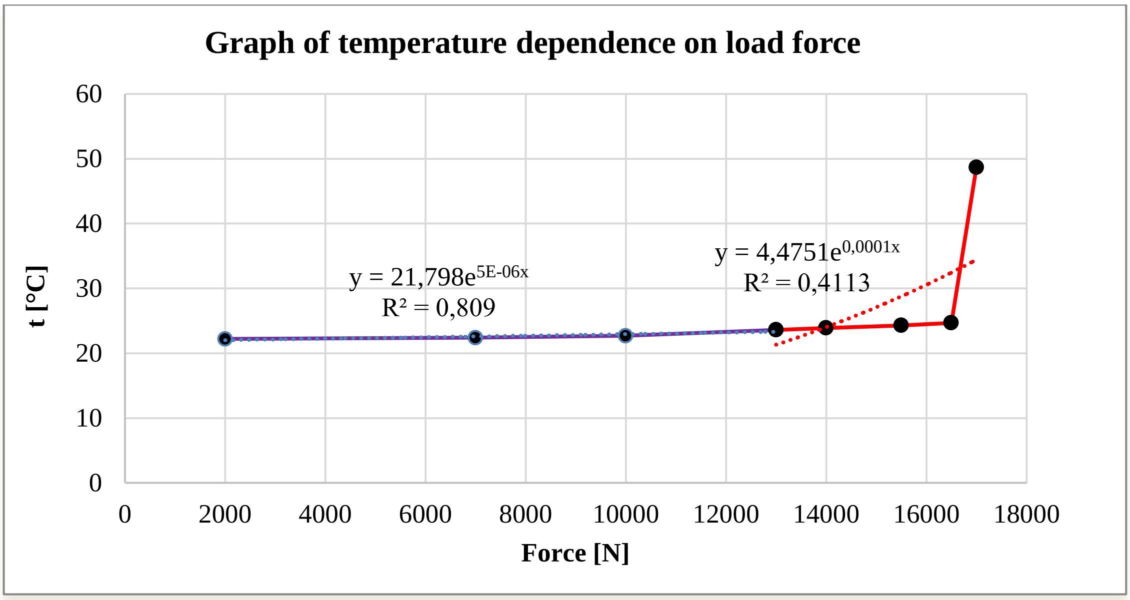

Fig. 15 *Graph showing the exponential increase in temperature during belt tensioning*

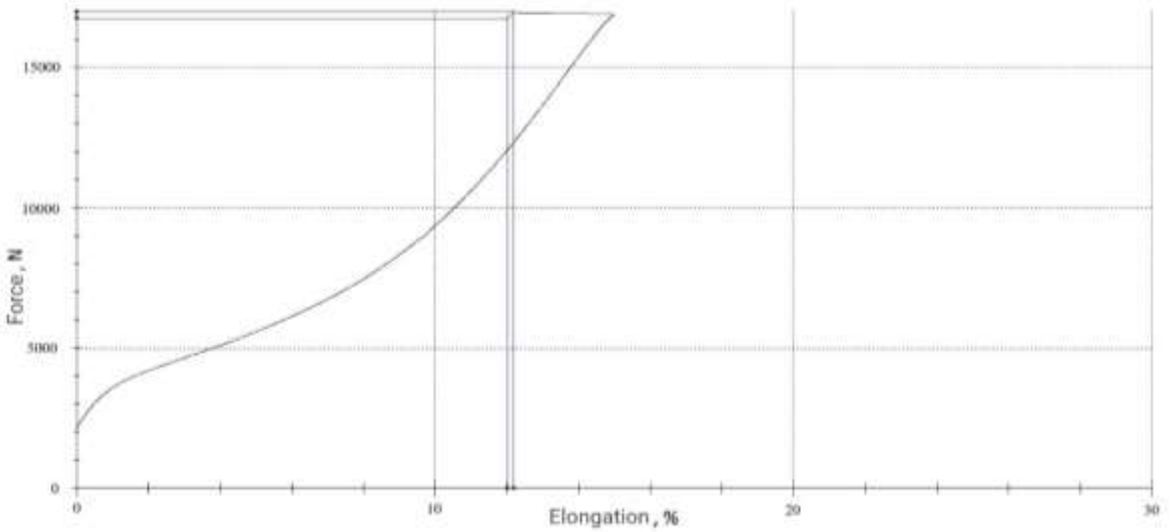

Fig. 16 *The course of the tensile test*

4 CONCLUSIONS

As part of the research, thermal imaging measurements were performed on samples of steel ropes and chains. The measurements monitored the dependence between the increase in temperature and the increase in force respectively stress. Thermal imaging measurement on a belt for a belt conveyor is one of the first measurements, which declares the basic measurement. The measurements will be followed by thermal imaging within the doctoral study. From this first measurement we can declare the following preliminary conclusions:

- temperature increase depending on force respectively the tension in the sample is gradual and the temperature rises sharply just before the sample is destroyed. The course of the dependence of temperature on force can be seen in the graphical dependence in Figure 14. The guidelines of correlation functions confirm this statement,
- several incorrect decisions were made during the measurement, which could affect the measured values,
- thermal imaging camera measurement must be continuous,
- it is necessary to determine the background temperature very precisely,
- in the case of belt conveyor belts, it is necessary to determine the measuring point very precisely - the skeleton or the outer covering layer, or the measurement must be performed by two thermal imaging cameras at the same time,
- when measuring the strip, the rubber was found to be a large insulator for heat transfer.

The above findings from the first measurement will need to be removed in the course of the forthcoming research, which will monitor the exact relationship between the temperature and the stress caused by the external force acting on the sample. As part of the research, we plan tests on steel ropes, rods, chains and belts for belt conveyors. The result of the research is monitored whether the temperature can be used as a parameter of non-destructive testing, which would be able to define the technical condition of the device well in advance, so as not to endanger the user and ensure the method of thermal imaging mechanisms.

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