Conveyor belt structure and mode of operation in mines

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ABSTRACT

The paper discusses the results of a study carried out to determine the thermal condition of a conveyor power unit using a thermal imaging camera. The tests covered conveyors in the main haulage system carrying coal from a longwall. The measurements were taken with a thermal imaging diagnostic method which measures infrared radiation emitted by an object. This technology provides a means of assessing the imminence and severity of a possible failure or damage. The method is a non-contact measuring technique and offers great advantages in an underground mine. The thermograms were analysed by comparing the temperature distribution. An analysis of the operating time of the conveyors was also carried out and the causes of the thermal condition were determined. The main purpose of the research was to detect changes in thermal state during the operation of a belt conveyor that could indicate failure and permit early maintenance and eliminate the chance of a fire. The article also discusses the construction and principle of operation of a thermal imaging camera. The findings obtained from the research analysis on determining the thermal condition of the conveyor drive unit are a valuable source of information for the mine's maintenance service.

Keywords: Thermal imaging; belt conveyor; diagnostics; underground mining; mechanical failure; preventative maintenance

Introduction

Tremendous progress and capital investment has been made in recent years in the development of coal production equipment for both longwall and room and pillar installations. This progress has inevitably resulted in considerable increase in mine outputs. In many instances, this improvement in efficiency in the production area, has highlighted the inefficiency of outbye belt conveyor systems. As a result of these improvements, the requirements of the mining industry have been reviewed and schemes to suit the demands of increased productivity have been developed. Within these developments, particular attention has been devoted to the standardisation of equipment. Thermal imaging measures an object body whose temperature is higher than zero because it emits thermal radiation. This thermal radiation is the part of the electromagnetic spectrum; its wavelength falls between 760 and 1 mm. This radiation is detected and measured by the thermal imaging device in two different ways—when the thermal detector absorbs infrared radiation completely (of any wavelength) and when the photon detector reacts only to radiation of a specific wavelength. The detector of a thermal imaging camera enables the energy of infrared radiation to be changed into an electrical signal. In the individual signal processing modules, the signal is amplified, converted into digital form and converted into the temperature value of the individual points of the image matrix. This is how a map of the distribution (thermogram) of the temperature of the object under investigation is created. The thermal imaging camera works on the principle of converting infrared radiation that can be emitted or reflected by an object, into an electrical signal and later into an image displayed on a computer monitor. The camera is composed of an optical system, an infrared radiation detector, electronic amplification, processing and a visualization path. Belt conveyors are mechanical, hydraulic or pneumatic means of transport, they operate in continuous or cyclic motion. Their purpose is to transport the excavated material over often considerable distances, with varying conveying speeds, capacities and conveyor belt lines. In underground coal mines, they are the primary form of transport. The drive systems used in mining can exclude or hinder diagnostic measurements. The results which are obtained by means of various measurements can be processed by dedicated software FLIR Tools. Studies on the development of longwall conveyors are presented in works—they are part of the innovative development of machinery and equipment. The popularity of the thermal imaging method to assess the technical condition of belt conveyors in a mine has been increasing . The first experimental studies using thermal imaging cameras were described in works, whose findings and the method developed contributed to minimising failures primarily in the mines of Polish State Mining and Metallurgical Combine (KGHM). Multiple diagnostic methods are recommended for costly machines and process lines. Control testing can prevent the occurrence of fires, which are one of the most dangerous hazards in underground mines. Excavations in closed areas are subject to natural hazards, mainly methane and fire. They can cause serious damage to machinery and equipment, and even pose a threat to human health and life. Based on the research carried out, the main causes of the thermal condition for the drive unit were defined as: belt slip in the drive, problems with optimal cooling of the drive, bearing friction, seizure of the brake system, seizure of the drive drums, and seizure of the pulleys. These causes are mainly generated in the contact zone: improper cooling of the drive unit, the drum coming into contact with the belt, or the pulley coming into contact with the belt. The main objective of this study was to identify the thermal condition of conveyor belt component structures and to analyse the risk of critical temperature increases. The tests were focussed on the drive unit, specifically the engine, the braking system and the gearbox. In order to measure the actual temperature distribution occurring in the main haulage belt conveyors, it was necessary to analyse the operating time of the belt conveyors and determine the cause of any thermal anomaly. The analysis of the working time of the main haulage conveyors was related to one working day in this study. The results are presented in the form of measurement images. They were developed using dedicated software. The obtained characteristics for the thermal state are presented in the form of diagrams. This paper presents a real-life example of a thermal condition survey for a measuring unit using a thermal imaging camera.

Materials and Methods

Due to improvements in modern mining techniques and the associated increase in the rate of advance of mechanised faces, it follows that the distance to the coal face is also increasing. This situation introduces the problem of transporting personnel to their place of work as quickly as possible, to ensure that they arrive in a fit condition and that the maximum time will be available for output during the shift. In relation to the rapid face advance referred to, longer trunk and gate belt conveyors are being installed and consequently, the practice of riding personnel on conveyor belt is increasing. Although the use of belts for man-riding was formerly forbidden by the Mines Inspectorate because of the hazards involved, the practice is now completely legalised as a result of the introduction of the necessary safety equipment. Details of the Codes and Rules of Practice are available in booklet form from the UK's National Coal Board's Production Department. The use of thermal imaging is a very important and useful research method because, as a method for object diagnosis, it allows fast, safe and also accurate measurements in even restrictive space. In a deep mine environment, cameras can be used to work in smoky, dusty and dark environments. The use of the thermal imaging method in the mining industry offers a wide range of research opportunities in view of the heat production that takes place during the operation of all powered equipment. Factors such as ambient temperature, humidity, air velocity, air volume in the excavation and emissivity have a significant influence on the measurement results. Using long-wave infrared radiation in the measurements, thermal radiation is recorded. The camera captures objects, people and high-temperature sources in limited or no visibility conditions. Thermal imaging cameras use energy that increases as the temperature of an object increases, and can be obtained from any object whose temperature is above zero. The measurements result in a total temperature distribution over the background of the object, which can be seen by the colour variation in the measurement image. The advantages of thermal imaging cameras are that they are non-invasive and can locate faults invisible to the naked eye. The test with a thermal imaging camera is based on measuring the temperature from the external surface, where the temperature distribution is non-uniform . In order to obtain the relevant quantities, an average is determined which forms the basis for fault finding as temperatures increase above the normal operating ones. In industry, thermography is used to control technological processes and, more specifically, the thermal state in order to predict and prevent failures. The image taken by the thermal imaging camera reflects the temperature of the device under examination and other surfaces, allowing the technical condition to be assessed. Equipment such as power grids, main fan stations, boilers for district heating and conveyor belts, among others, are examined using thermal imaging. In order to be considered reliable, the measurement must be carried out over a longer period of time and operate to its specification, e.g., the conveyor belt must be loaded with excavated material.

Objective and Scope of the Study

The objective of this study was to identify the thermal condition of an operational belt conveyor drive unit in an underground coal mine. The following tasks were completed:

*tests and measurements on the conveyor drive unit,
*an analysis of operating times of conveyors,
*determination of the causes of the thermal condition for the construction of conveyors,
*an analysis of the results and recommendations.

Analysed Main Haulage Conveyors

The main haulage belt conveyors used in the study transported the excavated coal from the longwall. The longwall mining was carried out conventionally with roof caving. The longwall was equipped with a powered roof support, a double-drum shearer and a scraper conveyor. The length of the longwall is 238 m and the panel length is 480 m. The thickness of the seam is between 2.5 and 3.1 m, with a slope between 23∘ and 25∘. The main haulage system from the longwall transports the excavated material to a 1000 m3 silo located in the mining shaft area. The analysed haulage system consists of six belt conveyors with a total length of 1846 m. The parameters of the analysed main haulage are presented in Table 1 and their location in Figure 1.

Table 1. Technical parameters of the analysed main haulage system.

Number of the Conveyor	Type of the Conveyor	Power (kW)	Belt Width (m)	Belt Length (m)	Performance Maximum (t/h)
PT-1	Intermet-1200	2 × 250	1.2	480	1388
PT-2	Vacat-1400	3 × 315	1.4	420	1512
PT-3	Intermet-1200	2 × 160	1.2	80	1220
PT-4	Pioma-1200	2 × 250	1.2	140	1220
PT-5	Pioma-1200	2 × 250	1.2	260	1134
PT-II	Pioma-1400	2 × 250	1.4	410	1500
PT-I	Bogda-1400	2 × 132	1.4	56	1500

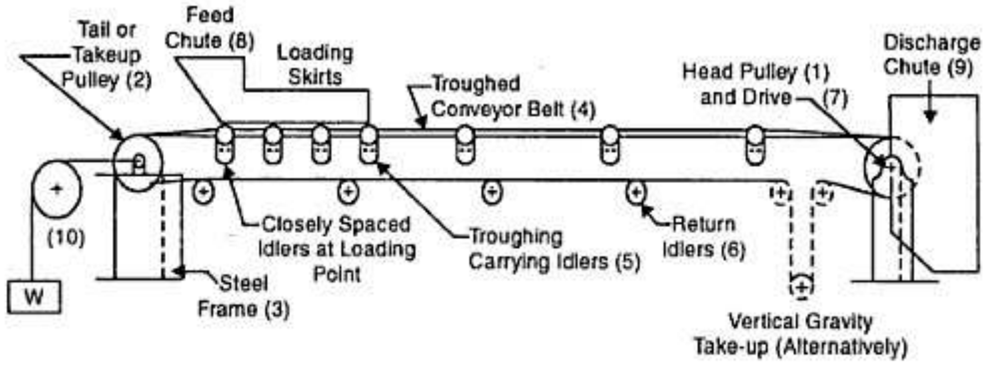

Figure 1. Layout of the conveyors of the main haulage system, (PT—a belt conveyor)

In all mining operations, the main objective is to achieve maximum output in the minimum period. To achieve this ideal, mining should be a continuous operation, but regrettably, is unattainable. The introduction of extensible belt conveying systems has contributed to an improvement in the loading cycle. The conventional method of extending conveyors is by the addition of conveyor sections at the return end and the insertion of an appropriate length of belt. Although this is a relatively simple operation, it is time consuming and adding multiples of belt has its obvious disadvantages. An alternative method is to apply an overlapping conveyor, generally a stage loader. With this system a degree of continuity is attained, but when the overlap is exhausted, the return end must be pulled back prior to adding sections and belt. The preferred system comprises a long skid mounted return end which forms the track for either a Stage Loader or Bridge Conveyor Support Trolley. The trolley is fitted with a horizontal and vertical articulated frame to accomodate deviations in the roadheader or continuous miner operation. The system operates in conjunction with an automatic storage type loop take-up unit. As the 'getting' machine advances, the trolley, The conveyor routes are made of coils supported on lower trestles, which are spaced every 3 m and each has two Ø 133 mm pulleys (Figure 2b), they serve to guide the lower belt in a V arrangement with a constant inclination angle of 10∘ and variable advance (−2∘,0∘, 2∘). The upper band is guided along the triangular supports to form a trough with an angle of 35∘ (Figure 2a). Each of the side pulleys of the top support has an oblique 2∘ lead-out in the belt direction and a belt distance of 1.2 m.

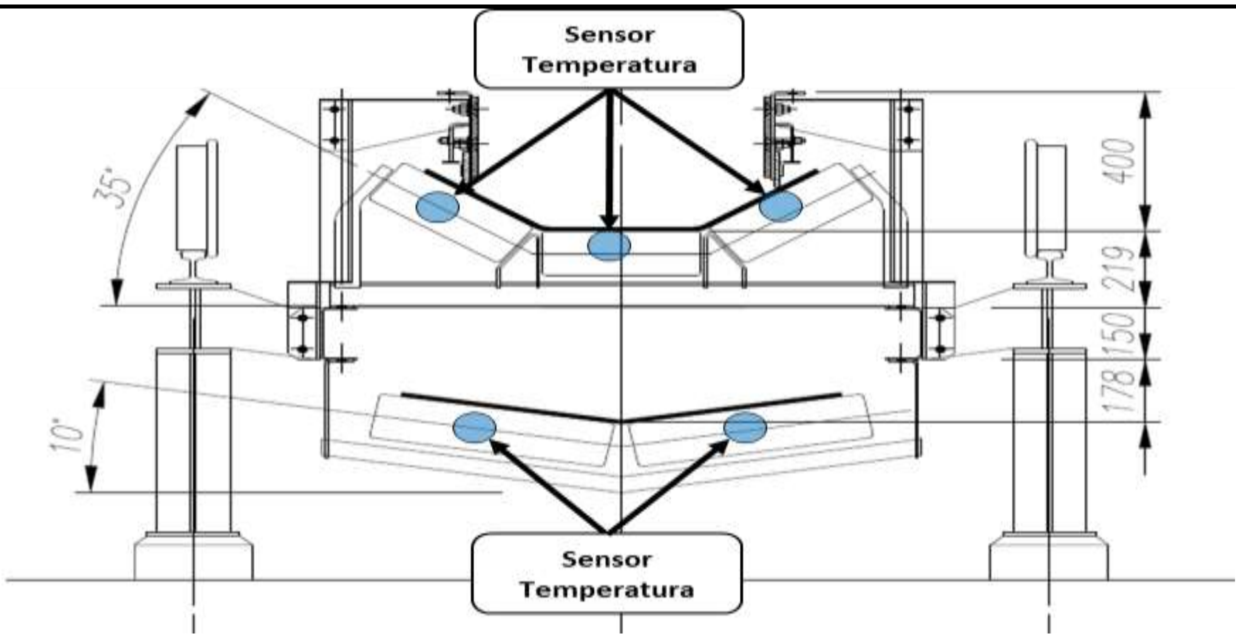

Figure 2. Support structure of the conveyor route: (a) The upper belt forms a trough with an angle of 35 ∘ ; (b) View of the upper and lower belt routing.

Design of the Conveyor Drive Unit

The conveyor drive drums are driven by drive units. The transmission of the take-off torque from the gearbox to the drums is affected by means of couplings. The drive unit is built on a drive drum module. The gearbox is attached to the drive body via an intermediate plate. Drive units consisting of motors and gearboxes require water cooling. Figure 4 shows an example of the construction of the drive unit.

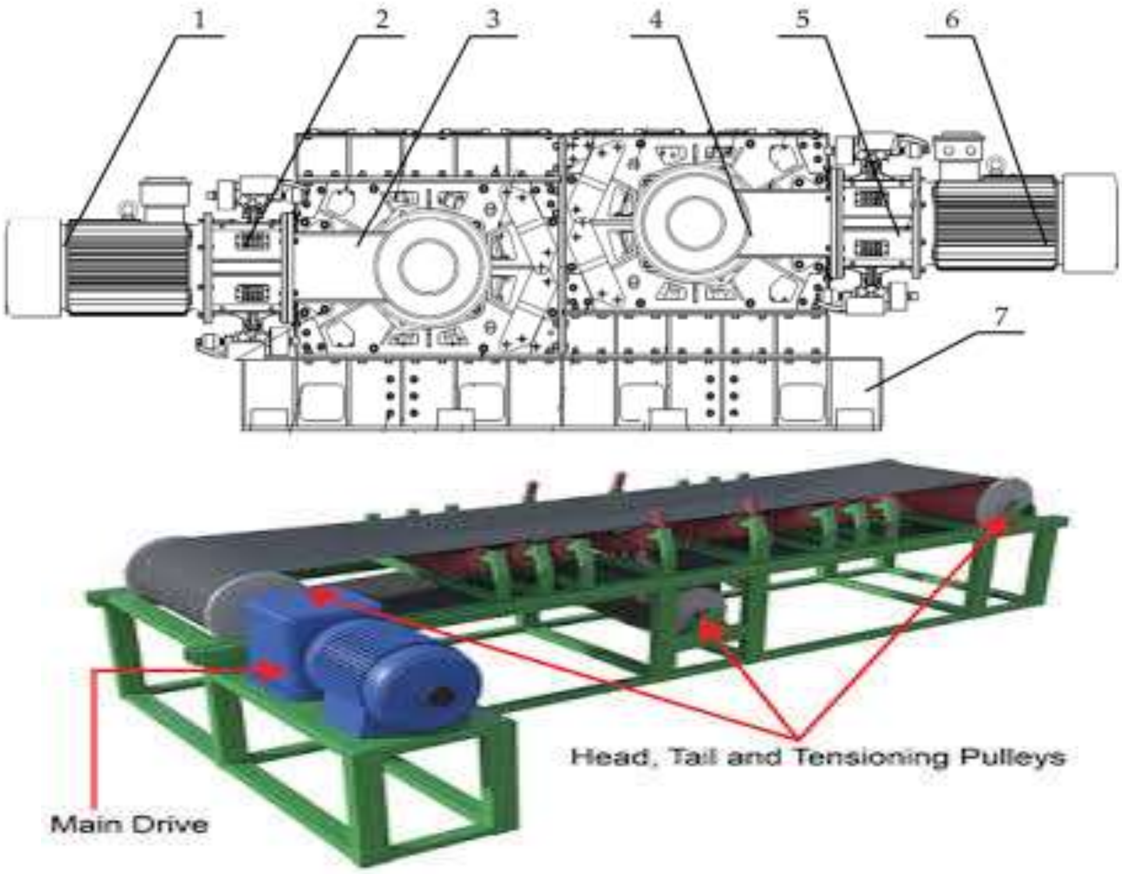

Figure 3. Conveyor drive unit, where; 1—engine, 2—left brake system (I), 3—left gearbox (I), 4—right gearbox (II), 5—right brake system (II), 6—engine, 7—foundat.

Results

It can be quite difficult to carry out measurements using a thermal imaging camera for this purpose in an underground mine. One of the main factors that influence the result is the prevailing dust in the excavation. The correct temperature range for the drive unit is influenced by the length of the route, the variable load, and the size of the drive drums. The main problem during the research was to obtain a suitable measuring distance. Conveyor drive components such as the motor, gearbox and braking system are built into a recess due to the dimensions of the workings. For major conveyor installations, a fixed thermal imaging device could be used and data sent to a central control room for continuous monitoring. Exceeding a threshold temperature, predetermined from field data, could trigger an alarm, for example. Maintenance personnel could then be sent to the unit to investigate the temperature anomaly and conduct preventative maintenance if needed. The following parameters were introduced to minimise measurement interference: emissivity, humidity, ambient temperature, and the distance of the camera from the object. Each of these measurements was additionally determined using a pyrometer type device. It was not possible to place the measuring equipment on a tripod due to the dimensional constraints of the excavation. The measured air temperature at the drive locations varied between 22 and 30 °C. The measurements taken were sequential, with a frequency of 5 min. The entire measurement session for a single test object lasted approximately 60 min, resulting in 12 measurements.

Analysis of the Working Time of the Main Conveyors

The operating time of the main haulage conveyors depends on many factors, including the mine's operating system and planned daily tonnage. The main haulage unit under analysis operates on a five-shift system. This is characterised by four mining shifts and a fifth maintenance shift. A maintenance-related stoppage of the conveyors to perform necessary checks or repairs is made between 5:30 and 8:00 a.m. The working time of the main haulage conveyors was analysed by data collected from the ZEFIR system. This system performs the function of continuous supervision of mine operations, for the operational management, alerting, documentation and analysis of the production process.

Control of the conveyor movement system using a thermal imaging camera

The application of booster drives fall into four main categories;

a) To increase the carrying of an existing conveyor system. This particularly applies in the mining industry where production rates are being improved due to increased mechanisation and the increasing use of equipment to higher technological standards.

b) To increase the length of an existing conveyor system. Again applicable to underground mining situations where the distance between the point of mineral extraction and the point of egress from the mine is continually increasing.

c) To eliminate intermediate transfer points in an existing series of in-line conveyors, by converting some of the existing drives into intermediate booster drives.

d) In any new belt conveyor scheme where site conditions and other considerations such as standardisation of equipment, standardisation of grade of belt, capital costs of equipment, belt and spares, running costs and maintenance costs indicate that a booster system would be the most beneficial arrangement. Details are available showing the varying conditions to which "boosters" are applied, which once again, demonstrates the high degree of standardisation of equipment involved. Testing of the individual drive units of the main haulage conveyors was carried out two hours after start-up of the morning shift. All conveyors tested were loaded with excavated coal material. It was assumed that the temperature value should stabilize after this time from the start up. Obtaining a series of measurement images from a single conveyor drive during sixty minutes of operation allowed us to calculate the minimum and maximum temperatures for the drive unit. The unit consists of the motor, gearbox and brake system. The construction of the drive, including the drums, was omitted from measurements. The tested constructions of the drive system consisted of two drive units, one in the left-hand version (II drive) and one in the right-hand version (I drive). Two thermal imaging cameras—FLIR 60 and Dräger UCF 9000—were used in the study. The measurement series taken on the equipment made it possible to locate the hottest areas within the drive structure.

Discussion

The obtained characteristic curves of heat distribution in the form of thermograms and graphs constitute an evaluation of the thermal condition of the individual elements of the tested driving unit of the main haulage belt conveyor. The measurements made refer to stable (constant) operation. For all tested main haulage conveyors, the highest temperatures were recorded for gearbox II and had a significant effect on the maximum temperature of the entire drive. For the PT-2 conveyor drive unit located in the collective ramp on E/III, the lowest of the maximum temperatures at around 29.9–34.2 ∘C. was recorded. Higher temperatures (50.1–54.6 ∘C) obtained from the measurements were characteristic of the PT-1 conveyor drive located in the belt gallery. In contrast, the same type of conveyor PT-3 achieved temperatures of 42.8–47.6 ∘C. In further measurements, temperatures remained between 47.2 and 52.6 ∘C for the drive unit of the PT-4 conveyor located in the eastern drift III. The presented comparison of temperatures obtained for the conveyor drive unit (Figure 9) shows that the PT-5 conveyor drive has the highest temperatures, remaining at 62.7 ∘C, which means it exceeded the critical value of 60 ∘C. This may indicate intensive use of the conveyor. The analysed measurements for the PT-II conveyor drive were at a level of 48.3–51.0 ∘C, which indicates correct operation. For the PT-I conveyor, temperatures ranging from 38.0 to 43.3 ∘C were recorded. A key element in the overall test procedure is to determine the values at which alarm states associated with temperatures exceeding 60 ∘C can be identified. The determination of these values is based on a statistical analysis of the results obtained for the main substitution tested. A summary of the measurements obtained for the main drive units are shown, with the temperature warning levels marked by a red dashed line.

Conclusions

It is difficult to deal adequately with the subject of standardisation benefits for face to surface equipment in the limited space and time available. To refer to the original comment, the development of coal production equipment has revolutionised the industry. We must, therefore, ensure that the outbye systems are capable of accommodating the resultant increased output. In developing these systems, management must be increasingly aware of the need, wherever possible, to give serious consideration to "Conveyor Standardisation — an Aid to Mine Planning". Thermal imaging is characterised by a non-invasive research method. Conducting this type of research is quite difficult in an underground mine. The use of stationary thermal condition monitoring on the main haulage can be quite difficult due to the dimensions of the workings. The application of the thermal imaging method to the monitoring of industrial rocesses, including underground mining, has made it possible to assess, based on the test results obtained, the thermal condition of the belt conveyor drive units. Thermal imaging technology makes it possible to solve many diagnostic problems easily and inexpensively by using a thermal imaging camera. The thermograms obtained depict the surface of the object under investigation, i.e., the areas with the highest or lowest temperature. Based on the research and analysis carried out, the main causes of the thermal condition of the conveyor drive unit were defined. These are the location and method of installation in the excavation. The tested units were located in a hollow of the excavation,

which for ventilation reasons affects the ventilation and adequate heat discharge. In order to address these issues, the design of underground workings must consider those remarks which can significantly improve the operating conditions of the machine and the quality of work for people. The relatively early identification of these causes can have a direct impact on the operational reliability of the conveyor drive unit. The relatively early detection of a thermal condition based on temperature measurements with a thermal imaging camera contributes to minimising the probability of a fire. The thermal imaging inspections carried out allowed the thermal condition of the power unit to be determined and identified the location of intense heat generation, which may indicate the beginnings of a fault condition. The thermal imaging measurements made it possible to diagnose the thermal condition of the drive unit without stopping the belt conveyor operation. The thermal state characteristics obtained for the drive unit under test determined whether a critical temperature occurs. A key element of the entire test procedure was to determine the values at which emergency states associated with temperature exceedances above 60 $^\circ$C could be visualised.

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