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Practical applications of thermovision measurements on electric machines

Abstract. *In the present paper we deal with application of thermovision systems in diagnostics on selected parts in electric machines, measurement conditions as well as an analysis of measured results.*

Streszczenie. *W artykule zaprezentowano zastosowanie systemów termowizyjnych do diagnostyki wybranych części maszyn elektrycznych. Przedstawiono , warunki wykonywania pomiarów oraz analizę wyników pomiarów.* ***Praktyczne zastosowanie termowizji do badania maszyn elektrycznych***

Keywords: thermovision system, infrared examination methods, thermogram, electric machine.
Słowa kluczowe: termowizja, metody badania w podczerwieni, termogram, maszyna elektryczna.

Introduction

Industry is currently based on the widespread use of electrical machinery and equipment without which production would be unthinkable. Requirements for the production growth and in particular on its quality, however, are closely related to reliability requirements of manufacturing equipment. Early diagnostics and monitoring of the technical condition of the equipment also result in an early detection of a malfunction (early stage malfunctions) which could cause relatively large damage during operation (e.g. early replacement of the bearing prevents it from burning or prevents the accident of the electric motor, the ventilator and the like). Of the whole range of fault diagnostics of electrical machinery and equipment, the most advantageous is the method without necessity to dismantle the machine.

Technical diagnostics can be defined as a process for detecting the current technical state of objects based on objective evaluation of the symptoms detected by means of the measuring technique.

One of the modern methods of investigation that can be used, for example, in developing of an experimental component in research and development work, is the application of industrial thermovision, thus the method of mapping of temperature fields. For sensing of two - dimensional patterns are currently the most preferred decomposition infrared measuring systems operating in real time, these systems are attractive especially when watching fast dynamic phenomena.

Theoretical analysis

In calculations of temperature rise of connections (e.g. clamp – conductor etc.), on other distributions of electric energy, the following criteria are respected [1]:

- magniture of loading during measurement,
- effect of wind speed on the size of temperature rise.

Concerning the heating determination we corne out for a greater approach from the analogy of the solving the dependence between the electrical current, temperatureand time and, in our case, between electrical current and heating. Though the solving of the dependence betwen electrical current and heating is considerably complicated, we can afford briefly to indicate it [2].

For the solving of bare conductor heating by the constant electrical current these assumptions are considered:

- current distribution in the conductor section is uniform,
- the conductor is homogenous and linear,
- the solution for smell hesting; the radiation influence is not in force in this case,
- there is the same temperature in all points of the conductor lengthwise.

Then the solution for the element of the length *dx* is given the equation of the thermal balance (Fig. 1)

$$dQ_2 + dQ = dQ_1 + dQ_3 + dQ_4 \tag{1}$$

where: *dQ* - heat in the element (e.g. terminal), dQ_1 - eat really „heating (terminal), $dQ_2 = dQ_3$ - heat dissipated from the terminal info the conductor, dQ_4 - heat dissipated info the surroundings, dQ_5 - heat radiatedinto the surroundings.

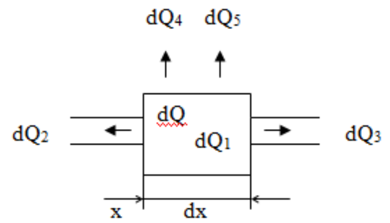

Fig. 1. Thermal balance illustrated schematically

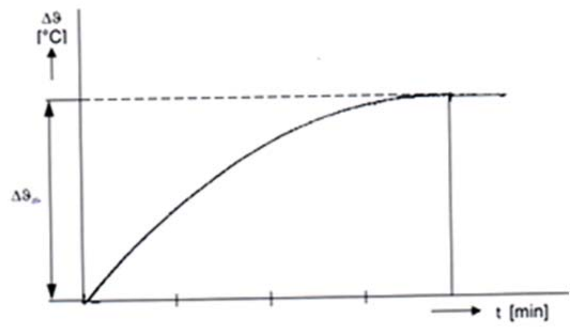

Fig. 2. Dependence of warming on time

On the assumption that alongside the conductor there is the thermal downfelll, that is if

$$dQ_2 = dQ_3 = 0. \tag{2}$$

Then the equation is arranged info the from

$$dQ = dQ_1 + dQ_4. \tag{3}$$

By ssubseguent sollution after substituting for the individual heats we can get the resulting equation for the temperature rise in the dependence on time

$$\upsilon(t) = \Delta\upsilon_\infty \pm (\Delta\upsilon_0 \pm \Delta\upsilon_\infty)e^{t/\tau}, \tag{4}$$

where for $\Delta\upsilon(t) = 0$, we get

(5) $$\upsilon(t) = \Delta\upsilon_{\infty}\left(1 - e^{t/\tau}\right),$$

where: τ – time constant, $\Delta\upsilon_0$ – temperature rise at time $t = 0$, $\Delta\upsilon_{\infty}$ – temperature rise in the stable state.

An analogous solution of dependence between electrical current and the connections warming against connected wire is not unambiguous in regard to following facts:
1) the case of a sufficiently long conductor is not solved, but the case of the connected to the conductor is solved and this fact is in force significantly,
2) the connections is not homogeneous,
3) the case of small warmings is not solved and therefore the influence of radiation can be applied,
4) at all points along the connections may not be the same temperature,
5) it is not solved the dependence of warming on time, but on load, it is about the steady values of warming.

The resulting warming of the connections over the conductor i.e.

(6) $$\Delta t = T_{sv} - T_l,$$

where: Δt – warming connections, T_{sv} – temperature connections, $T_{l,}$ – temperature conductor.

The warm - up course in the dependence on the load was solved providing that at the increased of load at connections junction (in the case if the connections junction is not in good condition) there is an increasing of warming, but in the case of increasing of warming the losses are increased too (eventually increasing cooling).

Comment: *heat from the connections junction propagates in three ways:*
- *conduction, i.e. heat dissipation by the conductor,*
- *convention, i.e. ventilation losses increasing with temperature,*
- *radiation, i.e. temperature radiation (radiated heat) increasing with temperature.*

For this reason, the dependence of warming on the load will probably not be parabolic (in the case if the wind speed will be not respected).

The mathematical solution has been proved to be very complex; therefore a set of experimental measurements has been done for verification of the heat-up of the connections junction on the load dependence.

Practical application of thermovision system

In our case, for the measurement in a specific operation, were used simultaneously two thermal imaging systems from different manufacturers.

Asynchronous motor and analysis of measured results

The degradation of insulation materials due to temperature puts increased demands on precise knowledge of the thermal conditions in a given electrical machine [3], [4]. The current progressive development in the field of rotating (but also non - rotating) electric machines forces us to continuously apply higher and more active materials, and thus the requirements for insulating systems are increasingly tightened. Experience shows us that in most cases they play a decisive role in determining the service life and reliability of these machines. The frame of asynchronous motors, which uses the cover IP 54, IP 55, crucially influences the transfer of losses into the cooler and thus also the temperature of the insulation winding. Based on the heat balance it can be said that just it is approximately 80 – 87 % of the total value of losses. In order to increase the thermal conductivity of the skeleton to the surrounding space, for example, the surface of the skeleton is enlarged from the outside (the so - called "ribbing") and at the same time also the value of the coefficient of heat transfer to the ambient (air) through the introduction of forced ventilation. With today's production technology, it is possible to achieve improved transfer of losses on the inner side of the skeleton, whether on the active part of the machine or the skeleton. On the relative conductivity of the material of skeleton, on the geometric dimensions of the skeleton (i.e., height, length, rib thickness, etc.) and also on heat transfer coefficients from the skeleton surface, depend then the heat distribution in the radial and axial direction. Asymmetric cooling with one fan on the shaft can be assumed.

The analysis of the experimental results on our asynchronous motor with a ribbed frame (Fig. 3) showed relatively good distribution of heat in the axial direction (we believe that it is probably due to very good thermal conductivity of the frame material - aluminium alloy). From the thermal image (for better presentation, we chose black and white image mode, grey toned) we could see the very good thermal arrangement (reduction) of the ribs in the radial direction.

Cooler places which are seen in the upper part can be justified by the longer and less effective ribs in the corners where there is plenty of cooling air. Darker areas on the risers of frame in place for attachment of bearing shields as well as in areas of mutual contact suggest more intensive heat flow in the bearing bracket and less cooled back of the machine.

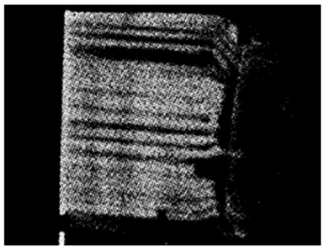

Fig. 3. Layout of the machine frame's temperature field (ribs of the frame)

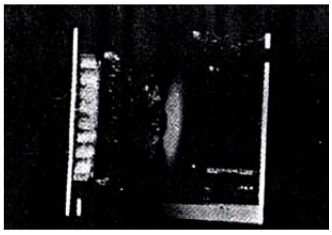

Fig. 4. Temperature field of the bearing shield (back side)

The relatively high temperature at the rear of the bearing shield (Fig. 4) is probably most likely affected by the temperature from the rotor losses. On this basis (visually observed maximum temperature above 100 °C), local overheating may also be expected in the operating mode (mainly due to high reversing or switching density). For correctness, we should also consider the systematic error, arising from various oblique observation of surface of the bearing shield and it should be eliminated.

The stator winding was observed at the dismantled fan with openings in the bearing shields. The warmest places of winding were probably caused by the increased current density, what is due to the narrowing of the cross section of the varnished wire.

Using thermovision simply we can also determine whether the engine is operating in the working temperature range or not. Larger warming of the central part of the electric motor may probably be caused by the stator currents in the coils of stator or by the bearing temperature at the frontal part (larger loading by the radial force), than the bearing located at the rear. Also, the slightly elevated temperature of the belt of an electric motor may be caused by greater friction (e.g., not sufficiently tensioned belt, and hence, it tends to slip and heat), and so on.

We can state that current modern investigation methods provide a number of applications in the field of development, research as well as in the experimental field and allow more and more thorough analysis of thermal conditions.

The resulting effect of the application of these devices has been confirmed earlier and expressed by economic indicators with a return of several years. Along with, it is necessary to emphasize that the currently obtained knowledge in the field of refrigeration in this way can not be obtained using other investigation methods.

Transformer

Analogously, when applying the thermovision systems on the transformers, it is checked if some parts of the transformer are not warming up, the transformer bushings are checked, but also the temperature distribution on the transformer vessels. It is confirmed that the combination of thermovision diagnostics, oil chromatography and other diagnostic methods creates very good conditions for the implementation of high quality defectoscopy of the mentioned machines [5], [6].

The measurement was carried out in:
Tepláreň Považská Bystrica s.r.o., thermal plant.

Technical data:

Transformer (T1):	ŠKODA 250 MVA
Turns (voltage) ratio:	242 kV ± 5 %/15,75 kV
I_{prim} :	586 A
I_{sec} :	9164 A
Connection:	YN d1, f = 50 Hz, u_k [%] = 13,3

On the color temperature scale (Fig. 5), the indicated temperature (to the right of the colour scale) corresponds to the interface of the same colour on the transformer thermal image (not a certain colour indicates the temperature but the colour interface). The value of the spectral emissivity is 0,80.

To the right of the thermogram are defined the temperatures SP 1 to SP 4, which indicate the value of the temperature on the right side of the transformer on the side of 15,75 kV in the area of the connections between the two distributors forming the transformer part.

The point IS 1 gives the mean (reference) value of the temperature in the area between the points SP 1 to SP 4. The values of the other two points PF 1 and PF 2 indicate the temperature of the transformer in the areas of the outlet of encapsulated conductors between the phases L3 - L2 and L2 - L1.

Transformer T1 was measured at an ambient temperature of 28 °C. During the measurements were in operation all fans (4 left and 4 right). The transformer temperature according to the installed thermometer was 54 °C.

The metal tube passing through the area of the outlet of encapsulated conductors between the phases L2 and L3 (the extreme left and the middle phase as seen from the 15,75 kV side) is heated by eddy currents up to 103 °C.

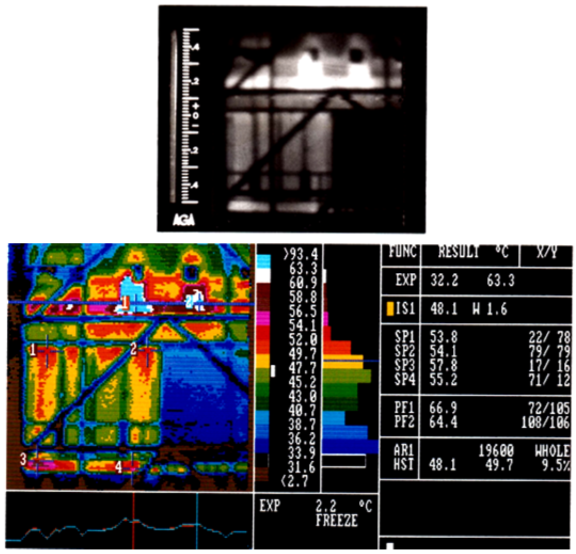

Fig. 5. The black - white thermal image and the thermogram of the measured transformer T1

The generator

Thermovision technology was also used for checking of electric machines and devices for detecting of the temperature on the pick - up systems and excitation systems of generators, power parts of electric machines, detecting of the temperature differences on the semiconductor valves in individual parallel branches of equipments, etc.

Measuring of the state of the magnetic circuit of the stator generator at induction heating.

Technical data:
Generator (G4): 220 MW;
U = 15,75 kV; I = 9500 A

Before the test, several current magnetizing turns (number 17) in the shape of a toroid were wound around the stator sheets. During the measurement, we have located a significant amount of disorders on the magnetic circuit of the machine. (The largest measured warming on the tooth compared to the minor teeth was up to 92 °C).

After two hours of heating, three heat points were localized which clearly indicated the presence of short circuits on the stator plates (the initial stator temperature of the generator just before heating was 19,2 °C). Here is just one image taken at a post from the turbine side, where two wrong locations and one good location are situated (Fig. 6).

Point SP1 is located as a wrong place at a temperature of 35,9 °C with the temperature difference of *dt* = 4,6 °C, point SP 2 is also a wrong place at a temperature of 36,7 °C, *dt* = 5,4 °C. A good place is designated by a point SP 3 at 31,3 °C.

Table 1. Measured temperatures on carbons

	Temperature [°C]	
carbon	+ (plus)	- (minus)
1	95,6	73,0
2	115	79,4
3	115	84,6
4	116	83,5
5	113	82,5
6	103	77,2

Measuring of the temperature of the collection device on rings and brushes has confirmed that the carbons at the positive polarity ring have a higher temperature than the carbons on the negative polarity ring (Fig. 7 and Fig. 8). Higher temperature of the collection device on the positive side is likely due to uneven carbon brushing, which can cause indistinct edges of the grooves of the ring rotor. There were also located brushes that probably did not have sufficient contact with the rings. The measurement results are shown in table 1 (only thermograms of the first three carbons are given).

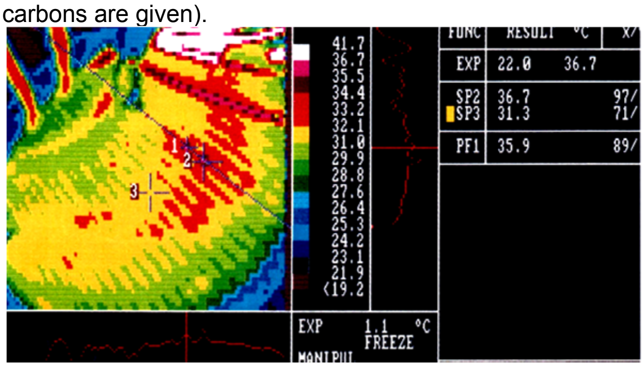

Fig. 6. Thermal image of generator stator

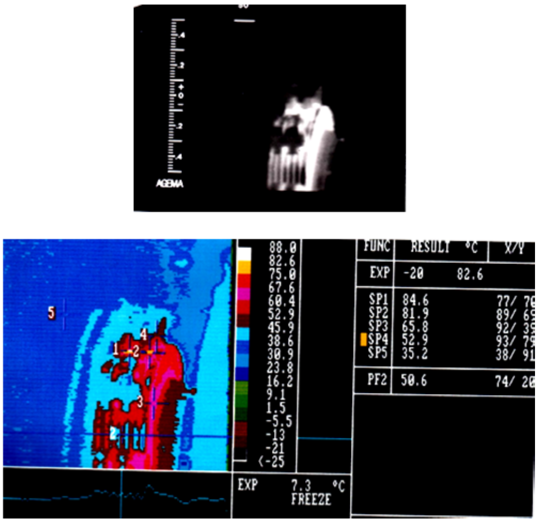

Fig. 7. Top view of carbon 1, 2, 3 - negative ring and their thermal image

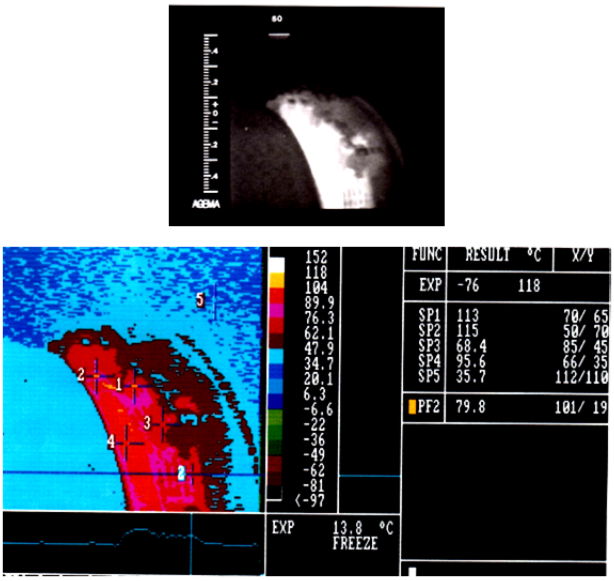

Fig. 8. Bottom view of the carbon 1, 2, 3 - positive ring and their thermal image

Under colour images there is the curve of temperature profile in cross section (blue colour). Points SP 1, SP 2, etc., indicate their temperatures and coordinates, PF 2 is the point of the temperature profile, its temperature value and the coordinate, EXP is a type of the selected temperature scale.

In addition to measurements on electric machines and instruments, we have also carried out measurements on thermal equipment with the identification of the place of overheating at their casing (sheathing). Based on the manager's statement, it can be clearly stated that the detected anomalies have helped to remove some hidden disorders (e.g. in a fireclay paneling, etc.). As it turned out, the realized measurements have helped and brought many savings in terms of shortening downtime.

Conclusion

The purpose of diagnostics is not only to measure but also to detect faults in the equipment without its dismantling, and thus to prevent from accidents and efficiently carry out repairs and minimize maintenance costs.

In metallurgical processes, in technologies or heat treatments as well as after a certain time of operation, the material or part of the machine equipment can acquire many internal or surface defects.

A very common problem, whether in engineering or other industries, is the determination of a fault when it is still unnecessary to dismantle the machine (diagnostics without dismantling). In this paper, we wanted to point out the possibility of using thermovision in this field of analysis and detection of material, product, etc.

This method is presented also by factographic materials, numerical indication of the measured temperatures in the localized places of faults and it can also serve for the diagnosis and detection of disorders in materials and other anomalies during operation of the equipment.

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