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Detection of worn cutting bits of longwall shearer

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Abstract

The method for detection of worn cutting drum bits in a longwall shearer using a thermovision camera is discussed in the paper. The results from testing the longwall shearer work are presented and a concept of temperature analyzer software is suggested. The performed studies allowed correlating the cutting drum bits temperature with their sharpness, which was the essence of the described bits condition monitoring method.

Keywords: thermovision, longwall shearer, diagnostics, detection, mining, image processing.

Detekcja zużytych noży tnących kombajnu ścianowego

Streszczenie

W pracy skupiono się na zaprezentowaniu wyników prac specjalistów z Instytutu Techniki Górniczej Komag, uzyskanych podczas realizowania projektu badawczo-rozwojowego INERG. Jednym z elementów projektu jest opracowanie automatycznego systemu do diagnostyki stanu elementów maszyny jaką jest górniczy kombajn ścianowy z wykorzystaniem termografii. W artykule przedstawiono etap detekcji zużytych noży tnących organu urabiającego kombajnu ścianowego, opisano zagrożenia wiążące się z ich zużyciem oraz zalety wynikające z wcześniejszego wykrywania stopnia ich zużycia. Zobrazowane zostały wyniki badań pracy kombajnu ścianowego oraz zaproponowana została koncepcja programowego analizatora temperatury noży tnących. Przeprowadzone badania pozwoliły na skorelowanie temperatury noży podczas urabiania ze stopniem ich ostrości, co w przyszłości umożliwi skuteczne diagnozowanie stanu noży tnących. Omówione również zostały kryteria jakie należy spełnić w celu zastosowania kamery termowizyjnej w podziemnych wyrobiskach górniczych oraz przykłady dotychczasowych zastosowań termowizji spotykanych w górnictwie węgla kamiennego.

Słowa kluczowe: termowizja, kombajn ścianowy diagnostyka, detekcja górnictwo, przetwarzanie obrazów.

1. Introduction

From all possible applications of thermography to various fields of technology, the closest to the mining industry is its use in power industry [3], especially to control switchgears and transformers – Fig 1. Transformers have to be inspected both during their typical operation and at interoperation, manufacture and repair stages. When a transformer is in operation, the external surface of its tank and lid (Fig. 1), its accessories, insulators and terminals are checked by thermovision cameras. The main purpose of tank and lid inspection is to detect anomalies in the temperature distribution on their surface.

In addition to visual review of the state of the electro-power equipment, the thermovision method is used for inspecting the rollers of belt conveyors in hard coal mines (Fig. 2). Such inspections are very important to the safety of working people. Size roller bearing causes the roller stop and the belt moving on the roller surface causes its warming up to a very high temperature. When the belt conveyor is stopped, the heat accumulated in the roller is transmitted to the belt through the adhesion point, and the belt can ignite, causing fire.

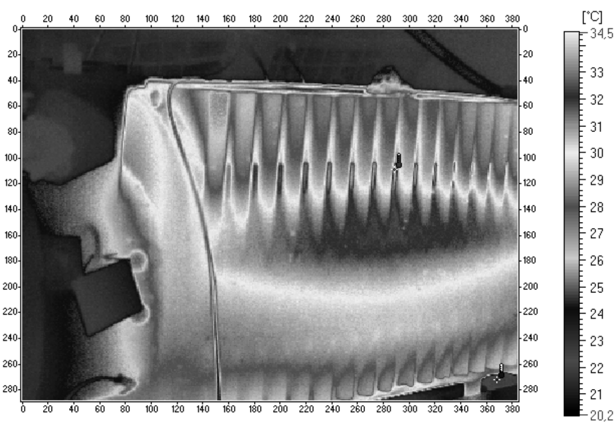

Fig. 1. The thermogram of a mine flameproof transformer station [4]
Rys. 1. Termogram kopalnianej ognioszczelnej stacji transformatorowej [4]

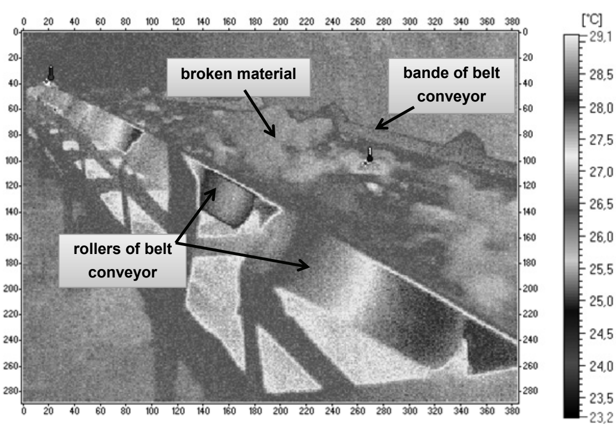

Fig. 2. The thermogram of a belt conveyor, transporting run-of-mine [4]
Rys. 2. Termogram przenośnika taśmowego transportującego urobek [4]

Sized roller bearings of a belt conveyor emit much more heat than efficient bearings. Constant thermal monitoring prevents the situation, when the roller has to be stopped, because of bearings damage.

Two above applications are the main examples of using thermography in the underground mining industry. Thermovision cameras are also used in monitoring of mine waste dump, which are on the surface of underground mining plants. Mine waste dumps are the most harmful objects for an environment. They contain high amount of coal and thus they are susceptible to self-ignition [2]. Risk of coal self-ignition is high, so mine waste dumps have negative impact on the environment and reduce its usability for buildings development. That is why precise determination of thermal condition of each mine waste dump as well as imaging spatial geometry of its hidden fires is necessary to start any management or recultivation project. Thermovision survey of interesting objects from the air (Fig. 3) is carried out to select areas of mine waste dumps for interior temperature measurements.

Specialists from the KOMAG Institute of Mining Technology, based on literature and main maintenance personnel knowledge, decided to carry out a thermal research of the longwall shearer machine.

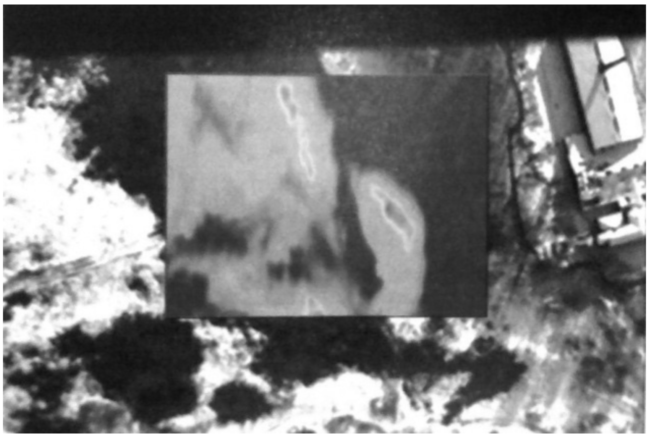

Fig. 3. An example of thermovision measurements taken from the air [2]
Rys. 3. Przykład termowizyjnego pomiaru lotniczego [2]

2. Tests and analysis of a longwall shearer operation

The tests were carried out in hazardous atmosphere, threatened by methane or/and coal dust explosion. According to the directives of the European Parliament and of the Council on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres (23 of March 1994), on the approximation of the laws of the Member States relating to electromagnetic compatibility (of 15 December 2004) and on machinery (of 17 May 2006), the camera should be extremely safe for the environment. There were two methods for using such a thermovision camera. The first method assumed protection of a camera by intrinsically safe casing. However, it was too expensive and it would take too much time. The second method consisted in putting the thermovision camera in an explosion-proof case and it turned out to be the best solution. The concept of that kind of a camera, which led to constructing a prototype, was developed in the KOMAG Institute of Mining Technology, within INERG research project (Fig. 4). This project is co-financed by the National Centre for Research and Development in cooperation with manufacturers from mining and thermographic industries.

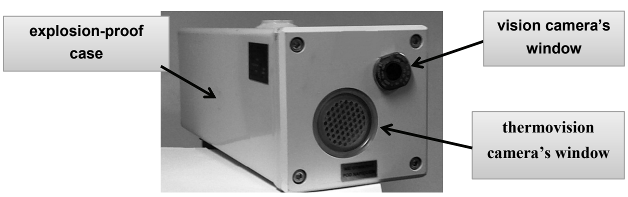

Fig. 4. The prototype of a thermovision camera in explosion-proof case [10]
Rys. 4. Prototyp kamery termowizyjnej w wykonaniu przeciwwybuchowym [10]

The basic parameters of the thermovision camera are listed in Table 1. Putting the camera in the explosion-proof case increased its weight from 1.5 kg to 17 kg. Fortunately, this camera was designed for stand tests, not for mobile use.

Tab. 1. Basic parameters of the used thermovision camera [10]
Tab. 1. Podstawowe parametry zastosowanej kamery termowizyjnej [10]

detector	FPA microbolometers 384x288 pixels
thermal image quality	384x288 or 320x240 pixels
field of view	30° x 23°
measurement's minimal distance	0.15m
image frequency	30/60HZ
thermal range NETD	≤0.08°C for 30°C
spatial resolution	1.4mrad
spectral range	8 - 14µm

The thermovision camera was attached to a canopy, in the second field of 40th powered roof support. The operator's stand was located in the maingate, 30 meters from the camera. The purpose of the tests was recording the thermographic movie during operation of the longwall shearer, and then make its analysis, to assess the monitoring effectiveness. A sample thermogram of the operating longwall shearer, extracted from the movie is presented in Fig. 5. The places of increased temperature can be explicitly determined. These are the cutting drum bits and gears installed in a longwall shearer arm. The bits are responsible both for cutting effectiveness and working safety. The bit that is no longer sharp enough is getting hotter and hit the solid coal instead of cut, causing sparks. Such a situation is very dangerous and can lead to methane ignition. From the tests it follows that there are two criteria for assessment of loss of bit sharpness: the temperature – rise of temperature means loss of bit sharpness, the mechanical deformation – bit deformation causes loss of its sharpness. Only the second case can be observed visually by miners, so we decided to provide them with a thermovision instrument whose task was to detect those bits which are not sharp enough.

The information recorded by the thermovision camera was verified after each test. As it appeared, all bits of significantly higher temperature that the surrounding environment were damaged (e.g. broken). Specialists from the KOMAG developed a concept of an automatic cutting drum bits temperature analyzer. This software is a part of the expert system, aiming at analysis of images sequence and, in a consequence, generation of information about the risk of bits damage. In this way, the servicing staff will be able to plan their replacement in advance, without unwanted stopping of the longwall shearer.

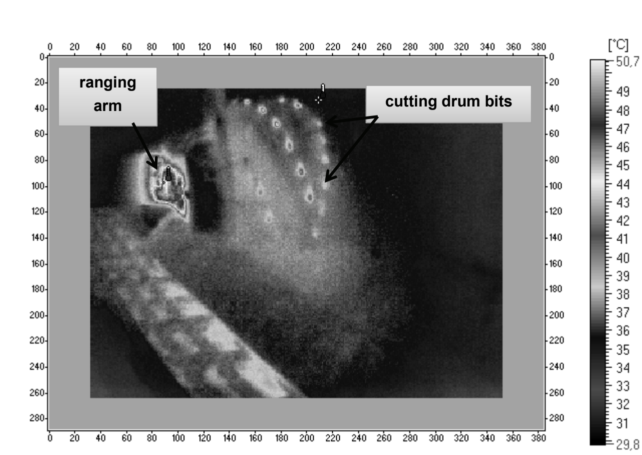

Fig. 5. The thermogram of an operating longwall shearer [10]
Rys. 5. Termogram pracującego kombajnu ścianowego [10]

3. The concept of automatic cutting drum bits temperature analyzer software

The software library delivered by the manufacturer of the VIGOcam V50 camera enables recording the measurement in the form of a thermovision image and a matrix of temperature associated with this image.

The analysis of the problem of designing the temperature of a cutting drum bits analyzer allows making presumption that it is impossible to base only on the matrix of temperature data, because it is difficult to adjust to conditions in which these data were obtained. It would force development of adjustment mechanisms of thresholds in a bits detection algorithm, depending on the temperature of bits and their surroundings. It is more convenient to analyze the image and determine the image areas where probably the bits are, correlate these information with the temperature data, and finally determine the average and maximum temperature of bits.

The literature shows that the processing of images, leading to the assumed results, cannot be limited to proper filtration of the images only [1, 6, 7]. It is required to use complex morphological operations, combined with advanced edge detection methods, and low level operations, related to the analysis of each image pixel position [5, 7, 8, 9].

It was decided that detection of objects on the image would be based on the edge detection method. After testing different edge detection methods, the best results were obtained using the Sobel method. The selection criterion was simplicity of adaptation of the results from the edge detection method to further processing steps. A large number of simulations show that in order to properly determine the thresholds for the Sobel edge detection method, it is convenient to use it on the image with equalized histogram, and then use it again on the primary grayscale image with known thresholds. The next steps of the cutting drum bits extraction algorithm are related to low-level processing, noise filtering, creating, completing and closing the areas on the image, as well as running the decision-making processes, which can classify the image as the desired one or not.

The algorithm performs the correct detection of bits location on the thermal image if there is a noticeable difference of its brightness (determined by thresholds) in comparison to the brightness of the local background. An example of the algorithm result is presented in Fig. 6 and Table 1.

Fig. 6. The visualization of the longwall shearer cutting drum bits temperature detection results [10]

Rys. 6. Wizualizacja wyniku działania algorytmu detekcji noży tnących organu urabiającego kombajnu ścianowego na podstawie uzyskanego obrazu termowizyjnego [10]

The application detected 6 bits (Fig. 6). To run the algorithm, we need to specify what is the temperature limit. The limit temperature means that all bits with the detected temperature over that value are not sharp enough. For the example from Fig. 6 we determined the temperature limit to 40°C ±5%. Each bit whose temperature rose over the determined limit was detected (Fig. 6).

The first version of the algorithm was running as a batch script, i.e. a properly parameterized program was started from the command line, the input image and the temperature matrix were loaded, and then the program gave the result. Considering the necessity of using the complex digital image processings, it was decided that at the stage of the designing and testing of the algorithm, the software had a form of script running in the GNU Octave environment. This environment has internal built-in functions, which simplifies image processing operations, improves debugging and is platform independent, i.e. can be run on computers with MS Windows, Linux and MacOs operating systems.

Tab. 2. The longwall shearer cutting drum bits temperature detection numerical results [10]

Tab. 2. Wynik działania algorytmu detekcji noży tnących organu urabiającego kombajnu ścianowego na podstawie uzyskanego obrazu termowizyjnego [10]

Zone number	Localization		Number of pixels	Max. temp.	Average temp.
	Y	X			
	pixel	pixel	pixel	°C	°C
1	29	198	71	47.25	39.16
2	37	211	80	45.19	39.07
3	53	223	35	39.39	38.42
4	72	233	59	41.18	38.57
5	84	244	34	39.36	38.13
6	114	209	25	39.64	38.76

Due to the necessity of running the software both in 32-bit and 64-bit systems, it was decided to use GNU_Octave 3.6.1 version. However, GNU Octave environment has some disadvantages:

- processing time of a single image is too long;
- GNU Octave, as an open software, does not allow for protection of the source code.

To solve the second problem, the additional application in C++ language, enabling to encrypt, decrypt, and run the GNU Octave script, was developed. In order to ensure continuous operation, it was decided to write the software in a form possible for compilation, to integrate it with properly created database as well as to ensure the proper use of the subroutine batch. The integration of the batch image analysis script, database communication and thermovision camera control procedures, was done based on the C++ Builder language. It was necessary to use additional libraries for the camera control and image processing.

The software interface is composed of the three main panels (Fig. 7):

- menu panel;
- primary data panel;
- secondary data panel.

After setting the time interval on the primary data panel, data records from the database will be displayed. Then the required record can be selected and depending on the options set, interesting details of the record can be displayed.

The software tests were carried out in the WindowsXP 32-bit SP3 and Windows7 64-bit operating systems.

4. Summary

The use of a thermovision camera to detect damage of a longwall shearer cutting drum bits increases work safety by reducing the risk of methane or coal dust explosion. Higher effectiveness of cutting is also ensured when the operator is sure that the used bits are still sharp. The performed research allows correlating the bits temperature during cutting with their sharpness and due to this the assumption enabling diagnosis of bits condition by determining their temperature during cutting is met. Detection of blunt bits is helpful to the operators of longwall shearers when it is regular, automatic and takes place at regular intervals, without involving the operator. The paper presents the results of the achievements so far in this field that will lead to building a fully self-decisive thermovision diagnostics system.

The publication was realized within the research project INERG co-funded by the National Centre for Research and Development and it presents the project results.

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