MONITORING OF LONG TERM THERMAL STRESSES OF ELECTRICAL EQUIPMENT

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This paper presents the importance of temperature measurements of electrical equipment, how thermal stress affects the proper functioning of equipment and also the design and development of a temperature logger that can monitor, acquire, process and analyze the thermal stress of electrical equipment. A thermal overload of the electrical equipment causes a pronounced wear and improper operation thereof. In order to have the best knowledge of the thermal stress of electrical equipment is vital to use a temperature logger capable to monitor the temperature of their constructive structure in a great number of points.

Keywords: thermal stresses, monitoring, temperature logger

1. Introduction

In order to diagnose the technical condition of electrical equipment, it is also necessary to know its thermal stresses, [1], [2]. The thermal stress degree has a direct influence on the technical and economic aspects and, by default, to maintenance of electrical equipment. Excessive heating (hyperthermia) jeopardize the normal operation of equipment and shortens its lifespan (operations), and on the other hand, a very low heat (hypothermia) leads to an oversized construction, irrational from the economically point of view.

The thermal stresses monitoring of equipment under voltage is difficult to performed, they continuously heating growth due to the conversion of a portion of the electromagnetic energy into thermal energy within the various structural elements. As a result of heat released in the equipment, in normal operating conditions, the temperatures of different constructive parts are increasing in time until they achieve corresponding values of stationary thermal state, when all the heat released in equipment is disposed into the environment.

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Temperature θ, of an electric equipment is determined by the ambient temperature θ_a (where it is located), plus the temperature rise ϑ resulted from the electro calorie effect of the equipment heating:

$$\theta = \vartheta + \theta_a . \qquad (1)$$

The main heating sources from an electrical equipment are: the conductors crossed by the electric current, the iron cores which are crossed by the time-varying magnetic flux, the electric arc (between the open contacts), the real power losses from insulation and the mechanical collisions, [3], [4], [5]. The other elements of the device can be strongly thermally stressed by propagation of heat from one element to another by heat conduction. The heat developed within the electrical elements cause an increase of temperatures to a stationary value (corresponding to steady-state), when the entire heat generated in the device was transmitted to the environment by convection. In order to ensure safe and reliable operation of electrical equipment (in terms of thermal stresses) the standards require (as according to the materials used and the operating conditions of electrical equipment) maximum allowable limits for steady state temperatures.

Hot zones are not always visible, and therefore, when the equipment must perform a major task, it is possible that this operation can not run due to the thermal overload of the equipment. Regular maintenance regarding the operating temperature of the equipment leads to a better understanding of existing problems or of the issues that may arise in operation, as well as a good organization of technical inspections, in order to prevent interruption in operation, or even, personal injury.

2. Thermal stresses of the electrical equipment

The conversion of electromagnetic energy into thermal energy occurs in the active materials (conductors, core irons and electrical parts). The thermal energy is carried out by heat transfer, the heat flow always being directed from the higher temperature areas to the lower temperature areas until the temperatures are equal. The heat transfer is achieved by conduction, convection and radiation.

The electrical conductors of the equipment ensure the electrical conduction and these parts are subject of different intensities of thermal stresses. In general, the conductors consist of homogeneous parts bar shaped, whitch are heated by the action of current that passes through them. In order to ensure thermal stability of electrical equipment, it is required that the final value θ_k of the temperature, at the moment t_k, to be under the rated limit for the nominal currents θ_{ad} and under θ_{kad} for fault currents, as in table 1.

The transient heating study of the conductive paths for long-term thermal stress will be based on the following simplifying assumptions: conductive path is homogeneous, the global thermal transmissivity and specific heat are considered invariant with temperature, temperature variation along the conductor is zero and

Table 1

Temperature limits for different conductor materials

No.	Material	Constructive type	θ_{ad} [°C]	θ_{kad} [°C]
1	Copper	Simple or painted conductor	60	200
		Overhead conductor	80	170
		Paper insulated cable, 3 kV	65	160
2	Copper	Paper insulated cable, 6 kV	65	120
		Paper insulated cable, 20 kV	55	120
		Paper insulated cable, > 20 kV	45	100
3	Aluminum	Simple or painted conductor	60	180
		Overhead conductor	80	130
		Paper insulated cable, 3kV	65	160
		Paper insulated cable, 6 kV	65	120
		Paper insulated cable, 20 kV	55	120
		Paper insulated cable, >20 kV	45	100

ambient temperature has a constant value. With these the general equation of the conductive paths thermal stress as in [6] is :

$$\rho_0\left[1+\alpha_R\left(\vartheta+\theta_a\right)\right]J^2=\gamma c\frac{\partial\vartheta}{\partial t}+\alpha_t\frac{\ell_p}{s}\vartheta, \vartheta(0)=\vartheta_0, \tag{2}$$

where ρ_0, and γ are the resistivity and the conductor material density at 0 °C, α_R is the coefficient of the resistivity variation with the temperature, J is the current density, c is the specific heat, α_t is the global thermal transmissivity, ℓ_p is the legth of the perimeter corresponding to the transversal section s, $\vartheta(t)$ is the conductive path's overtemperature. It will be noted:

$$\vartheta_p=\frac{\rho_0 J^2 s\left(1+\alpha_R\theta_a\right)}{\alpha_t\ell_p-\rho_0 J^2 s\alpha_R}, T=\frac{\gamma cs}{\alpha_t\ell_p-\rho_0 J^2 s\alpha_R}, \tag{3}$$

Taking into account that the critic value of the current density is:

$$J=J_{cr}=\sqrt{\frac{\alpha_t\ell_p}{\rho_0\alpha_R s}}, \tag{4}$$

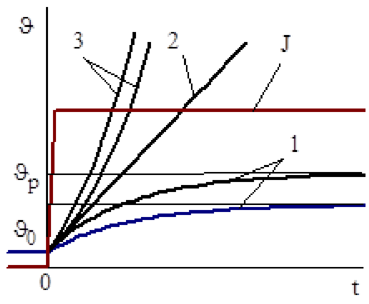

Fig. 1. Overtemperature transient state: 1- the conductive path's overtemperature for long thermal stress, 2, 3 – the conductive path's overtemperature for short thermal stress; J – current density

equation (2) admits the solution:

$$\vartheta(t) = \frac{\rho_0 J_{cr}^2 (1+\alpha_R \theta_a) t}{\gamma c} + \vartheta_0 . \tag{5}$$

Taking into account that $J \neq J_{cr}$, equation (2) has the solution:

$$\vartheta(t) = \vartheta_p \left(1 - e^{-\frac{t}{T}}\right) + \vartheta_0 e^{-\frac{t}{T}}, \tag{6}$$

where ϑ_p and T, are the steady-state overtemperature and the thermal time constant of the conductive path. Corresponding to equations (5) and (6), in Fig. 1 there are presented the $\vartheta(t)$ curves of the transient heating self-state of the conductor path for long-term continuous stress. The curves 1 show the time evolution of the overtemperature corresponding to $J_1<J_2<J_{cr}$ for which it results $\vartheta_p > 0$, $T>0$; the curve 2 corresponds to the solution (5) taking into account (4); the curves 3 presents the transient state time-varying of the overtemperature for $J>J_{cr}$ which corresponds to the fault regime.

3. Thermal stress monitoring device for electrical equipment

Monitoring temperatures requires the development of appropriate devices for thermal stress measuring of the electrical equipment, [7], [8], [9]. In this way, it was developed a device whose architecture was specifically designed to measure temperatures of the thermal stressed electrical equipment in 9 distinct points. The measurement of multiple temperatures corresponding to different points of the analyzed electrical equipment is the main advantage of this device.

In Fig. 2 is presented the operating diagram of the thermal stress monitoring device. In the measurement points there are placed K type thermocouples made from different materials Nickel-Chrome and Nickel-Aluminum which can measure temperatures within the range 0 to +1260 ^{o}C; the measured signals are then processed with digital converters with cold junction compensation and sent via SPI communication to the ATmega16 microcontroller, [8], [9].

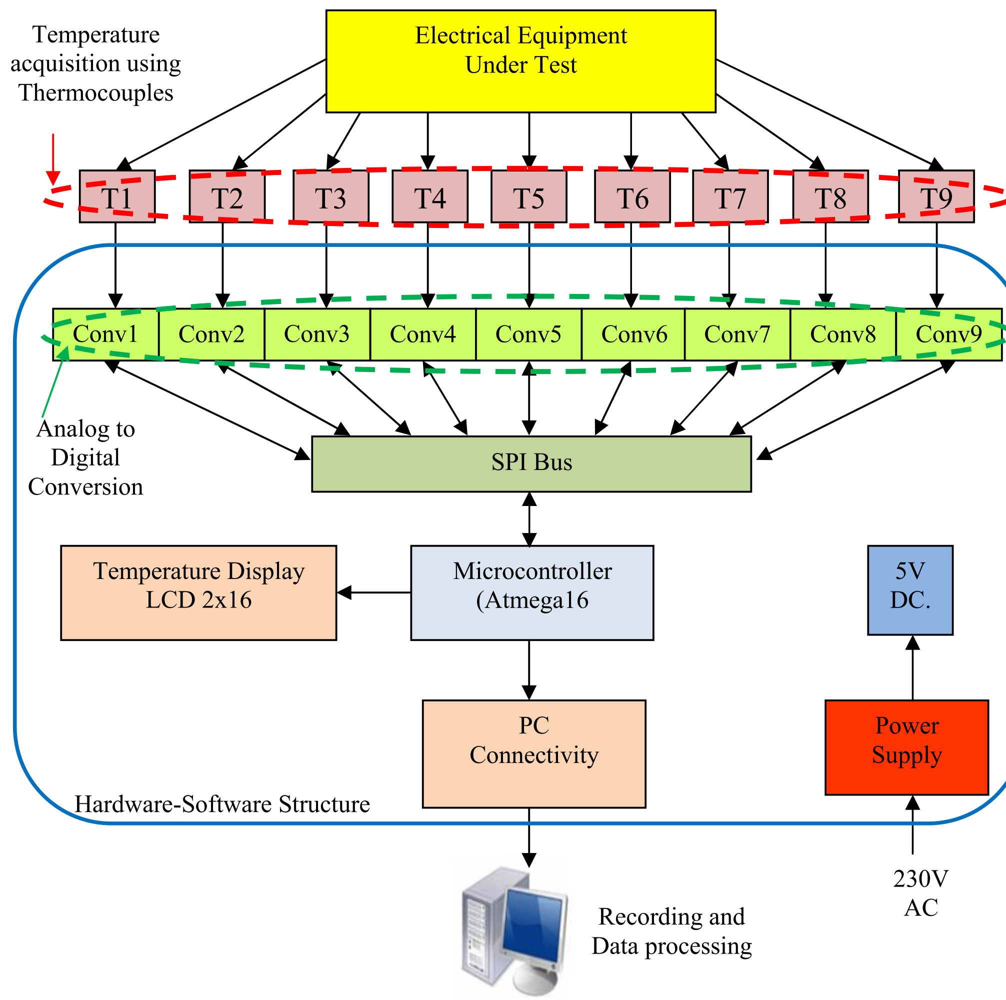

Fig. 2. Temperature logger–operating block diagram

The microcontroller will display on the LCD screen the temperature of the selected thermocouple. In the same time, the converted data containing the acquired temperatures are sent to a computer via USB cable where they can be seen or saved.

The device contains a power supply block with the AC input voltage between 90-264 V and the DC output voltage of 5 V.

Fig. 3 shows a photo of the entire device with all of the 9 thermocouples K-type, the computer serial communication cable and the power cable.

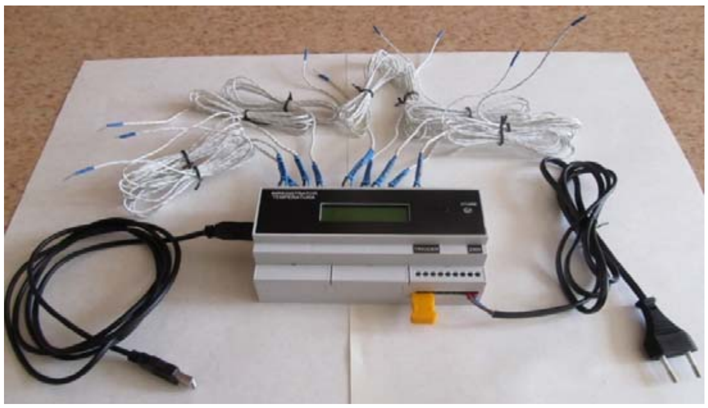

Fig. 3. Temperature logger

4. Experimental results

The temperature logger was used to measure and record the thermal stresses of a current path made from two different sizes conductor. The electrical scheme used is shown in Fig. 4.

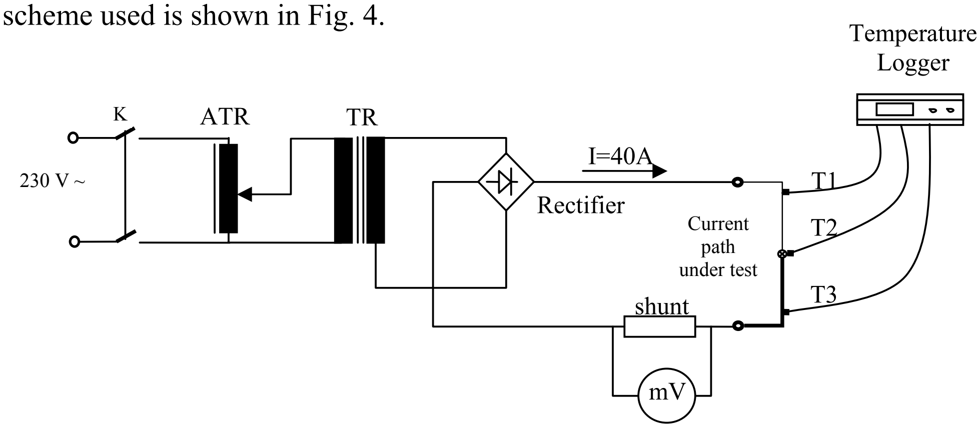

Fig. 4. The electrical scheme for measuring

The current path is made up of two copper wires, the cross sections of the two wires being 4 mm^2 and 2.5 mm^2. In order to highlight the thermal load on the current path we passed 40 A through it. The value of 40 A was chosen because this value corresponding to both conductors over permissible current limit. Thus, according to standards I7/2011, a conductor made from copper with a diameter of 2.5 mm^2 has a maximum rated current of 24 A, while for the diameter of 4 mm^2, from the same copper, the maximum accepted current is 32 A. Therefore we crossed through the current path, a higher value of the current than the limit values of both current conductors that make up the current path, in order to analyze the thermal stress under long-term stress.

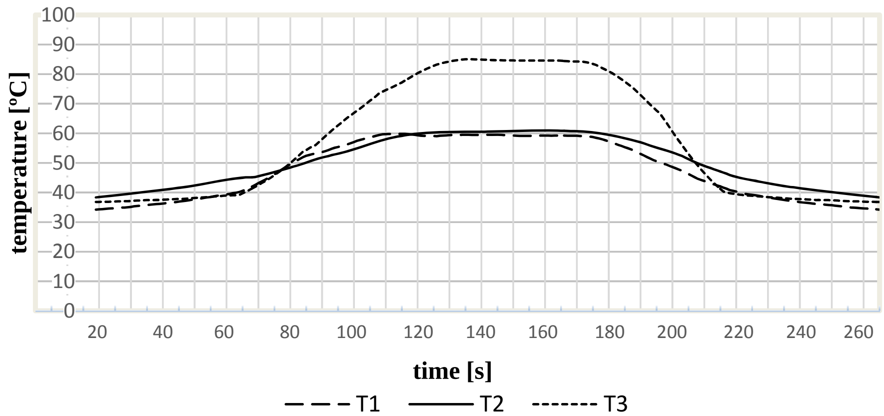

Fig. 5. Temperatures evolution vs. time for measured points

On the established current path were mounted three K-type thermocouples (T1, T2, T3) from the temperature logger. The other K-type thermocouples were attached to the insulation system and another one was used for environmental monitoring. After heating for a period of about 140 seconds, it observed that the current path temperature increase until stabilization. Thus, for the conductor with a cross section of 2.5 mm^2, the K type thermocouple placed in this point (T5), it recorded a maximum temperature of 85 °C. For conductor with a cross section of 4 mm^2, it recorded a maximum temperature of 61 °C, measured with thermocouple T4. The maximum temperature value recorded by the thermocouple mounted on connection between conductors was 59 °C, measured with thermocouple T3. Other thermocouples did not record temperatures with significant differences from baseline. As it can be seen in table 1, for both conductors are recorded higher values comparing to the rated temperature of the adequate long-term heating (60 ºC). Thermal time constants of the current path are different for those two wires and they have the values in range from 25 to 35 seconds.

5. Conclusions

Monitoring, measuring and analyzing temperature of electrical or mechanical equipment is a very inexpensive and very accurate method to detect existing problems. The down time of equipment used in the production process can lead to decreased productivity. The developed device allows simultaneous monitoring of 9 distinct points of constructive structure of electrical equipment under test. Experimental results confirm the usefulness and importance of the device. The large number of measurement points can highlight an area of the examined equipment where the rated temperatures are exceeded and it can prevent equipment damage or personal injury. The aim of the experimental testing was to identify in what point of the equipment (current path), allowable temperatures are exceeded. By developing the interface with the PC, temperature logger can store temperature data which can be used to schedule predictive maintenance. Similar to the method used in the experiment for monitoring thermal stresses of a current path, it can be monitored the thermal stresses of any type of electrical equipment form the electrical installations.

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