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AUTOMATIC ANALYSIS OF THERMOGRAMS AS A MEANS FOR ESTIMATING TECHNICAL OF A GEAR SYSTEM

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Summary

All objects whose temperature is above absolute zero emit infrared radiation in the wavelength range of 740 nm to 1 mm. This range is between radio waves and visible light. This phenomenon related to thermal radiation is used in thermal imaging methods to measure values and distribution of temperatures on an inspected object.

Thermal imaging method was also used to inspect a two-stage gear system from a power transmission system of a belt conveyor located in an underground mine. Performing repairs in favorable time or preparing for failures contributes to the shortening of standstill periods and therefore to the minimizing of financial losses caused by purchasing replacement parts and unintended emergency stops.

Processing of thermograms was done with the use of ThermoVision Processing software, which was designed at Machinery Systems Division, Wroclaw University of Technology, in particular for thermal imaging diagnostics of gear systems. The software automatically identifies gear-wheels and divides the gear system into predefined areas – Ar01 to Ar10. It allows for processing single files and whole folders.

The inspection allowed to create object characteristics and specify its temperatures during steady work, which will serve as point of reference when the inspection is repeated at intervals of approximately several months. As a result, significant changes of the gear's condition will become detectable, by calculating the difference between average temperatures for each area at two measurements. Temperature measurements are possible not only on the gear system but also on the motor shaft and the drive drum shaft. In the future, creating an application that would enable processing images of those parts will allow for multidimensional analysis of belt conveyor power transmission systems.

Keywords: thermal imaging, diagnostics, failure detection, gear system, belt conveyor, infrared camera

AUTOMATYCZNA ANALIZA OBRAZÓW TERMOWIZYJNYCH DO OCENY STANU TECHNICZNEGO PRZEKŁADNI ZĘBATEJ

Streszczenie

Wszystkie obiekty o temperaturze większej od zera bezwzględnego emitują promieniowanie podczerwone o długości fal w zakresie od 740 nm do 1 mm. Zakres ten zawiera się pomiędzy falami radiowymi a światłem widzialnym. Zjawisko związane z promieniowaniem cieplnym wykorzystuje się w metodach termowizyjnych do pomiaru wartości i rozkładu temperatur na badanym obiekcie.

Metodą termowizyjną zbadano dwustopniową przekładnię zębatą z układu napędowego przenośnika taśmowego znajdującego się w kopalni podziemnej. Wykonywanie naprawy w odpowiednim czasie lub przygotowanie się do awarii przyczynia się do skrócenia czasu przestojów, a tym samym zminimalizowania kosztów związanych z zakupem nowych części i niezamierzonymi przerwami w pracy.

Do przetworzenia termogramów z badań posłużono się programem ThermoVision Processing, który został opracowywany w Zakładzie Systemów Maszynowych Politechniki Wrocławskiej specjalnie na potrzeby diagnostyki termowizyjnej przekładni. Oprogramowanie automatycznie identyfikuje koła zębate oraz dzieli przekładnię na wcześniej zdefiniowane obszary - od Ar01 do Ar10. Możliwe jest przetwarzanie za jego pomocą zarówno pojedynczych plików jak i całych katalogów.

Badania umożliwiły stworzenie charakterystyki obiektu wraz z wyszczególnieniem temperatur w trakcie jego ustabilizowanej pracy co stanowić będzie punkt odniesienia, gdy pomiary zostaną powtórzone w odstępie najlepiej kilkumiesięcznym. Możliwe będzie wówczas określenie istotnych zmian stanu poprzez obliczenie różnicy średnich temperatur w każdym obszarze dla dwóch pomiarów. Oprócz przekładni zębatej możliwe jest wykonanie pomiarów temperatury na wale silnika i wale bębna napędowego. Stworzenie aplikacji do przetwarzania obrazów pochodzących z tych podzespołów pozwoli w przyszłości na wielowymiarową analizę stanu układów napędowych przenośnika.

Słowa kluczowe: termografia, diagnostyka, wykrywanie uszkodzeń, przekładnia, przenośnik taśmowy, kamera termowizyjna

1. INTRODUCTION

All objects whose temperature is above absolute zero emit infrared radiation in the wavelength range of 740 nm to 1 mm. This range is between radio waves and visible light. This phenomenon related to thermal radiation is used in thermal imaging methods to measure values and distribution of temperatures on an inspected object [3].

Thermal imaging diagnostics consists in non-invasive detection of changes in the machine's structure, based on the analysis of thermal signal. Increased emission of heat during the machine's operation may result from increased load or from damage that occurred during its operation [4]. Temperature measurement is performed indirectly, based on infrared radiation emitted by the inspected object.

Thermal imaging diagnostics has recently become a popular method for performing non-invasive damage detection. It allows not only to detect unwanted changes, but also to monitor machines or devices that operate in variable conditions.

Using thermal imaging diagnostics to estimate technical condition of machine systems in mining plants is also possible [7-12]. Performing repairs in favorable time or preparing for failures contributes to the shortening of standstill periods and therefore to the minimizing of financial losses caused by purchasing replacement parts and downtime. Thermographic data can be also used in another methods (data fusion) [13].

Thermographic tests can be used in different types of electrical machines in view of high resolution and accuracy of measurements [16, 17].

2. THE INSPECTED OBJECT

Thermal imaging method was also used to inspect a two-stage gear system from a power transmission system of a belt conveyor operated in an underground mine (Fig 4). The transmission system consists of an electric motor powering the transmission through elastic or hydrokinetic coupling (Fig. 1). The coupling reduces rotational speed and at the same time increases torque, which is then transferred to the drive drum.

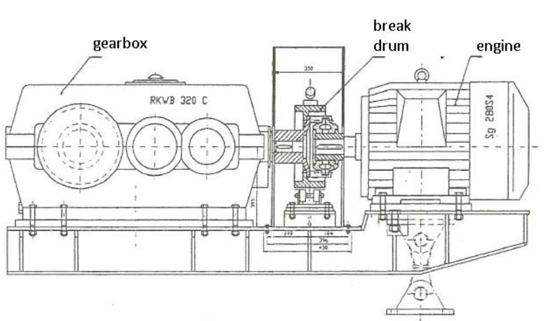

Fig. 1. A scheme of belt conveyor's power transmission system [1]

Damage detected during transmission system's operation may be related to bearings, teeth engagement areas or high-speed shaft. In case of bearing diagnostics, their abnormal functioning might be caused by improper lubrication, which will probably lead to their increased wear and ultimate failure. Teeth engagement failure may be caused by faulty construction, damaged bearings or by lowered fatigue strength. In case of a high-speed shaft, its malfunctioning takes the form of warping or runout [1].

The main advantage of using infrared camera for gear systems diagnostics is high resolution of the obtained results and lack of contact with the casing, unlike in case of standard temperature sensors.

3. MEASURING APPARATUS

Infrared camera records infrared radiation using detector's optical elements, which send the signal to the sensor's electronic circuitry, where it is eventually processed into image. It is then visible on LCD and allows for temperature readings to be taken in any fragment of the image. Thermograms shown in this article have been taken with FLIR T640 infrared camera, whose infrared detector's resolution is 640x480. The detector has therefore 307,200 pixels and images taken with it correspond to simultaneous work of 307,200 pyrometers, which allows to take temperature readings from each pixel. FLIR "T" series is adjusted to operating in industrial environment and allows for temperature measurements in the range between -40˚C and +2,000˚C [5]. The camera also offers visual field of 45˚ x 34˚, while maximum field for modern infrared cameras is 50˚ [6].

Fig. 2. Infrared camera series T600 [5]

4. MEASUREMENTS

Before the images could be taken, the camera's parameters had to be set in relation to emissivity, reflected temperature compensation, distance between the camera and the object and atmospheric conditions. This step was aimed at minimizing noise that accompanies measurements. In case of the inspected object, its emissivity was set to 0.97, while its reflected temperature was 20˚C. Ambient temperature around the test stand was 30˚C with air relative humidity at 65%. The camera was installed on a tripod, 3 meters from the inspected object. The inspection was performed for 94.5 minutes, with images taken at 30 seconds frequency.

Parameter values may be determined automatically in order to create a system ready to perform continuous thermal imaging diagnostics. A scheme of such system is shown in Fig. 3.

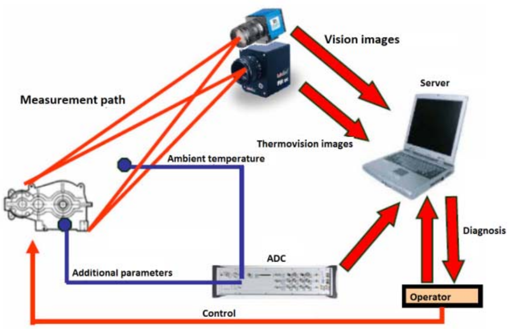

Fig. 3. Scheme of continuous thermal imaging diagnostics system [2]

Metal bodies reach higher emissivity after heating than metalloids. Emissivity of metalloids, on the other hand decreases as a result of temperature rise. Emissivity of individual objects is set within the range of 0.1 to 0.95; for a perfectly black body emissivity is 1. In case of polished surfaces emissivity is below 0.1. Objects reflect the radiation emitted by bodies in the neighborhood, which is why in such cases only reflected radiation measurement is possible. The more mirror-like the surface is, the more radiation is reflected. Another important factor is the body's ability to pass radiation through its own structure, depending on its construction.

Apart from external factors, the object's own parameters had to be considered. These were inter alia geometry, technological factors, operating factors and condition change resulting from normal operation.

Fig. 4. Digital photograph of the inspected gear system

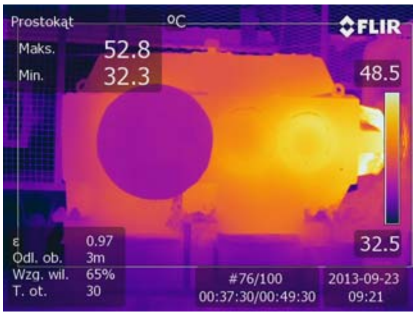

Fig. 5. Thermal image of the inspected gear system

5. Thermal vision application

Typical software requires an operator to manually put a grid on the thermograms (Fig. 6). The grid may be then copied to a series of images. A problem occurs, however, when the camera changes its position slightly during measurements. In such case the moment when the images started to be taken with displaced camera must be found. Also, the set of images must be split into at least two series, which entails repeated identification of each element in the gear system. Another difficulty is posed in case when large number of gear systems is inspected and quick processing of images is needed. This stands in opposition to the idea of continuous and automatic diagnostics, in which case the operator's activity should be possibly limited.

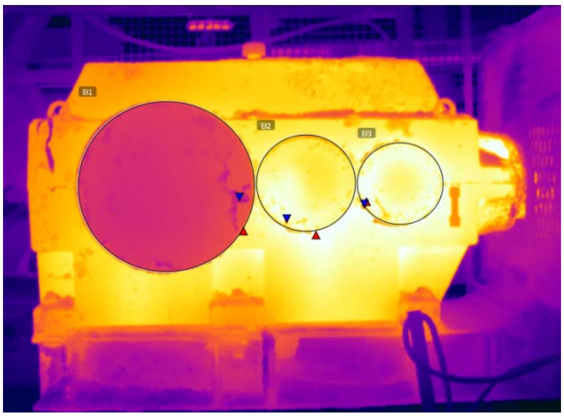

Fig. 6. Manually marked gears in the gear system

ThermoVision Processing software was designed at Machine Systems Division, Wroclaw University of Technology, in particular for thermal imaging diagnostics of gear systems Fig. 7). The software automatically identifies gear-wheels (Fig. 8) and divides the gear system into predefined areas – Ar01 to Ar10 (Fig. 9). It allows for processing single files and whole folders. Figure 10 shows images taken at the end and at the beginning of the measurements in order to present the difference in temperature distribution on the gear system. Thermographic image segmentation method has been used and described in other articles [14, 15].

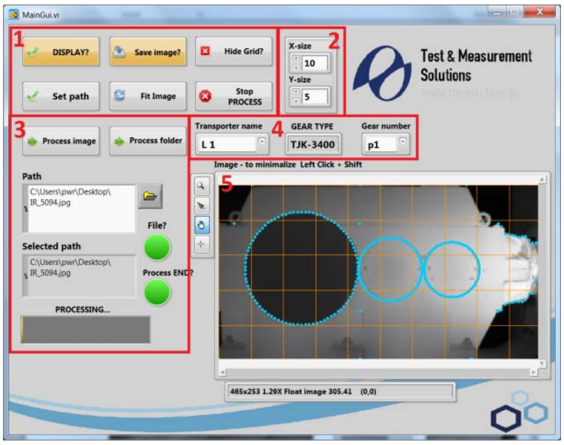

Fig. 7. Application window of ThermoVision Processing software

Application window is built of function buttons (1). These allow to adjust the application to user needs, i.e. to confirm a selected path, save file with results, preview an image, mark a grid for segmentation, adjust vision and stop processing. Defining grid size and segmentation is also possible (2). The software moreover has dialog box to select conveyor and gear system type (4), dialog box to select file path or input data catalog (3) and a box displaying currently processed image (5).

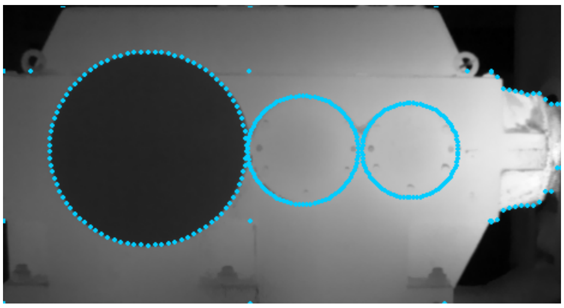
Fig. 8. Automatic identification of gears in TermoVision Processing application

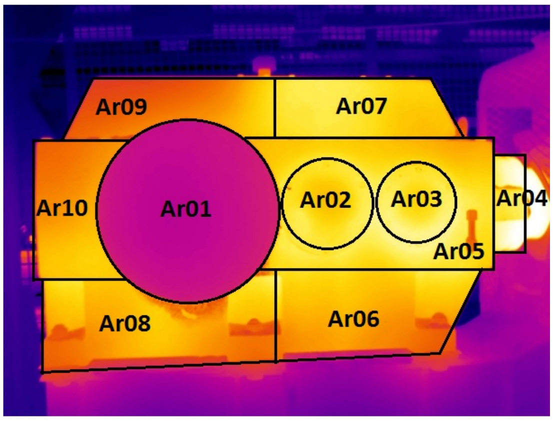

Fig. 9. Division of gear system into areas Ar

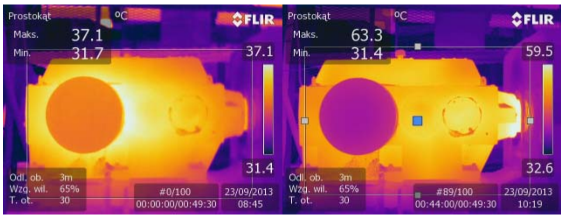

Fig. 10. Thermograms taken at the beginning (on the left) and at the end (on the right) of the measurement

Image segmentation allows to obtain temperatures for places where mesh of the grid is created. Thicker mesh allows to obtain temperature distribution in higher resolution. Temperature values from meshes are recorded in a text file, which allows for further analyses.

The results recorded in a text file, obtained from image segmentation with mesh size 150x80, were exported to METLAB environment. They served to create a three-dimensional graph of the gear system's temperature distribution for the first and the last image taken during measurements (Fig. 12).

The program also allows for generating a second text file with average temperatures for areas Ar. Fig. 11 shows change of average temperatures during the gear system's operation for each gear wheel.

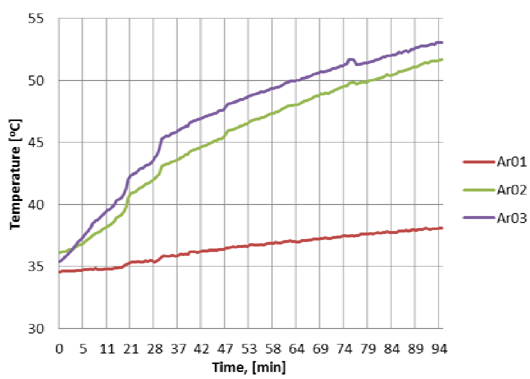

Fig. 11. Average temperature change for gear wheels (areas Ar01, Ar02, Ar03)

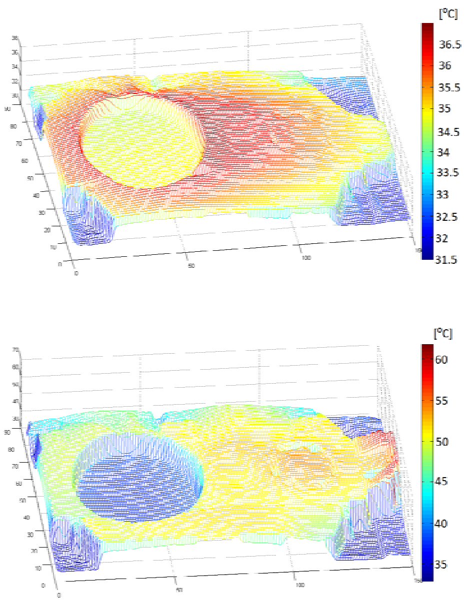

Fig. 12. Temperature distribution on the gear system at the beginning (up) and at the end (down) of the measurement

6. CONCLUSIONS

Thermal imaging diagnostics allows to perform non-invasive inspection of machine systems which work in changing operating conditions. Measurement results are recorded in real time, with frequency set by operator, so that their further processing is possible. Such method of measurement can be used to detect damage of a single element before failure of the complete system occurs. Owing to early damage identification, rational planning of repairs of particular elements is made possible, thus minimizing costs that occur due to failure and the need to purchase new parts.

ThermoVision Processing software designed at Machinery Systems Division, Wroclaw University of Technology enables its users to analyze thermograms taken during the measurement. It significantly shortens image processing time by automatically adjusting image size to the program window, dividing the gear system into areas and detecting gear wheels, as well as marking segmentation grid of operator-defined thickness, recording temperatures from the grid's nodes and average temperatures from Ar areas. The software generates output text files, which can be used for further analyses. Either single file or complete folder can be processed. By analyzing the images it is possible to detect changes in a single transmission (if measurements performed, for example after a few months) or comparisons between some of them. The user selects for further analysis whether the temperature is to be the maximum, minimum or average of the areas

The measurements performed as part of the experiment do not allow to detect significant changes in the gear system's technical condition. They allowed, however, to create object characteristics and specify its temperatures during steady work, which will serve as point of reference when the inspection is repeated at intervals of approximately several months. As a result, significant changes of the gear's condition will become detectable, by calculating the difference between average temperatures for each area at two measurements. Significant differences might then imply the conveyor's failure-prone condition, while no such differences will imply the gear system's proper operation. Such measurements should be performed in very similar atmospheric conditions in the mine.

The highest average gear wheel temperatures were recorded for the element located in area Ar03. Average temperature function curves are very similar for areas Ar02 and Ar03, which might mean they are significantly loaded or in poor technical condition.

Apart from thermal imaging diagnostics of the gear system, temperature measurements are possible also on the motor shaft and the drive drum shaft. In the future, creating an application that would enable processing images of those parts will allow for multidimensional analysis of belt conveyor power transmission systems.

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