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MEASUREMENT OF TEMPERATURE OF ELECTRICAL MACHINES USING TERMOVISION CAMERA

Abstract: The paper deals with utilization of infrared camera for temperature measurement of electrical machines. There is described the non-contact temperature measuring, and principle of sensors that evaluate quantity of incident infrared radiation. In the next part there is thermovision camera SAT-HY 6800 presented and the instructional manual for SAT Report computer programme created. This computer programme is used for analyzing of thermovision pictures from the SAT-HY 6800 thermovison camera. The paper contains description of temperature measuring of one-phase asynchronous motor type J22TO484. The last part of the thesis describes creation of animation of one-phase asynchronous motor type J22TO455. The animation is created in 3ds Max computer programme. The results and animation would be used either as addition in daily studies or as the replace of tutorial in combined form of study.

1. Introduction

Temperature is one of the most important thermodynamic properties determining the state of matter. Temperature is also one of the few physical quantities that cannot be measured directly, but through another physical parameter. It means that it is an indirect measurement. Temperature can be measured using both a spot and area contactless measuring method. The area contactless measurement is called thermovision.

2. Non-contact temperature measurements

The contactless temperature measurement is carried out using pyrometers or thermovision systems. The principle of contactless temperature measurement (also designated as infrared pyrometry) consists in the measurement of the surface temperature of bodies. The measurement is based on the fact that each grouping of matter with a temperature above the absolute zero (*0 K=-273,15°C*) transmits infrared radiation corresponding to its temperature. This radiation is called characteristic radiation. It is caused by the inner mechanical motion of molecules. Intensity of this motion depends on the temperature of an object. As the molecular motion represents charge displacement, electromagnetic radiation (photon particles) is emitted. While the light energy transfer takes place in the visible region of spectrum, approximately from 0,4μm to 0,78μm, the transfer of heat by radiation takes the spectrum region between 0,78μm and approx. 100 μm. Division of the spectral range of infrared radiation is not standardized.

A real body radiates (and absorbs) less than a black body. Its spectral concentration of radiant intensity H_λ is given by the relation

$$H_\lambda = \varepsilon_\lambda \cdot H_{0\lambda} \; [W \cdot m^{-3}] \quad (1)$$

where ε_λ is emissivity, or more precisely immisivity for wavelengths λ, $\varepsilon_\lambda<1$.

Matters that have different emissivities ε_λ for different wavelengths show also different deviations from the radiation of a black body; they are so-called selective radiators. However, there are bodies the emissivity of which can be considered constant in a large range of wavelengths. Such radiators are designated as grey bodies with emissivity ε.

Emissivity is defined as a ratio of the energy emitted by an object at a particular temperature to the energy of an ideally black body at the same temperature. The emissivity of a black body equals 1. Emissivity is a very important factor of infrared thermometry and its effect cannot be neglected. Emissivity depends on material, surface finish, surface oxidation and hold generally

$$\varepsilon = f(\lambda, T) \quad (2)$$

One of the most frequent measurement uncertainties at a contactless temperature measurement is an inaccurate emissivity setting of the measured material surface. The emissivity of the measured object can be determined using several methods. The emissivity values of some materials can be looked up in tables. It is also possible to heat the measured sample to a known temperature or to use an additional material or a special paint. The most frequently used method for determining emissivity in operating conditions is based on measuring the measured material surface temperature by a thermocouple and a thermal camera (or pyrometer) simultaneously.

The thermovision system (thermal camera) shows the temperature distribution on the surface of an observed object. The temperature distribution is represented using thermograms (thermal images) in which the measured object is shown in various colour shades or grey scales. There are two basic types of thermovision systems – systems with optical-mechanical scanning (scanning systems) and systems with a matrix detector.

3. Temperature sensors

A temperature sensor is a functional member making up the input block of the measuring chain, i.e. the block that is in direct contact with the measured environment. The term temperature sensor is equivalent to the term temperature pickup (an independent structural part of a temperature measuring device containing a temperature probe), and also to the term temperature probe (a part of the sensor converting temperature to a different suitable physical quantity). A heat device detector or a thermometer (temperature measuring devices) is also designated as sensors.

According to the physical principle, temperature sensors are divided to resistance, thermoelectric, semiconductor with PN transfer, dilatation, optical, radiation, chemical, noise, acoustic, magnetic, and other sensors such as capacitance and aerodynamic sensors. According to the signal transformation, sensors are divided to active and passive sensors. According to their contact with the measured environment, sensors are divided to contact and contactless sensors.

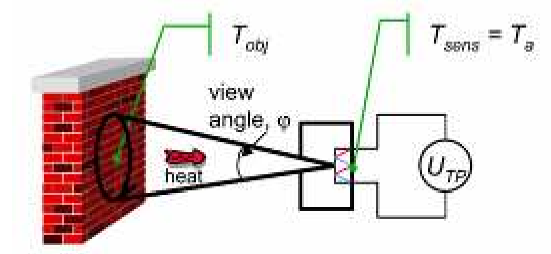


Fig. 1. The measurement of object temperature using thermoelectric sensor [2]

Fig. 2. Example of thermoelectric sensors from the company PerkinElmer optoelectronics [2]

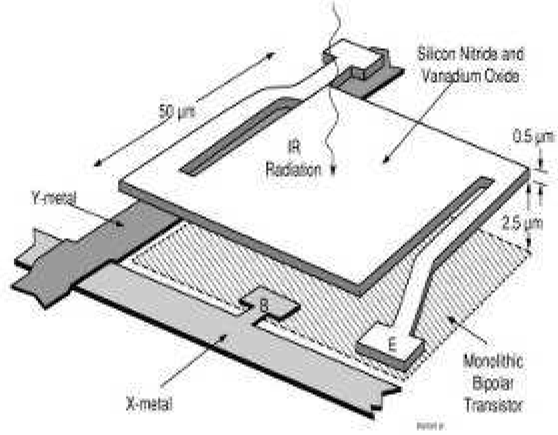


Fig. 3. Detailed view of the structure of one microbolometer pad [3]

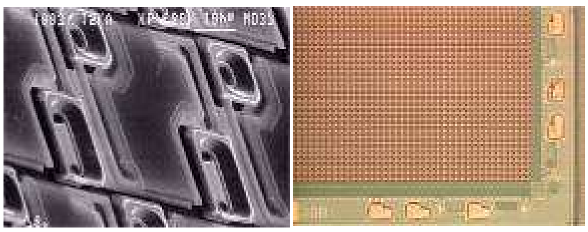


Fig. 4. Photo of real design of microbolometer; left - detail one pad; right – quarter of microbolometer chip [3]

4. Thermal camera SAT – HY 6800

The thermal camera measures the emitted infrared radiation and shows it in the form of a temperature field of the surface of the measured object. The camera is equipped with an integrated 24° lens, a replaceable battery and a number of accessories. It is a hand portable camera resistant to dust and splashed water, suitable to be used in the field. The image (thermogram) can be viewed in the integrated real-time viewfinder.

Fig. 5. Thermal Camera SAT – HY 6800

Although it is, as the name implies, a thermovision camera, it cannot store video sequences, but only still images. So it is rather a "still camera" which stores infrared images in pseudo colors on a memory card. Images are stored in a special format called .SAT. To open and subsequently process them, it is necessary to have the program SAT Report. The basic element of the thermal camera is an uncooled FPA micro-bolometer.

The SAT Report program is used for analyzing infrared images from the thermovision camera SAT HY-6800. As the program version dates back to 2003, the user interface is not very "friendly". The latest version or at least the program update is not available on the manufacturer's website [1]. The program is adapted for creating final inspection reports of measurements; a more thorough temperature analysis of images is cumbersome and rather time demanding. For example, just to find the temperature of a certain point in an image, it is necessary to set relatively many data in various dialog boxes.

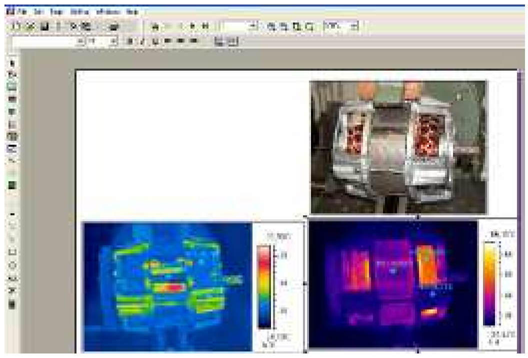
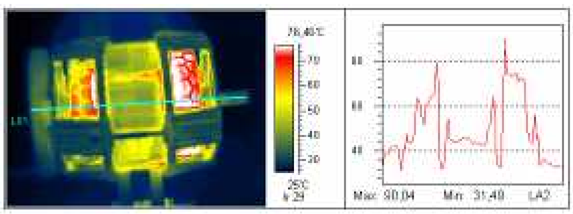


Fig. 6. Basic user interface of program SAT Report

An infrared image is stored to the final report in the .SAT format. A photograph or image with the extension .JPG or .BMP can be included in the final report. The entire report can be saved to a file with the extension .IRP or exported to a file with the extension .DOC.

The program displays infrared images in pseudo colors based on the temperature data stored with the image. It is possible to choose one of six color palettes to obtain a suitable color display of the image according to specific requirements. The scale of temperatures that are in the image is displayed at each image.

Four basic parameters (conditions during measurement) can be set in the program for each image – emissivity, the distance of the measured object from the thermal camera, ambient temperature, and relative humidity. If any of the parameters changes, the temperature data stored in the image are recalculated automatically. This can be used to find out how these parameters affect the performed measurement. Naturally, the parameters can be set directly in the thermal camera during the measurement alone.



Line Analysis	LA2
Line1	Value
Line Lable	lr29-L01
Line Color	******
Max	90,04
Min	31,49
Avg	51,21
Cursor	---
ems	0,95
dist	1
Max X-pos	198
Max Y-pos	106

Fig. 7. Linear analysis and exported data in table

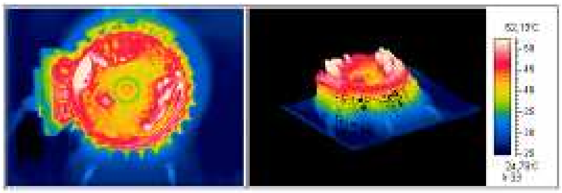


Fig. 8. 3D view of infrared image

5. Measurement of one-phase asynchronous motor J22TO484

The aim of the measurement was to find out how the motor cooling was affected by the air flow created by the ventilator located on the motor shaft and how the motor warmed up without the ventilator. It was also monitored when the thermal protection would react if the motor was not cooled by the ventilator. Another aim was to find out how accurate the measurement with the thermal camera was and if it was at all suitable for this type of measurement.

The motor was fixed in a fixture, connected according to the diagram in 7 and sensed at regular intervals by the thermal camera fixed on a tripod. The motor was measured in its idle state and supplied by the mains voltage increased by 10%. So the most adverse case of the largest permissible deviation of mains voltage U=230·1,1=253 V (in relation to the motor warming up) was considered.

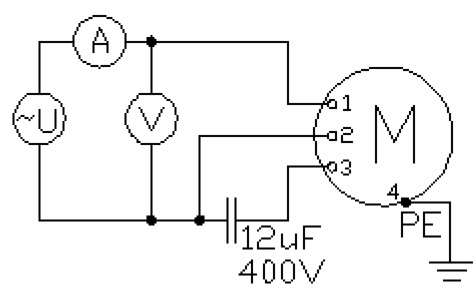


Fig.9. Schematic diagram for the measurement of thermal stress of the engine

At the beginning of the measurement, the motor's ambient temperature was T_0=25°C – measured by a laboratory mercury thermometer. After connecting voltage, the motor started to warm up. After a certain time, the temperature of individual parts of the motor settled on a certain value. In that point, the heat produced by the motor losses and the heat dissipated by flowing air (produced by the rotating ventilator and the rotor blades) to the environment were at equilibrium. From the beginning of the measurement until the temperature settled, 14 images were acquired by the thermal camera. At the same time, temperature was measured by a thermocouple (type K) in three places – on the rotor’s packet of laminations, on the winding head and on the bearing shield (see Fig. 8). Then the motor stopped, the ventilator was removed from the shaft, the motor was turned again and it was monitored at what temperature the motor's thermal protection would trip. Another four thermovision images were acquired before the protection reacted.

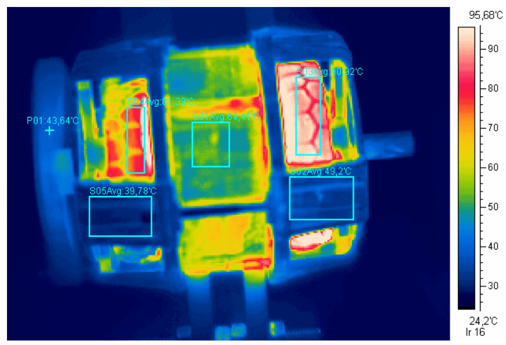


Fig. 10. The evaluated parts of the machine

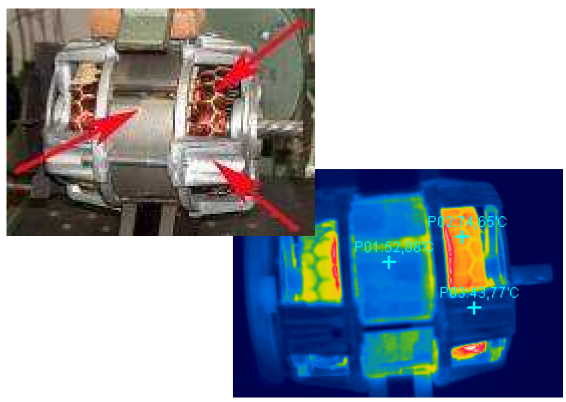
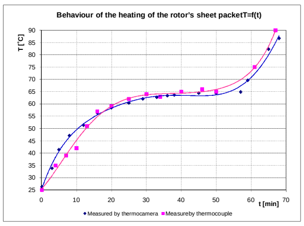


Fig. 11. Places measured by thermocouple

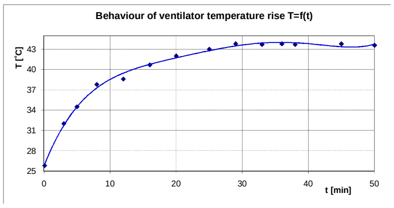
According to the temperatures measured by the thermocouple, the emissivities of parts of the motor can be determined when analyzing the images. The temperature measured by the thermocouple is considered the reference temperature, then in the SAT Report program the emissivity of the selected part of the infrared image is set with such a value that the temperature analyzed by the program is equal to the measured temperature.

The emissivity of measured parts was determined by comparing the temperatures measured by the thermal camera and the temperatures measured by the contact thermocouple. The correct emissivity value was the value at which both measuring devices showed an equal temperature.

The heating of the rotor's sheet packet, bearing shields, right winding head and ventilator was analyzed (here it is advantageous to use the abilities of the thermal camera to sense the moving and rotating parts using the contactless method as it would be very difficult to measure these parts using the contact method).



Graph 1 – Behaviour of the heating of the rotor's sheet packet



Graph 2 – Behaviour of ventilator temperature rise

The aim of the measurement was to find out how the air flow created by the ventilator located on the motor shaft affects the motor cooling and how the motor warms up without the ventilator. From the graphs it is clear that under the given conditions during the measurement, the motor temperature settles in about 35 minutes. Packet of rotor sheets is heated by ΔT_1=40°C, right bearing shield by ΔT_3=25°C, left bearing shield only by ΔT_4=15°C, right winding head by ΔT_7=65°C, left winding head by ΔT_7=55°C and finally ventilator by ΔT_9=19°C. Based on the results it can be said that the half of the motor on which the ventilator is located (the left part in this case) is cooled by the flowing air in such a way that it is cooler by 10°C than the other half of the motor. At the settled temperature, the hottest part of the motor is, logically, the winding the right head reached the temperature T_1=91°C. The measured temperatures correspond to the calculated and detected values according to ATAS's sources.

After the ventilator was removed, the motor started to overheat immediately and after approximately eleven minutes, the temperature of the right winding head rose up to the value T_9=125°C, while the left head was by another 3°C hotter – T_{10}=128°C. At these temperatures, the motor's thermal protection, which is set to the value T_{och}=135°C, reacted. So it reacted correctly.

6. The description of asynchronous motor animation

The animation of a one-phase asynchronous motor serves as an example of the process of assembling basic parts of a motor during production into a single unit and it indicates the method of cooling of such motor.

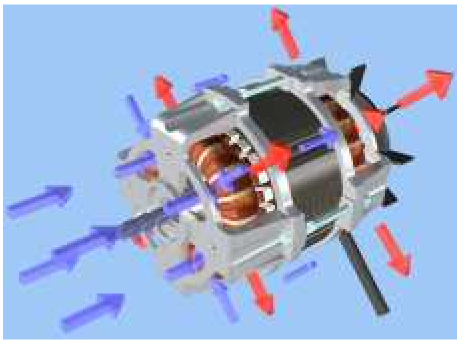


Fig. 12. The simulation of motor cooling

Fig. 13. The ventilator location

Most parts of the motor was modelled at programme Inventor a subsequently imported to programme 3ds Max 9. Rendering of all 6 500 frames in resolution 800 x 600 points lasted approximately 2 hours and scene contains 424 objects. Finally, the animation was created in resolution 1024 x 768 points; this generally took more than 50 hours. Animation have 3 minutes and 36 seconds, resulting file is about 43 MB.

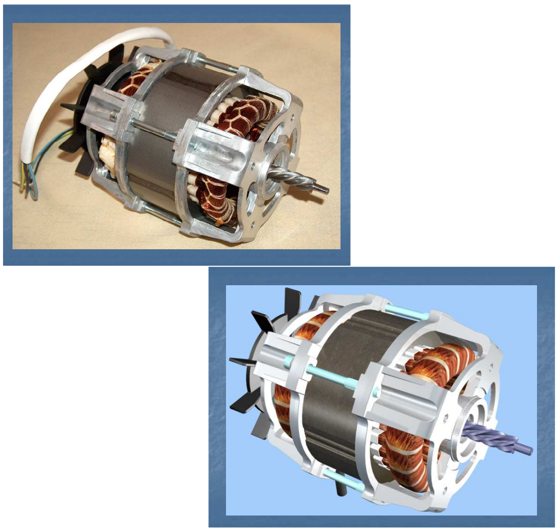


Fig. 14. Photo and model of motor J22TO455

7. Conclusion

The paper brings acquaintance with the problems of the contactless temperature measurement, in particular with thermovision. It describes an analysis of thermovision images acquired by this camera in the environment of the SAT Report program. It also deals with what ambient factors affect the contactless measurement and what should be avoided during this measurement. The most important is certainly to set the emissivity of the measured surface correctly. Measurement would be inaccurate without knowing this quantity.

Thermovision is ideal for temperature measurements in which it is necessary that the measuring device does not intervene with the running operation. Also, it is suitable for measuring moving or rotating parts such as the measured ventilator in our case. Thermovision is also applied for measuring parts that are difficult to access or parts under voltage (distance measurement). The disadvantage is that only the surface temperature can be measured.

The thermal camera measurement is relatively simple, quick and comfortable, but it is necessary to know the regularities of contactless measurement, factors affecting the measurement and, in particular, the correct emissivity of the measured surface, otherwise one cannot rely on the measured values and they are only for orientation. If all contactless measurement principles are observed, the accuracy of the results is within two percent, as stated by the manufacturer.

Acknowledgments

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References

[1] *Support and Download* [online]. c2006 [cit. 2009-03-27]. <http://www.sat.com.cn/english/ /index.php>.

[2] Vojáček A.: *Thermopile sensors = radiační pyrometry*. 2005 <http://automatizace. hw.cz/mereni-a-regulace/ART189-thermopile-sensors-radiacni-pyrometry.html>.

[3] Vojáček A.: *Co jsou bolometry a mikro-bolometry*. 2005 [cit. 2009-03-13]. <http://automatizace.hw.cz/mereni-a-regulace/ ART196-cojsou-bolometry-a-mikrobolometry>

[4] *Review of infrared systems : Thermal imaging systems* [online]. 200 [cit. 2009-03-25]. <http://www.inframet.com/review.htm>.

[5] Líbal J.: *Utilization of infrared camera for temperature measurement of electrical machines, Master´s thesis*, Brno: VUT, FEKT, 2009, 67 p.

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