ANALYSIS OF RAPID TEMPERATURE CHANGES OF THE OBJECT WITH HIGHER THERMAL CONSTANT

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Abstract

The paper describes a dependence of change of the power load-factor when analysing an object with a higher time constant. The inertia of the protective layers and the temperature field distribution of the surface layers are shown. Analysis of the temperature change is carried out in three methods. Measurement of surface warming was carried out independently by two thermocouples, the first one with a leading wire diameter of 0.12 mm and the second one of 0.012 mm. The time constant difference of the sensors is influencing the measured temperature pattern, so the accuracy of measurement. Measured object is metallised resistor with maximum load of 1 W.

Key words: measurement, thermocouple, temperature field, dynamic change of temperature, sensor.

INTRODUCTION

The pulse load mode is one of the most common operational modes in switching circuits. Another correlation that is shown, is a link comparison of the temperature measurement using broadly different time constants of the sensor (HROMASOVÁ AND LINDA, 2016).

In operation of the object is particularly important to know the operating characteristics of the device. A power increase over maximal load capacity can lead to a damage of the resistive layer which subsequently shows different characteristics, therefore it is important to know the operational temperature characteristics for different cooling modes. Thereafter it is possible to select appropriate operational parameters for a maximum load of the object during pulse load mode. For analysis of the object are applied 3 methods of measurement (LINDA AND HROMASOVÁ, 2016). Since the spot measurement is aggravated by inaccuracies of information inconsistency, the analysis is complemented with images of infrared spectroscopy.

Kalita and Wegrlarski analysed a solution of an impact of dynamic changes in temperature on degradation processes and procedures in resistive layers in the article „Dynamic states of temperature in pulse loaded thick film resistors“ (KALITA AND WEGLARSKI, 2001). In the model is taken into consideration substrate, protective layer and mechanism of heat exchange with the environment (SAKASHITA, 2016; SESSLER AND MOAYERI, 1990). The output is determined by the influence of heat accumulation in the resistor layer under dynamic load. The analysis was carried out as a pulsed one with a high load factor. (JIAO ET AL., 2015)

The contact temperature measurement is defined as a direct contact of the sensor with the measured object. We can therefore distinguish between permanently located sensors on the object, and those that are in contact with the object only at the time of measurement. During the contact measurements must take into account a number of parameters such as the surface flatness (curved), surface quality (polished, oxidized, rough) and a surface treatment (varnishing, laminating), thermal conductivity at the contact, the heat dissipation of sensor, etc. Basic requirements for the sensors are light weight, small size, and suitable construction modifications. Light weight of the sensor provides a rapid warming, and therefore a small time constant and the associated dynamic in correlation with the measured object. Small size ensures more accurate measurements, for example on a semiconductor object, SMD resistors and other. The thermocouples suit the most for these requirements, where only the cross section of the used wire matters. It can also be used for measuring high temperatures above 1000 °C (HROMASOVÁ AND LINDA, 2016). This paper aims to conduct an analysis of the temperature course distribution during a dynamic load of the resistance component.

MATERIALS AND METHODS

In practice, in most cases, we do not encounter only one thermal energy conversion (sharing). As a general rule we encounter two, or all types of thermal energy sharing. Fig. 1 shows heat sharing through SMD resistor wiring. The figure shows the heat transfer from the lead wires to the pads. Another type of heat transfer is radiation, i. e. a heat exchange with the surrounding environment. These effect subsequently influence the actual measurement on the objects. (FARRÉ ET AL., 1998).

Under the assumptions is evident that the measurements on such element will be most suitable in the middle on small area, where the temperature gradient is not distorted. A heat dissipation occurs in location of heat transfer and near "feet", and therefore we would measure lower temperature. This element of dynamic distortion will be examined in the actual analysis alongside with conclusions.

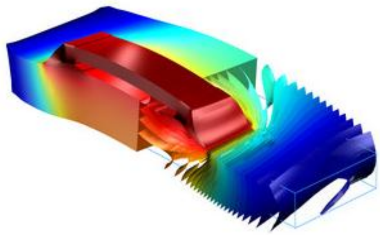

Fig. 1. – Model of heat sharing of SMD resistor with surroundings. (COMSOL, 2009)

Fig. 2a) shows the dynamic temperature pattern in the resistive layer with a power pulse of 100 W with a duration of 1 μs, i. e. the temperature response to a very short pulse. The pulse response is linear. Fig. 2 b) shows another case of power pulse response of 1 W with a duration of 10 ms. The response represents a non-linear pattern with stabilization and a linear pattern of temperature change (KALITA AND WEGLARSKI, 2001).

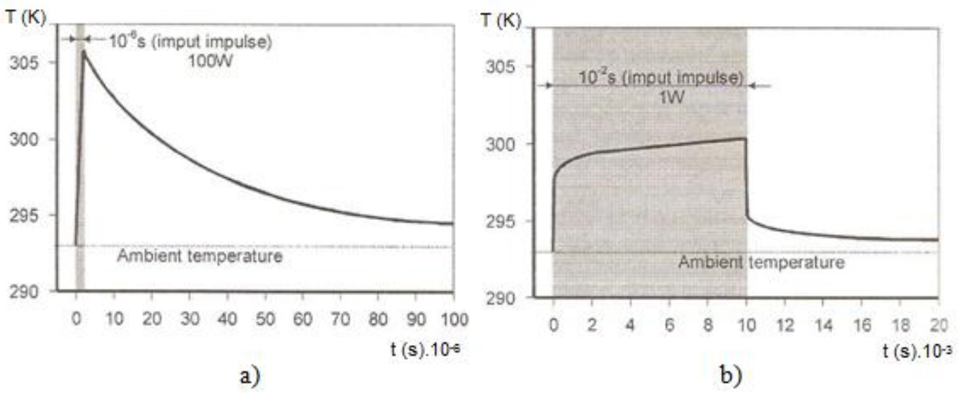

Fig. 2. – Dynamic temperature pattern in the resistive layer: a) 100 W, 1 μs, b) 1 W, 10 ms (KALITA AND WEGLARSKI, 2001)

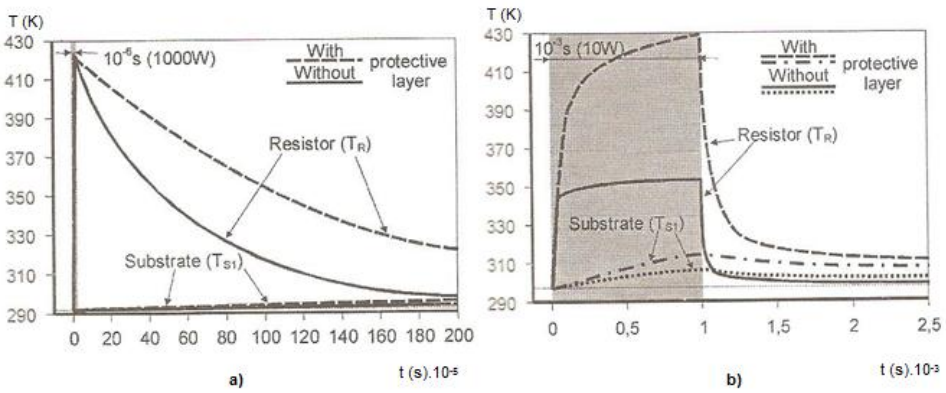

Fig. 3. – Dynamic temperature pattern in the resistive layer with/without protective layer: a) 1000 W, 1 μs, b) 10 W, 10 ms (KALITA AND WEGLARSKI, 2001)

Fig. 3a) shows the temperature pattern when the power load is 1000 W with a duration of 1 µs. An increase of the maximum achieved temperature, and influence of heat accumulation through individual layers of the model are evident from the pattern. The most evident is the effect on Fig. 3b) at a load of 10 W with a duration of 10 ms (KALITA AND WEGLARSKI, 2001).

It follows from the above that we could draw up requirements or principles for a correct positioning of the measuring section on the object, i. e. ensure a minimum thermal resistance between the measuring section and the measured object surface, ensure maximum heat transfer coefficient from the object to the measuring device, ensure minimal heat flow from the measuring device to the environment and finally one important requirement, but to a certain extent hardly feasible, not to distort a thermal field in measured location, this condition can be met by a proportion between the sensor surface and the measured object (KREIDL, 2005).

In simple terms, the objective is to maintain thermal conditions on the object surface in the same configuration as if there was no sensor. Fig. 4a) shows the deformation of the isotherms after stabilization of conditions when sensor is applied, whereas without the sensor, the isotherms take place on the object surface (CHEN ET AL., 2015).

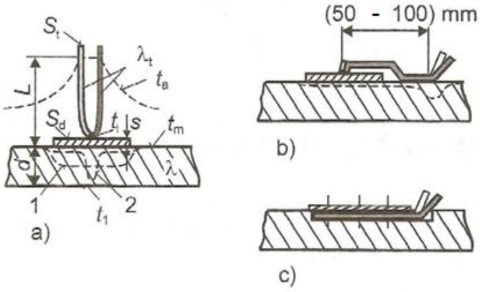

Fig. 4. – Measurement of surface temperature using a thermocouple: a) incorrect configuration, b) correct configuration, c) configuration with a cover plate (KREIDL, 2005).

When conducting a surface measurement of the object temperature, the contact of the measuring device causes a change of heat transfer between the object and the environment in the measurement location, that distorts the temperature field inside of the object (Fig. 4). In this way, the measured temperature will be different from the actual one that would be on the object without the measuring device (LINDA ET AL., 2012). The sensor attached to the object warms itself up, and therefore removes heat from the measured object. Furthermore, the sensor may cause a) permanent heat dissipation (the measured temperature is lower) or b) preventing heat dissipation (the measured temperature is higher).

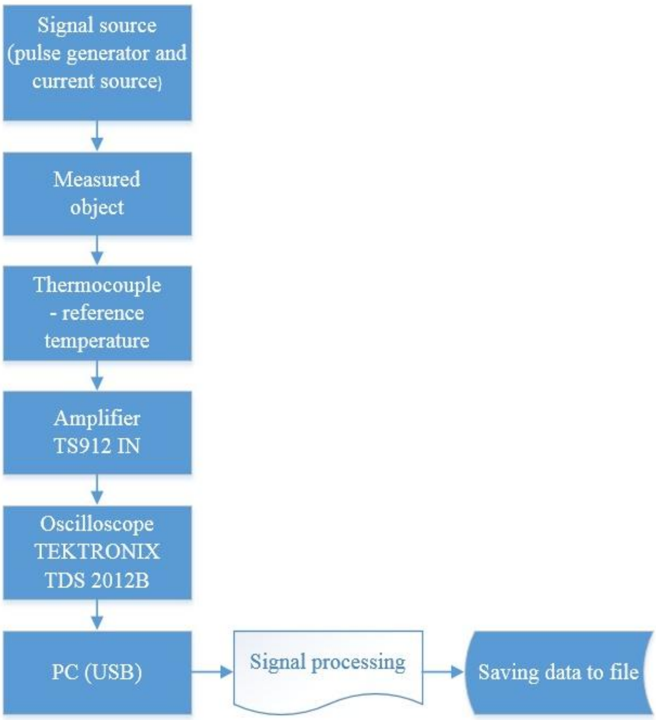

Fig. 5. – The diagram of the measuringc hain

Use of sensors is necessary for the above measurements, whose conductors must have the cross-section S_t as small as possible and low coefficient of thermal conductivity λ_t.(KREIDL, 2005)

The established laboratory environment (Fig. 5) for measurement of pulsed temperatures waveforms on selected power loaded objects, is comprised of pulse generator, loaded/measured object and measuring devices.

Used measuring methods can be divided into three groups. The first method "The measurement of a steady-state" is based on measuring surface temperature of the electric component up until its stabilization. This method is favorable for the possibility to observe the component's behavior at a permanent load, or up to the critical load, and subsequently concludes how many of such cycles the component is capable to endure without an evident damage, or without changing parameters (HUESGEN ET AL., 2008; CHEN ET AL., 2015; KALITA AND WEGLARSKI, 2001). This method is showing an apparent oscillation when measured with a micro thermocouple, which is only a reaction to the measurement of the power pulses, and this change is detailed in another type of test. This phenomenon is not as evident in the second type of thermocouple, where there is furthermore a heat dissipation through conductors that have 10 times larger diameter (YA ET AL., 2016; ZHAO ET AL., 2015).

The second method "The Pulse Test" is based on examination of the surface temperature waveform as a response to one or more pulses at the input of the system, as in our case. The result of such analysis is not only about the exact dynamics of the response, but also about the maximum transferable power of the component (HROMASOVÁ AND LINDA, 2016).

The complementary method, which is primarily used to analyze temperature distribution on the electronic component's surface, is called "The method of measuring local temperature ". In our case, we chose it with regard to selected resistors, where because of dimensions, is convenient to know waveforms of the thermal gradient on the component's surface (SONG ET AL., 2016).

RESULTS AND DISCUSSION

Metallic resistor 1 W, method "The measurement of a steady-state"

Fig. 6, Fig. 7 and Fig. 8 show the patterns for metallic resistor 1 W with load factor of 0.0385, 0.056 and 0.0741. For measurement we used thermocouples 5TC-TT 0.12 mm and CHAL0005 0.012 mm. The influence of the object's thermal capacity is evident from the patterns, which reduce system dynamics. Comparison of the thermocouple's measured patterns gives us a clear indication of the slow change in surface temperature under power load pulses (HROMASOVÁ AND LINDA, 2016). Among the measured patterns are large deflections because the changes of surface temperature are slow. It can therefore be established that the measurements can be conducted on this type of resistor even with a lower time constant systems. However, it is difficult to mention the time constant of the sensor, because the manufacturer does not exactly specify the time constant, it is defined only as "very low time constant" (LINDA AND HROMASOVÁ, 2016).

Fig. 6 shows a load factor of $z = 0.0385$ for the case number of cycles $n_p = 60$, pulse duration $t_1 = 20$ m sand no pulse period $t_2 = 500$ ms, the measured temperature is 62 °C. The time when the temperature decrease occurs via equalizing of the thermal gradient is 7.5 s.

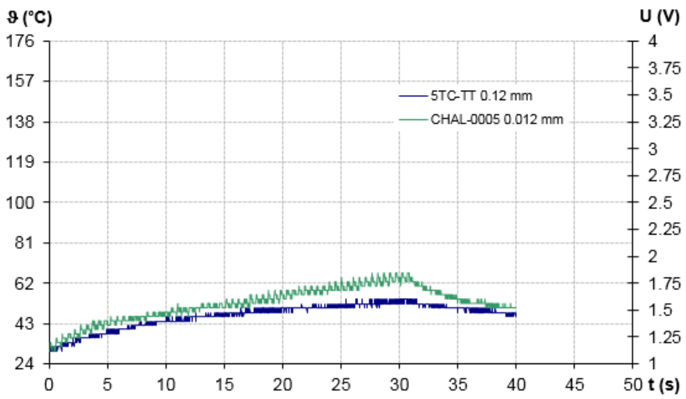

Fig. 6. – The measured waveform – case a) z = 0.0385

Fig. 7 shows a case with load factor of $z = 0.0566$ for the case $n_p = 60$, $t_1 = 30$ ms and $t_2 = 500$ ms, the achieved temperature is 89 °C, the pattern shows apparent flicks measured by the thermocouple. The difference compared to the previous case is 27 °C, when load factor increased by 0.0181.

Fig. 8 shows a case with load factor of $z = 0.0741$ for the case $n_p = 60$, $t_1 = 40$ ms and $t_2 = 500$ ms, the achieved temperature is 100 °C. The difference compared to the previous case is 11 °C, when load factor increased by 0.0175. The time when the temperature decrease occurs via equalizing of the thermal gradient is 7.5 s.

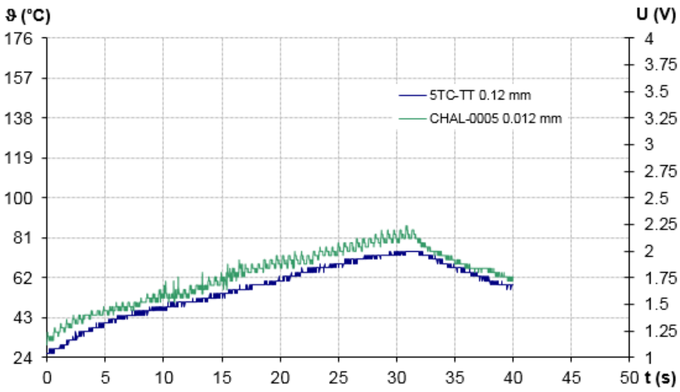

Fig. 7. – The measured waveform – case b) $z = 0.0566$

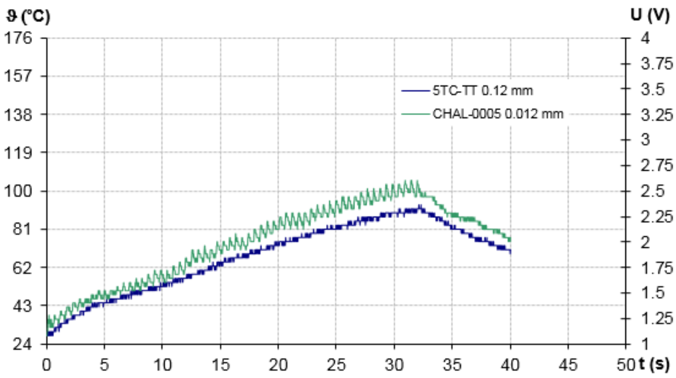

Fig. 8. – The measured waveform – case c) $z = 0.0741$

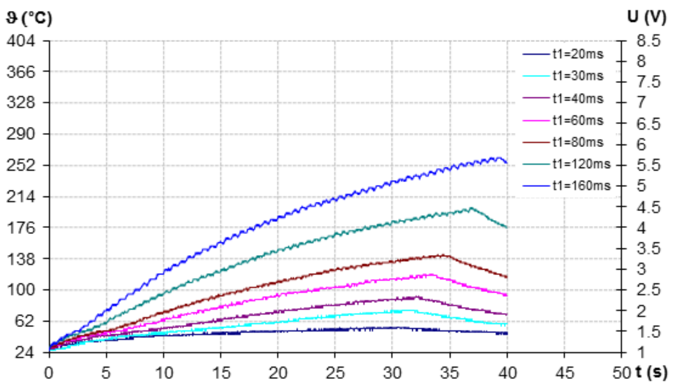

Fig. 9. – Measurement with change load factor, $n_p = 60$, $t_2 = 500$ ms

Fig. 9 shows an analysis of load factor change when a shift of decrease interval and a steepness of temperature onset occur. The time interval t_1 is in range from 20 ms to 160 ms in the nonlinear scale. For measurement we used thermocouple 5TC-TT 0.12 mm. The measured temperature reaches a maximum of 260 °C for $t_1 = 160$ ms. The temperature decrease interval shifted from 7.5 s to 2.5 s due to the temperature increase to the critical limit which is determined by the temperature gradient when 45 °C. Nonlinear scale of

the load factor was chosen as a result of low temperature increase through change by t_1 = 10 ms, and then by 20 ms. Load factor z_i is 0.0385; 0.0566; 0.074; 0.1071; 0.1379; 0.1935; 0.2424.
Fig. 10 and Fig. 11 show images from thermal camera for the case of n_p = 60, t_1 = 40 ms and t_2 = 500 ms Three images are given in chronological order, so that the delineation of the examined areas is visible. A dependence of heat dissipation through wiring of the resistor and an increased temperature of the resistor's core is obvious from the carried out images. Fig. 10 shows a warming up of the resistor, and Fig. 11 shows a cooling of the resistor.

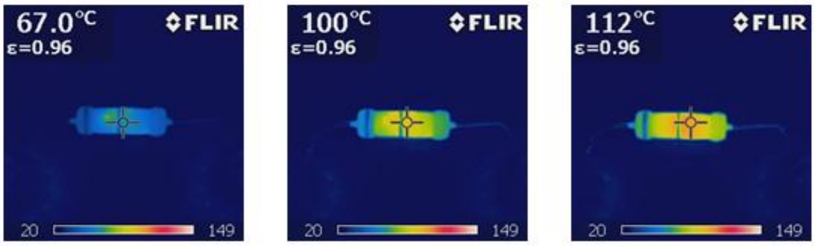

Fig. 10. – Images from thermal camera - warming up of the resistor

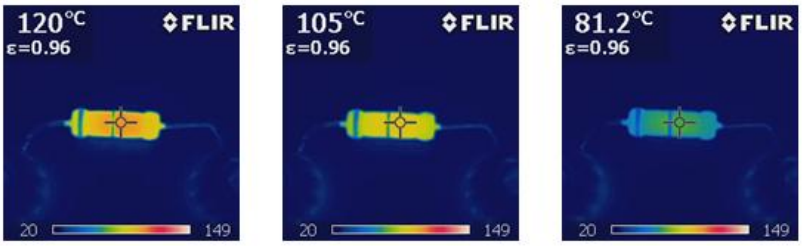

Fig. 11. – Images from thermal camera - cooling of the resistor

A strip that is presented by a cold colour is the labelling by a gold strip on the resistor. The strip disrupts the heat dissipation by its conductivity, and therefore it is not suitable to conduct a contact measurement in this location, it would lead to a lower temperature measurements. It is therefore necessary to analysis the component's surface before conducting the actual contact measurement. For the purpose of infrared measuring, the surface was not modified. The surface was abraded for the contact measurement so that the measuring would not affect the lacquering of the surface.

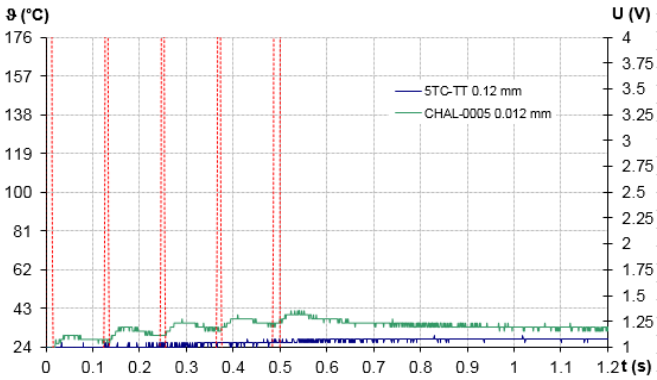

Fig. 12. – The measured waveform – case a) z = 0.167

Metallic resistor 1 W, method "The Pulse Test"
Fig. 12 shows a pulse test for a resistor with a load capacity of 1 W with load factor of 0.167 for the case number of cycles n_p = 5, pulse duration t_1 = 20 ms and no pulse periodt_2 = 100 ms. Fig. 12 shows an apparent dynamic change of the surface temperature, which, however, does not copy the pulse dependency, the expression is phase-shifted, and in this dependence is the effect of heat transfer through inlets, and a heat

radiation to the surroundings, much more evident. The maximum temperature reached is 45 °C.

Fig. 13 shows a pulse test for a resistor with load factor of 0.286 for the case $n_p = 5$, $t_1 = 20$ ms. The time change $t_2 = 50$ ms is more evident than in, previous cases and affects the final temperature pattern and therefore leads to a disruption of a heating period. This phenomenon is more noticeable with components of higher mass and is proportional to the changed time t_2.

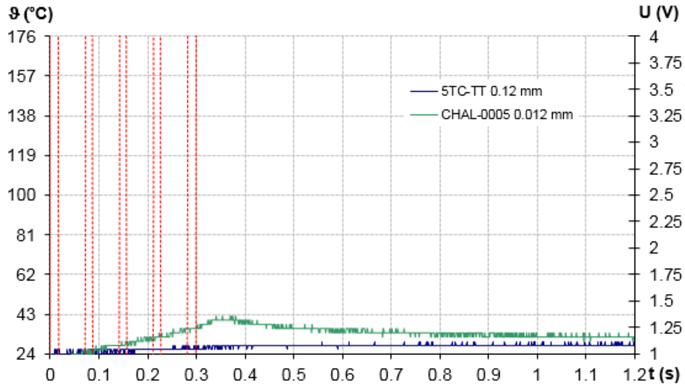

Fig. 13. – The measured waveform – case b) $z = 0.286$

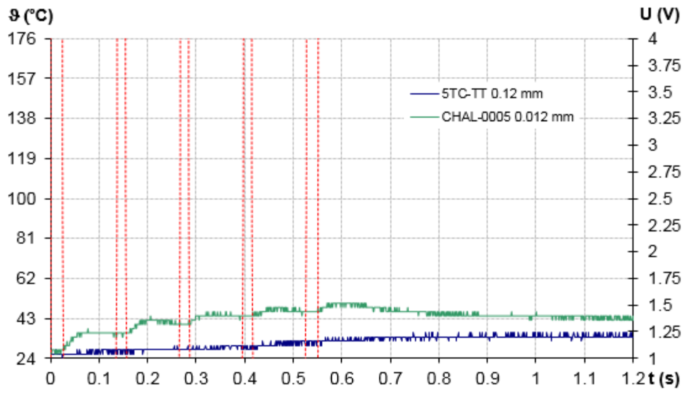

Fig. 14. – The measured waveform – case a) $z = 0.231$

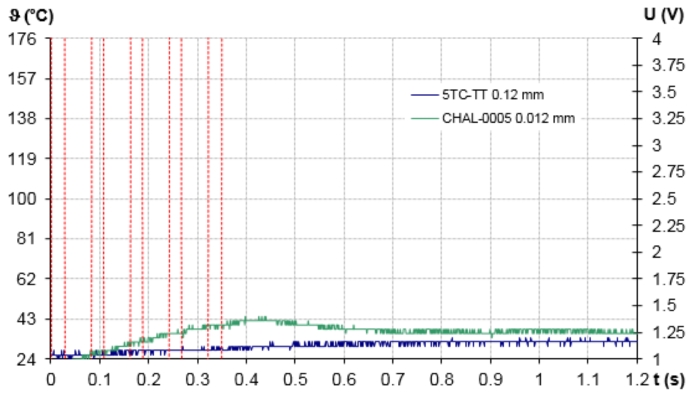

Fig. 15. – The measured waveform – case b) $z = 0.375$

Fig. 14 shows a pulse test with load factor of 0.231 for the case $n_p = 5$, $t_1 = 30$ ms and $t_2 = 100$ ms. Fig. 15 shows a pulse test with load factor of 0.375 for the case $n_p = 5$, $t_1 = 30$ ms and $t_2 = 50$ ms.

Fig. 16 shows a pulse test with load factor of 0.286 for the case $n_p = 5$, $t_1 = 40$ ms and $t_2 = 100$ ms. Fig. 17 shows a pulse test with load factor of 0.444 for the case $n_p = 5$, $t_1 = 40$ ms and $t_2 = 50$ ms.

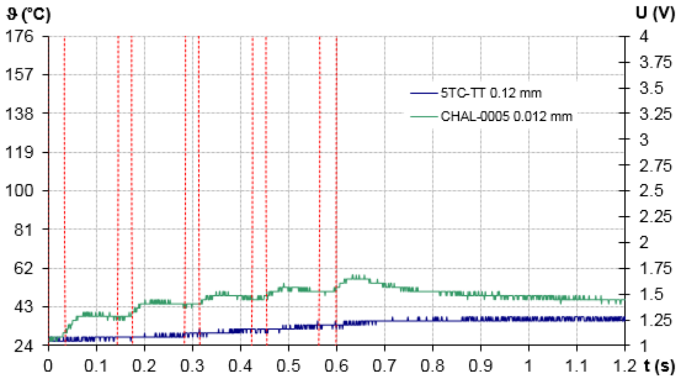

Fig. 16. – The measured waveform – case a) $z = 0.286$

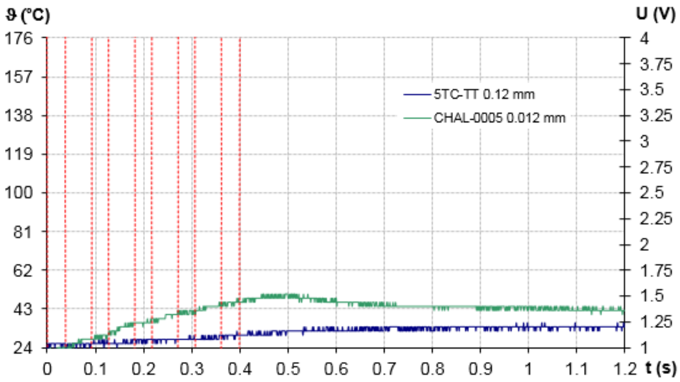

Fig. 17. – The measured waveform – case b) $z = 0.444$

Fig. 18 shows dependence and comparison of temperature vs. load factor in time sphere. See picture for evident dependencies of used thermocouples. There is an evident flattening on the other set of images, that is caused by this factor.

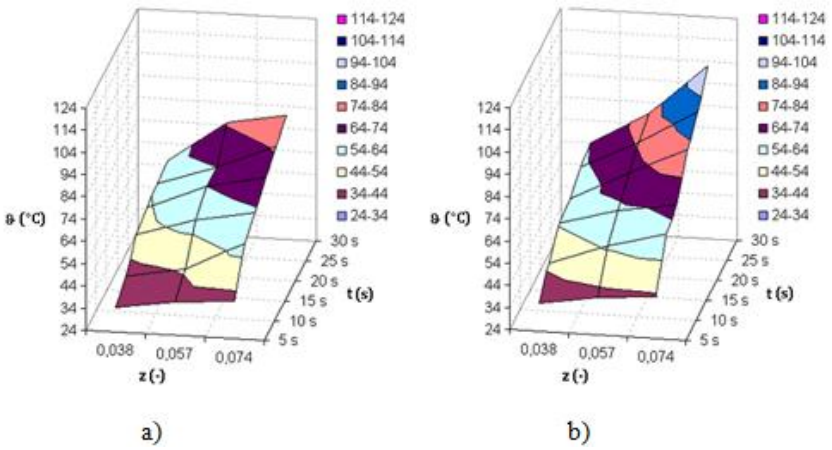

Fig. 18. – 3D dependency graph of surface temperature vs. load factor, resistor 1 W measured with thermocouple a) 0.12 mm and b) 0.012 mm

During the pulse test, only in some load factor combinations (Fig. 12 and Fig. 14) a phase shift of the measured signal is apparent, compared to the power pulses at the input, similarly as described in the measurement on the object with half load (FARRÉ, ET AL., 1998). During a temperature dependence analysis using the method to a steady state, no significant deviation is apparent when using sensors with different time constants, this is caused by the thermal inertia of the object compared to the dependencies mentioned in the paper (HROMASOVÁ AND LINDA, 2016).

CONCLUSIONS

This paper describes the dependence of the temperature pattern under dynamic load of the object with a higher time constant. Due to the high time constant, negligible power pulses of the temperature are apparent during measurement. A permanent damage takes place on the resistive layer of the resistor, which leads to a change of its parameter, esp. the resistance and the maximum power load. The resistor case is unable to transfer the created thermal energy quickly, which leads to a local overheating of the resistive layer section. The measurement is supplemented by shots from infrared spectrometry which shows thermal changes of the volume. For a cost and data evaluation reasons, this method is not applicable for continuous measurements in electronic applications. If it was necessary to use non-contact temperature measurement, it would possible to use pyrometers with a thermocouple output. They can be incorporated into existing electrotechnical measuring systems because their output characteristics are the same as a conventional thermocouple.

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