Preliminary research to determine the thermal condition of the belt conveyor's drive unit in an underground hard coal mine

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Abstract. The paper presents preliminary research conducted to determine the thermal condition of the main belt conveyor transporting coal from the longwall. The results show the thermal condition of the conveyor and in the further stage are used to effectively diagnose possible causes of damage to the belt conveyor’s drive unit. The tests were performed on the conveyor whose operation is strategic to the mine. The research comprised a thermal imaging camera that allows taking contact-free measurements. The main purpose of a thermal imaging measurement is to detect changes in thermal conditions without the need to stop the conveyor belt. The paper presents the methodology and discusses the manner of performing underground measurements as well as a procedure for processing the results. The final conclusions concerning the technical condition of the drive unit were based on the results and their analysis.

1. Introduction
The launch of Industry 4.0 boosted the technological progress of specialized mining machinery and devices [12, 18, 24] in both the underground mining industry as well as the open-pit mining sector [6, 22]. Technological development has contributed to the improvement of safety. In recent years, several research works related to the failure-free and efficient operation of longwall conveyors have been conducted [4, 11, 25]. Underground coal mining is carried out in an environment where natural hazards occur, including methane release and fire hazards [16, 19, 21]. They both significantly lower the performance of underground machines and devices [5]. A longwall complex includes a shearer, a scraper conveyor and powered roof support that protects the shearer and the conveyor against the impact of the rock mass [20]. The output is transported from the longwall by means of belt conveyors that together from a transport line of a mine [1].

Mine maintenance service usually uses thermal imagers in order to control the mechanical devices and to check whether the electric devices operate properly. The thermal imaging camera helps to quickly diagnose the technical condition of a mechanical device. This type of devices, such as the
drive unit of the belt conveyor in an underground mine that was tested as a part of the research, always generates some amount of heat as a result of friction of flow of electricity; moreover, if the unit or its components is not working properly, then considerably more heat is released. This can be related to friction or blockage of moving parts, their improper lubrication or damage to the cooling system [3,8].

This paper discusses the results of the research on thermal condition of the belt conveyor’s drive unit. The conveyor is a part of the main output transport unit in an underground hard coal mine. All temperature samples were taken using a thermal imaging camera; the results were reviewed in terms of operation time of the belt conveyor, taking into account the time elapsed since its start-up, downtime, and continuous operation. All factors along the route of the belt conveyors that affect the temperature and operation were included in the tests and the results were used to develop the graphs reflecting the variability of temperature values. The research was aimed at determining the probability of failure on the basis of obtained measurements of the thermal state of the belt conveyor’s drive unit.

2. Thermal imaging

Thermography is defined as the process of recording and processing digital images obtained for the infrared range in order to obtain information about the distribution of temperature on the surface of a given object or a set of objects forming a so-called scene [2]. The transmission of visible light energy takes place exclusively by means of radiation, whereas in the case of thermal energy, the exchange uses three separate elements. These are convection (also called lifting), thermal diffusion (or thermal conduction) and radiation [13].

Thermal imaging is a method of measuring the intensity of infrared radiation in the range of 3 to 5μm (short-wave thermal imaging) or 8 to 12μm (long-wave thermal imaging). The camera makes contact-free and non-destructive measurements and the results are reliable only when the emissivity of the tested object is provided. The emissivity \( \varepsilon(\lambda, T) \) is defined as the amount of energy emitted in the form of an electromagnetic wave of a given length of \( \lambda \) by a body of a given temperature \( T \). Max plack [2], a German scientist, defined it by the following formula

\[
\varepsilon(\lambda, T) = \frac{c_1}{\lambda^5 \cdot (e^{-c_2 \cdot \lambda T} - 1)}
\]

where, \( \varepsilon \) – emissivity,
\( T \) – temperature,
\( \lambda \) – wavelength,
\( c \) – the speed of light,
This means that the higher the emissivity value, the more energy a given object emits, the better the thermal image is obtained.

The use of thermal imaging in the industry to control technological processes, and more specifically the technical condition used to efficiently prevent or predict emergency situations, has become common over the last years. Thermal imaging tests are carried out on such devices as power networks, main fan station equipment, district heating boilers and heating networks, and belt conveyors [10, 15, 17, 23]. For the measurement to be considered reliable, it must be carried out over a longer period and in compliance with the adopted specification, for example, the conveyor must carry the load of the output.

Thermal imaging is a vital and helpful research method, as it allows for quick, safe, and accurate measurements in any space. It uses long-wave infrared radiation to record the thermal radiation that is emitted by a given object. The measuring device is equipped with various types of detectors using infrared radiation to calculate the temperature of the target. The results in a total temperature distribution against the background of a given object are shown in images where values are represented by colours. Thermal imaging is a tool that can provide multiple solutions in terms of rapid diagnosis of the state of emergency in the mining industry.
3. Description and construction of a thermal imaging camera

Thermal imagers can be used in many industries, including medical, manufacturing or mining. Advances in the technology of manufacturing infrared detectors have provided the increasing sensitivity and resolution of thermal imaging cameras and the development of electronics allowed to mix the mass and power consumption of the camera.

The thermal imaging camera processes infrared radiation, emitted or reflected by the objects, into an electrical signal and then into the image displayed on a monitor. The camera consists of an optical system, infrared radiation detector, electronic amplification, processing, and visualization path. It reacts to the temperature generated by almost every object with a temperature higher than absolute zero, which is the source of infrared radiation, and its intensity depends on the temperature and surface characteristics of the object or body. The detection, recognition and identification range of thermal imaging cameras depend mainly on three parameters: thermal resolution, number of detectors in the matrix and its viewing angle [9]. The camera presented in Figure 1 is equipped with a laser pointer that allows for spot registration of the temperature. The camera automatically finds the hottest and coolest points of the object, which is graphically displayed and provides the temperature in the upper left corner of the screen [14].

![Figure 1. Construction of the camera that was used in the tests; 1 – sunshade, 2 – display, 3 – four-way control button, 4 – switch, 5 – camera mount, 6 – retractable lanyard attachment point, 7 – strap attachment point, 8 – camera lens, 9 – laser pointer, 10 – IR lens, 11 – USB port, 12 – Snapshot button.](image)

4. Testing the belt conveyor’s drive unit

The drive of the tested conveyor belt is built of side walls connected in pairs, forming a shell that sits on the frame. One of them is additionally built on distance beams. The shells are connected by means of screw joints. The flange electric motor is cooled with water. It is connected to a gear via a flexible coupling and attached to the coupling housing flange. The coupling housing has two functions: it covers the coupling and attaches the disc brake to it. The gear shaft is connected to the drive drum by a bolted flange connection. The flange on the drive drum shaft is fixed by a clamping ring. The drive
units are supported on articulated supports arranged on the drive’s frame. Torque from the motor through the coupling and cylindrical-bevel gearbox is transmitted to the drive drum with rubber lining. The drive shell is a structure that can be dismantled and consists of divided walls fixed to a rigid frame. The drum is mounted in the walls of the shell by means of bearings. The whole drive is designed to be mounted on the foundation using foundation bolts or to be anchored in the floor. The drive is adapted to cooperate with the structural channel track. The (disc) brake unit used in the drive is used to stop the conveyor and hold it at a stoppage [7]. Each drive unit consists of the following main components:
- gear,
- coupling housing,
- electric motor,
- disc brake,
- flexible coupling.

Figure 2 presents the structure of the tested belt conveyor's drive unit type PIOMA-1200.

The belt conveyor’s drive unite type PIOMA-1200 of the main output transport unit was tested during the mining shift and two hours after the start-up as it was assumed that this period is long enough for the temperature to stabilize after the launch. The conveyor was loaded with output. The obtained series of images from one conveyor's drive during 60 minutes of operation made it possible to determine the minimum and maximum temperature for the drive unit consisting of the gearbox, motor, and brake system. The construction of the drive, including the drums, were omitted. The tested constructions of the drive system consisted of two drive units. One left (I) and one right (II), the shell of the drive frame, supports and the remaining parts of the drive.

The research team used the thermal imaging camera type Drager UCF 9000 that is approved for use in underground mine conditions. The temperature samples allowed to locate the hottest areas of the drive unit. The following thermograms show the distribution of the recorded temperature for the belt conveyor.
Figure 3. The left gear of the conveyor.

Figure 4. Temperature distribution of the gear.

Figure 5. The left engine of the conveyor.

Figure 6. Temperature distribution of the engine.

Figure 7. The right gear of the conveyor.

Figure 8. Temperature distribution of the gear.

Figure 9. The right engine of the conveyor.

Figure 10. Temperature distribution of the engine.
The results were used to develop temperature characteristics of the drive unit; they are listed in Table 1. The diagrams (Figs. 11 and 12) show temperature values, with red as the maximum registered values and blue as the minimum values.

**Table 1. Temperature samples of the belt conveyor's drive unit type PIOMA-1200.**

| Conveyor’s drive unit | Minimum temperature °C | Maximum temperature °C | Temperature amplitude °C |
|-----------------------|-------------------------|-------------------------|--------------------------|
| gear I                | 53.2                    | 58.0                    | 4.8                      |
| engine I              | 28.3                    | 34.2                    | 5.9                      |
| brake system I        | 25.0                    | 29.0                    | 4.0                      |
| gear II               | 57.1                    | 62.7                    | 5.6                      |
| engine II             | 24.0                    | 28.2                    | 4.2                      |
| brake system II       | 26.0                    | 31.7                    | 5.7                      |

**Figure 11.** Temperature change within 60 minutes for the tested drive unit I type PIOMA-1200.
Twelve measurements were taken within the assumed time interval of 60 minutes. The diagram (Fig. 11 and 12) show small drops and increases in minimum and maximum temperature. No interruptions to the operation of the conveyor due to a temporary stoppage were observed during the test. The average temperature of water for cooling engines and gears was about 21°C. The temperature of water after passing through the cooling system at the discharge to the drainage pipe was on average about 33°C. The temperature of the environment in which the belt conveyor type PIOMA-1200 was operated reached 27°C. Figures 13 and 14 present the thermal state of the drive unit. The pictures were taken with a camera with Thermal Scan function on.

**Figure 13.** Temperature distribution of the engine around the excavation.

**Figure 14.** Temperature distribution of the drive unit.

The list of results for Figures 13 and 14 that illustrate the tested unit of the conveyor in the main output transport unit, can be used as a foundation for measures aimed at finding the solutions to fix the problems that affect the continuity of the mining process.

### 5. Conclusion

The temperature samples were taken with the use of a thermal imaging camera in order to determine the technical condition of the drive unit of the belt conveyor, which is a part of the main output transport unit in the underground hard coal mine. The results measurements helped to diagnose the
thermal condition even without stopping the machine. This type of equipment is designed to immediately display the results.

The key element of the whole test procedure was to determine the values that would show when the temperature exceeds 60°C. The thermal state of the conveyor’s drive unit was presented on the basis of a series of measurements. The developed test results in the form of graphs demonstrate temperature characteristics. They did not indicate any technical changes that could have potentially caused the failure.

The determined characteristics presented in the diagrams combined with the data listed in the table is used to evaluate the thermal condition of individual elements of the belt conveyor's drive unit. Each measurement was taken once. The results do not show any changes in the technical condition of the drive unit. The characteristics of the device determined whether a critical temperature is reached. The results presented in this paper can be a reference point for further tests.

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