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UTILIZATION OF THERMAL SYSTEMS AT POWER ELECTRICAL ENGINEERING

NOWE OPCJE TERMOUKŁADÓW

Abstract: The main theme of the paper is using of thermal camera to measure temperatures in electrical engineering. First the physical principles of heat transfer are mentioned. Then the thesis deals with methods of determining the correct emissivity of the measured object and in the next point with sensors designed for sensing infrared radiation. There is also part dedicated to evaluation software Report Sat Standard, which was used to evaluate pictures taken with thermal camera SAT-HY 6800. Part of this work is the measurement of the EC motor thermal imager, which took place in the electric company ATAS Nachod. Attachment to this paper is animation of EC motor created in Autodesk Inventor.

1. Introduction

With regard to the fact that most properties of materials are thermally dependent, temperature measurements are one of the most frequently taken measurements. However, to determine temperature in rotating machines or in not easily accessible places, instruments for contact temperature measurement cannot be used. In such cases non-contact temperature measurement is used.

Thermographic systems measure infrared radiation which is emitted by every solid with a temperature higher than absolute zero. So the problem occurs with back-scattered or transmitted radiation the amount of which is dependent on the surface and colour of a body. For this reason, the term surface emissivity is introduced.

Several types of sensors are used for non-contact temperature measurement in thermographic systems.

Measurement was made with thermal camera SAT-HY 6800, with program Sat Report Standard.

2. Heat Transmission

The way of heat transmission is dependent, in particular, on the type of environment through which heat is transmitted. Basically, three basic ways of heat transmission are distinguished: by conduction, by convection and by radiation [1]. It is obvious that depending on the environment, also a combination of the above-mentioned ways will occur at heat transmission.

3. 1. Emissivity

The electromagnetic radiation may be comprised of several components. It means that the overall radiated energy may be comprised of emitted radiation (E), back-scattered radiation (R) and transmitting radiation (T).

Then apply: $\mathbf{E+R+T=1}$

The ratio of components in radiation is different for each material. This means that each material may reflect or transmit more or less thermal radiation from the surrounding heat sources and thus bring an error into the measurement. Due to this, the term emissivity is introduced. Emissivity gives the ratio of really emitted energy to energy emitted by an ideal black body of the same temperature. [2]

3.2. Determination of the emissivity of an object surface

Determination of the emissivity of an object surface is most often carried out using the following methods:

1. Emissivity tables of frequently used materials
2. Warming the measured sample to a known temperature
3. Using a special coat, tape
4. Using a drilled hole
5. A combination of other methods of surface temperature measurement (the most frequently used)

3.3. Infrared measuring systems

A thermographic camera is a device allowing displaying the distribution of surface tempera-

tures of an observed object based on its infrared radiation. The imaging device displays the temperature field of the measured surface by means of a so-called thermogram.
Today's thermographic systems are divided into two basic groups. The first group of devices is based on the principle of opto-mechanical scanning and the other on the system with matrix detector. [7]

4. Evaluation Sat Report Standard software

The appropriate software is used for the subsequent analyses of measured images. The Sat Report Standard utility program is supplied to each SAT-HY 6800 camera with which the measurement will be taken.

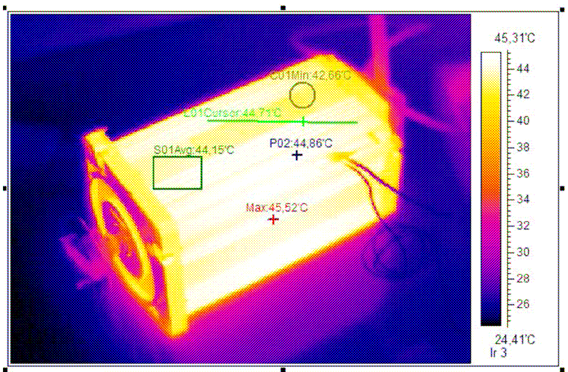

Fig. 1. Environment of Sat Report Standard program

5. Infrared camera SAT HY 6800

The SAT-HY 6800 thermographic camera was used for the measurement of heat curve. It is a colour portable thermographic camera. A non-cooled FPA micro-bolometer is used as an infrared radiation sensor. The camera has a built-in 24° lens, and reaches a resolution of 384 x 288 pixels and only records still images (so-called thermograms), which are later processed in the appropriate analysing software SAT Report Standard. However, some types of analyses can be performed straight in the camera, for example, an analysis of isotherm or displaying temperature in a particular area.

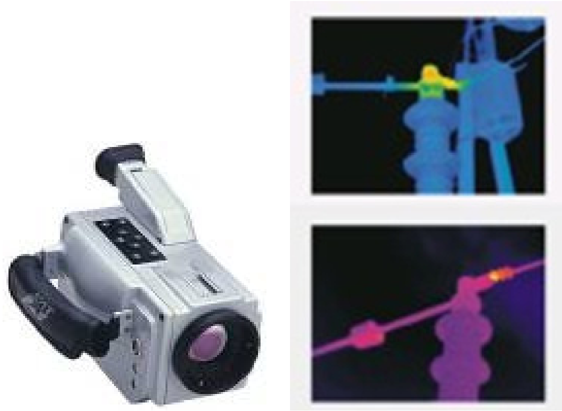

Fig. 2. Thermocamera SAT – HY 6800 and its thermograms [4]

6. EC motor G62UL306

It is a measurement of heat curve of an electrically commutated motor using the SAT-HY 6800 thermographic camera.
With its design and arrangement, an EC motor is basically similar to a three-phase synchronous generator, specifically a synchronous generator with a three-phase winding on the stator and permanent magnets on the rotor. As an EC motor is sometimes referred to as a reversed direct-current motor, there is a certain similarity to the DC motor design. However, it differs from it by one fundamental difference – the presence of permanent magnets on the rotor and winding on the stator unlike the DC motor which is of the exactly reversed design.
Although with its design it is more similar to a synchronous generator, it rather behaves as a direct-current motor.
Two structural arrangements of EC motors can be currently distinguished – motors with homogenous windings and motors with concentric windings located on the stator poles [3].
The measured EC motor features an integrated control circuit, therefore it is sufficient to connect it, for example, to a computer via RS232 data link and to simply control the motor using the EC Motor Control program. This motor is designed as a closed flanged six-pole motor with rare-earth-based permanent magnets on the rotor. The integrated power and control electronics provides the function of servo-amplifier with vector control [5].

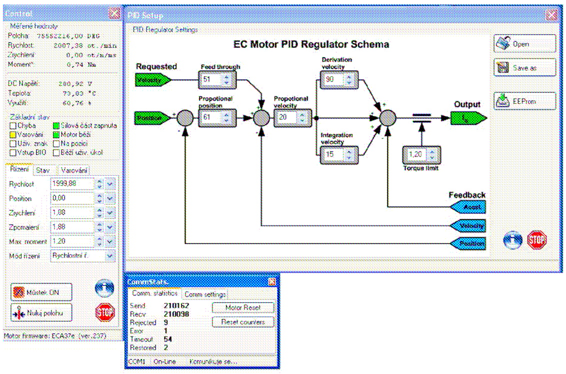

Fig. 3. Control program of EC motor – EC Motor Control

Tab. 1. Parameters of EC motor G62UL306

Parameters of EC motor G62UL306	
Nominal speed [sp/min]	3500
Maximum speed [sp/min]	4000
Nominal torque [Nm]	1,6
Maximal torque [Nm]	3,5
Nominal power [W]	600
Weight [kg]	4.0

7. Measurement of EC motor G62UL306

As the motor is equipped with an integrated control circuit in the form of printed circuit, which is provided with power components, it is therefore useful to measure their warming by a thermographic camera.

All measurement of the printed circuit temperature took 100 minutes. [6]

For Table III:

ϑ_1 - *Temperature measured by thermocouple integrated at motor (barrier inside the motor)*

ϑ_2 - *Temperature measured by thermocouple on the stator rib*

ϑ_3 - *Temperature measured by thermocamera on the stator rib*

ϑ_{C01} - *Temperature measured by thermocamera at place C01*

ϑ_{C02} - *Temperature measured by thermocamera at place C02*

ϑ_{C03} - *Temperature measured by thermocamera at place C03*

ϑ_{C04} - *Temperature measured by thermocamera at place C04*

Tab. 2. Measured values on EC motor G62UL306

Measured values															
t [min]	θ_1 [°C]	θ_2 [°C]	θ_3 [°C]	θ_{C01} [°C]	θ_{C02} [°C]	θ_{C03} [°C]	θ_{C04} [°C]	t [min]	θ_1 [°C]	θ_2 [°C]	θ_3 [°C]	θ_{C01} [°C]	θ_{C02} [°C]	θ_{C03} [°C]	θ_{C04} [°C]
0	24,00	24,00	24,00	26,38	25,59	26,54	24,86	52	63,83	60,10	61,00	96,19	95,59	103,21	81,38
2	30,06	26,70	26,70	48,56	39,8	52,35	38,49	54	64,32	60,60	59,76	96,12	97,29	104,88	81,28
4	31,64	30,20	30,15	75,98	69,71	82,28	63,18	56	65,29	60,90	61,35	97,35	97,53	105,09	82,69
6	33,50	33,50	33,25	77,29	69,56	84,22	64,18	58	66,03	61,70	61,85	98,03	97,22	105,24	83,28
8	35,20	35,60	35,65	78,96	71,19	84,85	65,35	60	66,76	62,30	62,82	98,32	94,48	105,94	83,51
10	37,26	39,10	39,10	79,58	70,91	86,08	65,79	62	67,05	62,58	62,32	98,92	97,64	107,65	83,92
12	39,20	36,40	36,55	81,01	77,42	87,31	67,1	64	67,86	63,10	63,15	99,48	98,81	108,19	84,25
14	40,80	42,30	42,10	81,75	75,32	88,02	67,76	66	68,59	63,50	64,56	99,70	94,78	108,51	84,59
16	42,37	39,80	40,1	82,76	78,26	90,51	69,48	68	68,83	64,30	65,80	99,84	97,30	108,07	84,37
18	44,08	41,60	41,55	84,35	79,31	90,60	70,06	70	68,95	64,50	64,49	100,43	96,87	108,68	84,33
20	45,91	43,80	43,80	84,99	83,02	91,61	71,51	72	69,32	65,70	65,95	100,05	96,84	109,02	84,07
22	47,49	44,70	44,51	85,8	83,27	92,07	72,23	74	69,93	65,50	65,52	100,90	99,68	109,86	84,93
24	48,83	46,70	46,59	86,49	82,79	92,90	73,04	76	70,29	65,30	66,70	101,28	10,45	110,64	85,56
26	50,66	48,10	48,21	87,31	86,89	94,49	73,98	78	70,90	65,90	65,74	101,67	101,56	109,95	86,09
28	51,76	48,60	48,59	88,15	86,79	94,98	74,74	80	71,30	66,10	66,84	101,82	99,89	110,5	85,61
30	53,10	49,30	49,22	89,48	86,67	97,83	75,49	82	71,64	66,30	66,42	102,00	98,11	111,03	86,53
32	54,20	51,50	51,59	90,15	86,05	97,01	76,19	84	71,39	65,90	65,92	101,79	102,09	110,79	85,85
34	55,42	52,10	52,32	90,92	89,93	98,89	76,93	86	72,12	67,50	67,51	102,5	100,40	111,89	86,28
36	56,76	53,00	53,21	92,16	87,35	99,69	77,64	88	72,61	67,90	67,72	103,07	100,87	112,19	87,51
38	57,61	53,60	53,82	92,59	89,86	99,14	77,98	90	72,85	67,70	67,92	102,85	100,58	112,56	87,09
40	58,34	54,20	54,10	92,82	91,95	99,76	78,36	92	72,85	67,80	66,20	102,74	100,25	110,55	86,92
42	59,44	55,80	55,75	93,31	92,38	101,04	78,73	94	72,98	68,20	69,85	103,17	100,19	112,34	86,44
42	60,05	56,70	56,72	93,94	92,98	101,48	78,93	96	72,85	68,80	67,10	102,26	100,87	111,28	86,06
46	61,03	56,80	56,92	94,28	92,68	102,44	79,41	98	73,22	68,40	69,50	102,67	101,3	112,61	86,67
48	62,00	58,20	58,92	94,86	94,89	102,15	80,44	100	73,71	68,50	68,31	103,47	100,82	112,69	87,11
50	63,10	58,70	58,79	95,91	93,81	103,65	81,27	102	73,83	68,80	68,94	103,44	101,95	113,01	87,38

The course of the measurement was that the thermographic camera was aimed at the measured part of the electric motor, which was fastened in the stand of a dynamometer by which the motor was also loaded. The EC motor alone was controlled from a laptop and the EC Motor Control program through which the basic parameters were set. Then the temperatures in the room and on a few selected parts of the printed circuit were recorded. The distance of the thermographic camera from the measured part of the EC motor was measured. Then the temperature was recorded using both a thermocouple and the thermographic camera every two minutes. The recorded data are shown in the table of measured values. (Table II).

As all measured components are of the same mat colour, the emissivity determination was relatively easy. All of the four measured components have emissivity ε = 0.95. With regard to the fact that the emissivity of the surface around the component is different, it is relatively difficult to determine the mean temperature of the component. Due to this, a circle was created around the component and its area was assigned with the same emissivity value as the measured component. Then all that had to be done was to display the maximum temperature on the area of that circle.

In only several minutes of the measurement it was clear that three points warmed most on the printed circuit, specifically the integrated circuit marked C01, transistor C02 and resistor C03. The integrated circuit C04 marked in Figure 4 warmed considerably less.

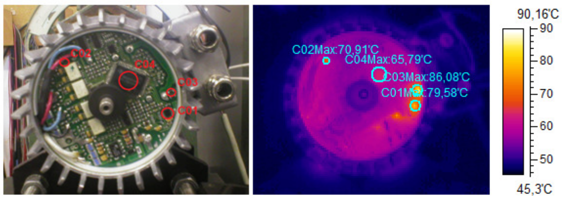

Fig. 4. Thermogram from 20., 30., 40. and 50 minutes

It is apparent from the thermogram on Figure 5 that the temperature on the power components rose steeply after the first 10 minutes from the mean 24°C up to 86.08°C, which is the temperature of resistor C03. The coldest remains the integrated circuit C04 (65.79°C).

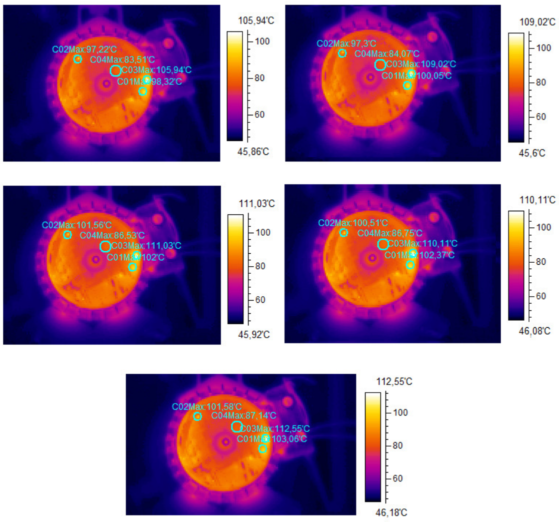

Fig. 5. Thermogram form 20., 30., 40. and 50. minutes of measurement

It is clear from the measured values that the components warmed to a relatively high temperature. Some of them exceeded even 100°C.
The graph on Figure 6 shows clearly that the temperature on the components rose steeply, almost linearly in the first 10 minutes.
The graph also shows the temperature dependence of the inner partition of the stator onto which the control printed circuit board is screwed. This temperature was measured with the sensor integrated straight in the EC motor. Then also the temperature on the stator fins was measured with the thermographic camera.

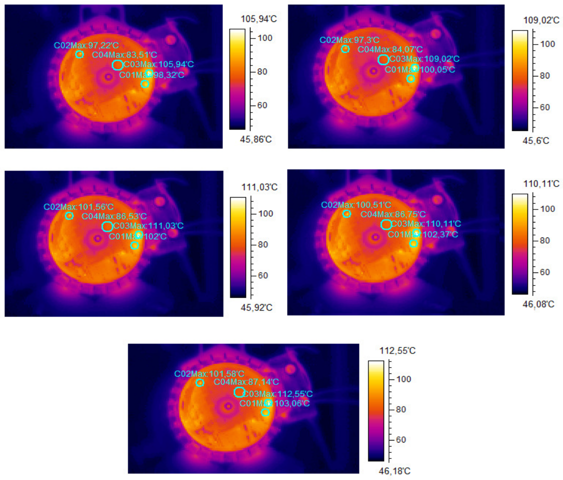

Fig. 6. Thermogram from 60.,70., 80., 90. a 100. minutes of measurement

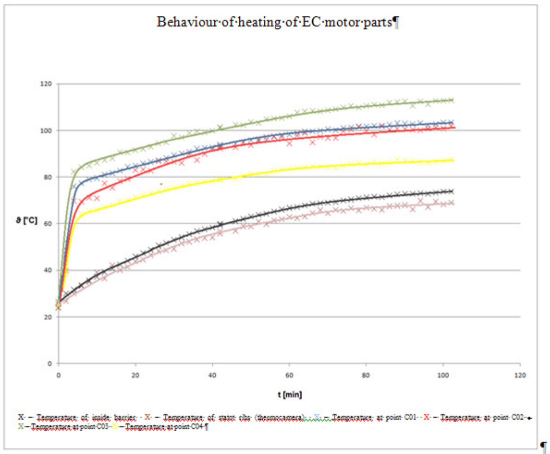

Fig. 7. Behaviour of heating of EC motor parts

At the same time, the temperature on the stator ribs was measured by the thermocouple, so the values measured by the thermographic camera and the measuring probe could be compared. The graph on Figure 8 shows that no large deviations occurred.

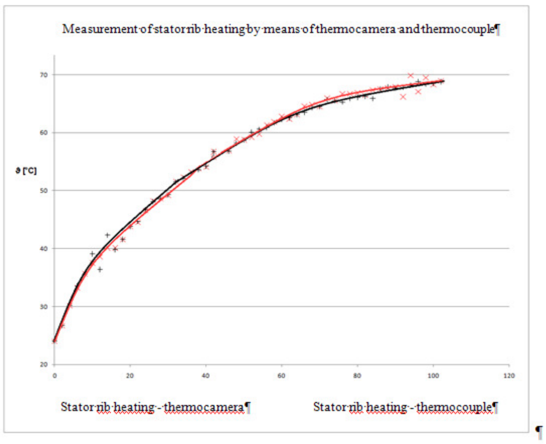

Fig. 8. Measurement of stator rib heating by means of thermocamera and thermocouple

Table III shows the calculated error in the measurement by the thermographic camera, when the reference temperature was the temperature measured by the probe with thermocouple. In the graph, this error is shown in time dependence. It is clear from the graph that the largest error occurred in the 14th minute.

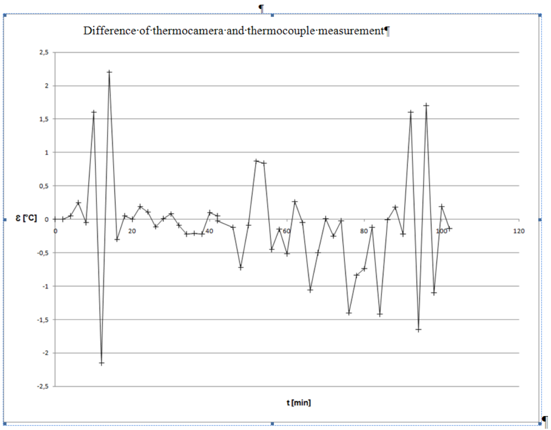

Fig. 9. Difference of thermocamera and thermocouple measurement

Tab. 3. Evaluation of measurement error by thermocamera

Evaluation of errors of measurement with thermocamera											
t [min]	ϑ_1 [°C]	ϑ_2 [°C]	ϑ [°C]	t [min]	ϑ_1 [°C]	ϑ_2 [°C]	ϑ [°C]	t [min]	ϑ_1 [°C]	ϑ_2 [°C]	ϑ [°C]
0	24,00	24,00	0,00	36	53,00	53,21	-0,21	72	65,70	65,95	-0,25
2	26,70	26,70	0,00	38	53,60	53,82	-0,22	74	65,50	65,52	-0,02
4	30,20	30,15	0,05	40	54,20	54,10	0,10	76	65,30	66,70	-1,40
6	33,50	33,25	0,25	42	55,80	55,75	0,05	78	65,90	65,74	-0,84
8	35,60	35,65	-0,05	44	56,70	56,72	-0,02	80	66,10	66,84	-0,74
10	39,10	39,10	1,60	46	56,80	56,92	-0,12	82	66,30	66,42	-0,12
12	36,40	36,55	-2,15	48	58,20	58,92	-0,72	84	65,90	65,92	-1,42
14	42,30	42,10	2,20	50	58,70	58,79	-0,09	86	67,50	67,51	-0,01
16	39,80	40,1	-0,30	52	60,10	61,00	0,87	88	67,90	67,72	0,18
18	41,60	41,55	0,05	54	60,60	59,76	0,84	90	67,70	67,92	-0,22
20	43,80	43,80	0,00	56	60,90	61,35	-0,45	92	67,80	66,20	1,60
22	44,70	44,51	0,19	58	61,70	61,85	-0,15	94	68,20	69,85	-1,65
24	46,70	46,59	0,11	60	62,30	62,82	-0,52	96	68,80	67,10	1,70
26	48,10	48,21	-0,11	62	62,58	62,32	0,26	98	68,40	69,50	-1,10
28	48,60	48,59	0,01	64	63,10	63,15	-0,05	100	68,50	68,31	0,19
30	49,30	49,22	0,08	66	63,50	64,56	-1,06	102	68,80	68,94	-0,14
32	51,50	51,59	-0,09	68	64,30	65,80	-0,50	-			
34	52,10	52,32	-0,22	70	64,50	64,49	0,01				

8. Conclusion

Thermographic systems currently undergo an extensive development owing to which they are more perfect and more reasonably priced. Also for this reason, thermographic cameras find wide applications in numerous sectors such as electronics, building industry and engineering. Although these cameras are able to measure temperatures very precisely if certain conditions are fulfilled, they are most often used for rough measurements. This includes, for example, measuring the temperature distribution on an asynchronous motor, when all that has to be found out in the first phase is which places are more thermally loaded and which less. In the building industry, this method is used for measuring heat leakages in buildings.

In the case of precise measurements, it is necessary to know the surface emissivity and the distance from the measured object.

The development will probably proceed the direction of increasing the resolution of acquired images and the miniaturization of devices in the future. The further development may bring a price decrease and thus a more massive expansion.

Acknowledgments

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9. References

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