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Thermal diagnostic in electrical machines

Abstract. *This article presents information about issues requiring particular attention during thermal tests of electrical machines. It presents mistakes that can be made and describes the influence of parameters such as: relative humidity, reflected temperature, atmospheric temperature, distance from an object and emissivity, on the tests results. It presents examples of practical use of infrared measurements in the production of electrical machines.*
Streszczenie. *Ten artykuł przedstawia informacje dotyczące problemów wymagających szczególnej uwagi podczas termicznych badań maszyn elektrycznych. Przedstawia błędy, jakie można popełnić oraz opisuje wpływ takich parametrów jak: wilgotność, temperatura odbita, temperatura otocznia, odległość od badanego obiektu oraz współczynnik emisyjności. Przedstawia przykłady praktycznego wykorzystania pomiarów termowizyjnych przy produkcji maszyn elektrycznych. (**Diagnostyka termalna w maszynach elektrycznych**)*

Keywords: electrical machines, measurement errors, motor protection, thermal image sensors, thermographic camera.
Słowa kluczowe: maszyny elektryczne, błędy pomiarowe, ochrona silnika, czujniki termiczne, kamera termowizyjna.

Introduction

Thermography, commonly called thermovision, is based on the detection of infrared radiation emitted by objects with a temperature above absolute zero. Thermography converts this radiation into visible light, resulting in a thermal image. This image is a map of the temperature field on the object's surface which is made possible the power of radiation depends on the radiant property of bodies. Such tests can be performed using thermovision cameras. Nowadays, thermography allows digital recording of the temperature distribution on the test object. This "temperature map" is interpreted graphically. The thermal image of the object is seen on the viewfinder because all temperatures are assigned to a different color. In practice, data is stored as a map of temperatures. The same object may look different depending on the adopted color-scale and relationship to scale of temperatures. Thermovision system is special kind of thermometer that can make temperature snapshots from a distance in many places. Thermovision is a effective and noninvasive diagnostic method. Using thermographic cameras, one obtains the surface temperature field of tested objects into pictures. The measurement resolution depends on the transducer type in the camera, for which the current standard is 0.1°C. The main advantage of this method is that the measurements are made during usual working conditions [1].

Fig.1. Test object.

The most common errors in thermographic measurements

To accurately measure the temperature distribution on the body of electrical machines, it is necessary to separate the influence of wished sources from disturbances that have to be compensated. In order to do this automatically, the camera must be informed of the following parameters:

- the atmospheric temperature,
- the distance between the object and the camera,
- the relative humidity,
- the emissivity of the object.

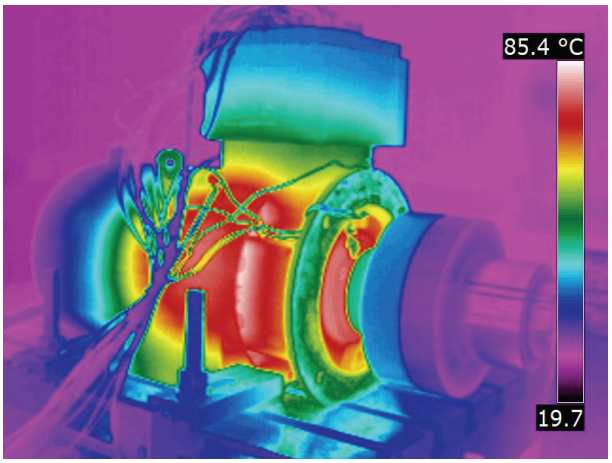

Fig.2. Thermal image with correct parameters set in camera

The atmospheric temperature influence on thermographic measurements

Incorrectly setting the atmospheric temperature in the parameters of the camera doesn't have a large influence on the results of the measurements.

The 11 °C change of atmospheric temperature has little influence on the results of the measurements. A change of 0.7 °C is less than 1% of the measurement value [1]. (See Table 1)

Table 1. The atmospheric temperature influence on thermographic measurements

	ϑ_{MIN} [°C]	ϑ_{MAX}[°C]	$\vartheta_{ATM.TEM.}$[°C]
Correct parameters	25.9	84.2	22.0
Wrong parameters	27.1	84.9	11.0

The influence of the distance between the test object and the thermographic camera

The selection of an appropriate distance between the tested object and the camera lens has a high influence on the reliability of the test results for small size elements. If the choosen distance is incorrect, then small points in the test object can remain undetected [1].

However, if the distance between the object and the camera is set incorrectly the influence on the overall results is negligible. A miss calculation of distance by a factor of 20 produces a difference of 0.1 °C. (See Table 2)

Table 2. The influence distance between the test object and the thermographic camera

	ϑ_{MIN} [°C]	ϑ_{MAX}[°C]	Distance [m]
Correct parameters	25.9	84.2	2.0
Wrong parameters	25.9	84.1	1.0

The humidity influence on thermographic measurements

The incorrect humidity has little influence on the thermographic measurements, as shown in Table 3.

Table 3. The humidity influence on therographic measurements

	ϑ_{MIN} [°C]	ϑ_{MAX}[°C]	Humidity[%]
Correct parameters	25.9	84.2	50
Wrong parameters	25.9	84.1	25

The influence of emissivity on measurement results

The most important object parameter to set correctly is emissivity which, in short, is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody. Normally, object materials and surface treatments exhibit emissivity ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has a much higher emissivity. Oil-based paint, regardless of color in the visible spectrum, has an emissivity over 0.9 in the infrared [1].

Correct setting of the emissivity coefficient is very important. A piece of machinery was painted with an oil paint with known emissivity. In this case the camera registered a temperature of about 44.5 °C, which is 12.5 °C higher than a metalic surface with unknown emissivity . (See Fig.3.)

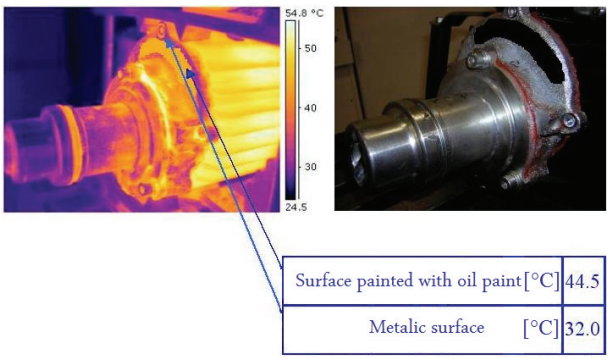

Fig.3. The emissivity in the thermographic measurement of electrical machines

Determining the correct emissivity coefficient is very simple. Place a piece of adhesive tape with a known emissivity glue on an electrical machine. Then, evenly heat the object to higher than room temperature, at least 20 K. The next step is to register the thermal image using a thermographic camera set to the emissivity coefficient of the adhesive tape.The registered thermal image should read the tape temperature. Then, aim the camera at an area without the tape, and change the emissivity coefficient of the camera until the temperature of the electrical machine will be the same as the previously measured temperature of the tape.

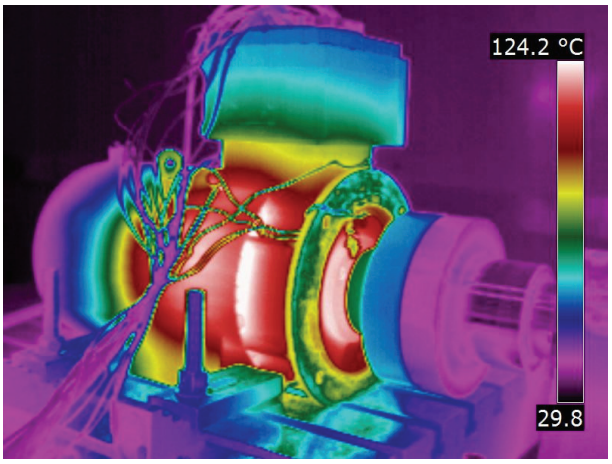

Fig.4. The effect of an incorrect determination of the emissivity coefficient

When the emissivity is set incorrectly the test object temperature is about 35.0 °C higher then if the emissivity is set correctly (Shown in Fig. 4. and Table 4). This situation may fall the diagnostic and lead to bad conclusions [1].

Table 4. The effect of incorrect determination of the emissivity coeficient

	ϑ_{MIN} [°C]	ϑ_{MAX}[°C]	Emissivity
Correct parameters	25.9	84.2	0.9
Wrong parameters	29.8	129.2	0.45

Research on the diagnosis methodology

Presentation of the detailed rules of research is very difficult [1]. However, there is a few principles which should be applied to each application:

- determine the aim of the research,
- identify the object of the research,
- identify technical and environmental conditions of the object,
- perform the test,
- process the results of measurements and edit the report.

Fig.5. Thermographic camera

Examples of the practical use of infrared measurements in the production of electrical machines

Thermal tests are characterized by high accuracy of measurements and may be applied to different types of electrical machines tests [2]. Thermal tests may be used in some tests, such as:

Windings connections test

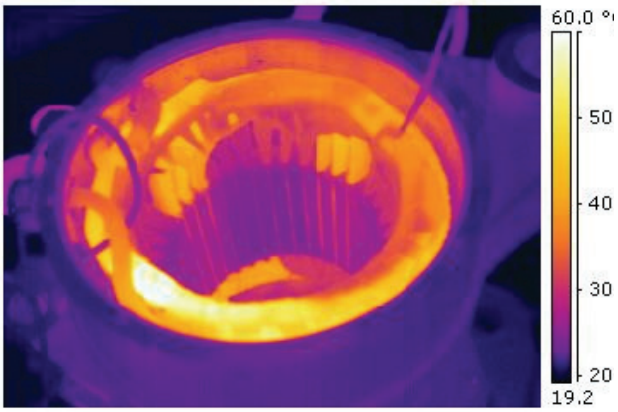

Fig.6. Winding connections test

This measurement is conducted by observing test circuit with a current flowing through it. In this circuit current doesn`t exceed the nominal value. The recorded thermal image presents heating of winding. If phases are supplied, the Fig.6. and Fig.7. show, for example, correct positioning of the stator windings [2, 3].

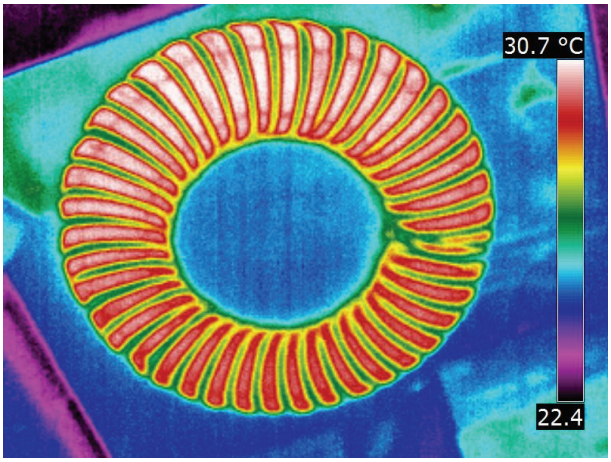

Fig.7. Winding connections test

Phase continuity test

Warning! This test allows to precisly locate a short-circuit between turns.

The short-circuit area is characterized by a higher temperature. Thermal image shows also part of the winding shunted by a short-circuit also [4].

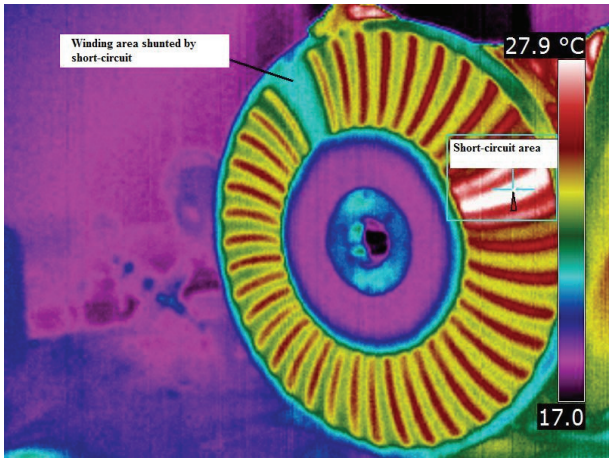

Fig.8. Short – circuit detection

Cooling ducts test

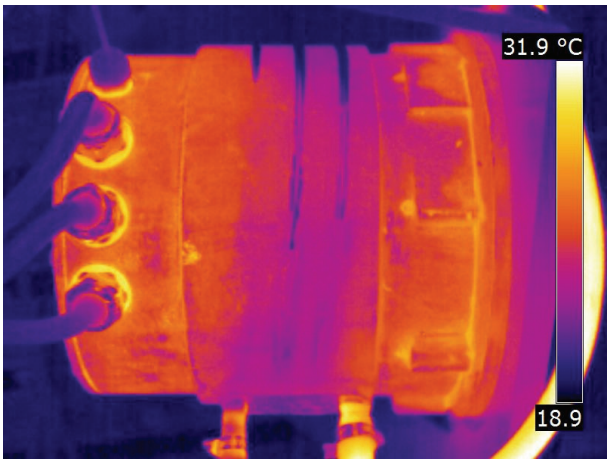

Fig.9. Cooling ducts test

Cooling ducts test is important in the liquid-cooled electrical machines. Risk of air trapped inside of cooling system or fistula formation exists in these machines.

Estimation of thermal condition of bearing mountings

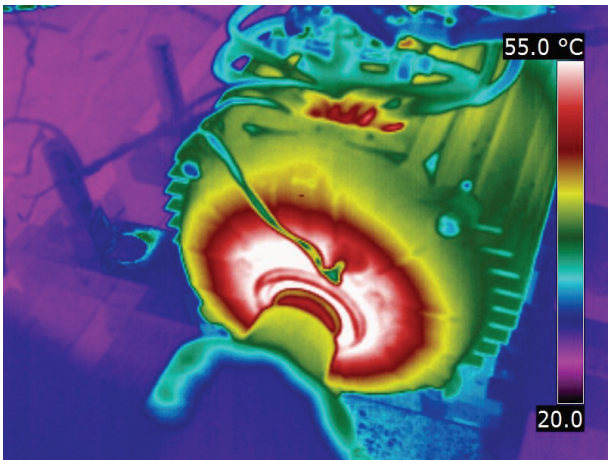

Fig.10. Heating of bearings

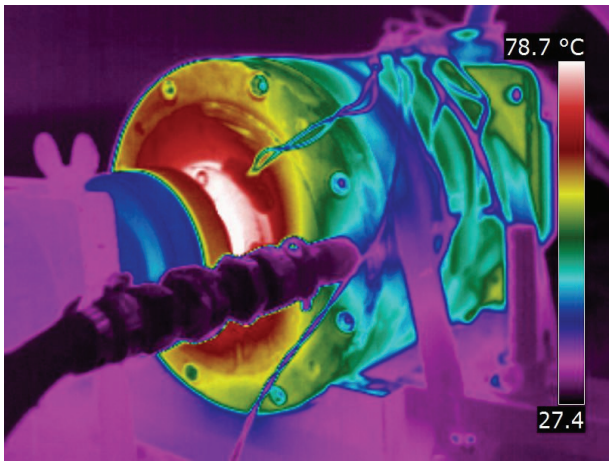

Fig.11. Heating of bearings

Thermovision tests determine overheating of bearing mountings in the electrical machine [5]. The reason may be:

- lubricant mismatched,
- too low or too high the level of lubricant,
- too tight fit of bearing,

- uneven surface of support,
- exhaustion of seals,
- unbalance of rotor,
- vibrations,
- shaft currents.

Bus correctness connection test

Incorrect connections can cause terminal overheating or damage. These problems are usually caused by: low quality, too loose connections, corrosion, oxidation, damage or contamination of the contact surface [3].

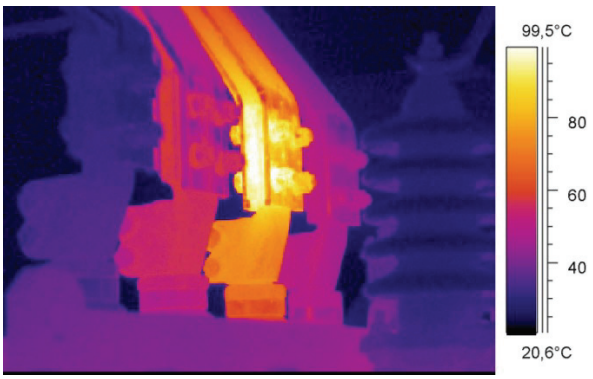

Fig.12. Overheating connections

Summary

Thermography is a non - invasive and effective diagnostic method used in electrical machine tests. Most important advantage of thermovision tests is the fact, that measurement technique is contactless. This is important when testing high-voltage power devices and human presence near the operating machine is prohibited.

It cannot be forgotten that the mere possession of a thermographic camera equipment is only a prerequisite for the implementation of this form of research. In order to carry out useful diagnostic tests, it is necessary to have sufficient knowledge related to the operation of machines, their construction and the thermal phenomena occurring within rotating machines and electrical equipment [6,7].

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