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## THE COMPUTER DATA PROCESSING AT DETERMINING OF THE GRAIN'S RESISTIVITY IN VARISTOR MATERIALS

*Abstract. Procedure of the data processing by means of Microsoft Office Excel program was developed for the oscillographic method of determining the grain's resistivity  $\rho_g$  in varistor materials. The templates for Microsoft Excel to compute  $\rho_g$  and the superheat temperature of varistor sample on a base of data obtained at scanning of the bitmaps of oscillograms were created.*

**Introduction.** The electric resistivity of grains in varistor's ceramics  $\rho_g$  is an important parameter in determining the performance of varistors [1]. The oscilloscope method for determining of  $\rho_g$ , using exponential voltage pulse, was proposed in [2]. Since the method is based on the concept of differential resistance, its correct implementation requires high-precision determination of the voltage values from the oscillograms. Previously, it was shown [3] that at scanning of raster analog oscillograms by means of graphical editor Adobe Photoshop or specially developed for this purpose the program, one can ensure the accuracy of voltage determining with a relative error does not exceed  $\pm 1,5\%$ . When determining the electrical resistivity of the grains in varistor ceramics substantial amount of data obtained by scanning of oscillograms, time consuming to process them. Greatly simplify the processing of data and reduce the time allows the program to work with spreadsheets, Microsoft Office Excel.

**Problem definition.** The aim of this work is to develop a technique for processing data in Microsoft Excel at determining the grain resistivity in varistor ceramics and to create the templates for this technique.

**Major part.** The method proposed in [2], is based on the dependence of the differential resistance  $\rho_{dif}$  of varistor ceramics on the current density  $J$ , which is described by the expression:

$$\rho_{dif} = \rho_g + A^* J^1, \quad (1)$$

where  $A^*$  is the constant value.

According to the equation (1) a linear relationship between the differential resistivity of the varistor ceramic  $\rho_{dif}$  and the reciprocal current density  $J^{-1}$  takes place. Therefore, if to build the dependence

$\rho_{dif} = f(J^1)$  using a plot of current-voltage characteristics (CVC) and linearly extrapolating this dependence to the  $J^1 = 0$ , we can find the resistivity of grain  $\rho_g$ .

To get a plot of current-voltage characteristics for sample of varistor at high currents, method uses a single voltage pulse of exponential form

$$U(t) = U_0 \exp(-t/\tau), \quad (2)$$

where  $U_0$  – pulse amplitude,  $t$  – time,  $\tau$  – time constant.

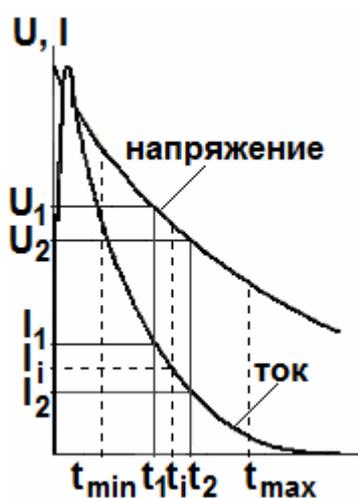


Figure 1 – Schematic images of oscillograms

In Fig. 1 schematically shows the oscillograms of voltage and current, recorded by means of a two-beam storage oscilloscope. Current oscillogram was recorded as the voltage drop across a precision resistor ( $R_T = 1$  Ohm) connected in series with the sample. Oscillograms in Fig. 1 represent in a parametric form the current-voltage characteristic of varistor sample where the time  $t$  is parameter. To determine of the grain resistivity it need to use the plots of oscillograms lying in the time interval

$$t_{min} \leq t \leq t_{max}.$$

These plots are necessary for building of the dependence (1). Plots divided into equal intervals  $\Delta t = t_2 - t_1$ , corresponds to the time  $t_i = (t_2 + t_1)/2$ . For points of time  $t_i$  the values of current  $I_i$  and differential resistance  $R_{dif}$ , can be found using the formulas:

$$I_i = (I_1 + I_2)/2, \quad (3)$$

$$R_{dif} = (U_1 - U_2)/(I_1 - I_2). \quad (4)$$

Basing on the values of area  $S$  and the thickness  $L$  are known for a sample, the values  $R_{dif}$  and  $I_i$  lead to specific values  $\rho_{dif}$  and  $J$ , is plotted (1) and by linear extrapolation to the  $J^1 = 0$  is determined the value of  $\rho_g$ .

The digital camera was used for creation of bitmaps of analog oscillograms. The thus obtained image files allow obtaining necessary information using the Adobe Photoshop program or by the special program to scan of raster images [3].

The scanning results are the coordinates of points on bitmap of oscillograms, which allow finding the voltage at these points using a scale voltage [3]. The error in this case not exceed  $\pm 1,5\%$ . The array of coordinate values in pixels is recorded at scanning of oscillograms (horizontal coordinate - time  $t_i$ , vertical - voltage  $U_i$  and current  $I_i$ ). This array can be processed by means of Microsoft Excel for plotting the dependence  $\rho_{dif} = dE/dJ = (dU/dI)(S/L)$  on the inverse current density

$J^1$ . In this case it is convenient to use the pre-built templates in Microsoft Excel. Example of such template is shown in Fig. 2.

|    | A    | B    | C   | D    | E    | F   | G             | H  | I            | J        | K       | L                   | M    | N    | O        |                |  |  |  |
|----|------|------|-----|------|------|-----|---------------|--|--------------|----------|---------|---------------------|------|------|----------|----------------|--|--|--|
| 1  | t1   | I1   | U1  | t2   | I2   | U2  | J, А см-2     | 1/J  | dE/dJ, Ом см | Rдин, Ом | Rст, Ом | beta                |      |      |          |                |  |  |  |
| 2  | 1300 | 1186 | 195 | 1600 | 1389 | 272 | 63,7          | 0,016  | 2,978        | 10,4     | 99,6    | 9,6                 |      |      |          |                |  |  |  |
| 3  | 1350 | 1225 | 206 | 1650 | 1414 | 283 | 57,8          | 0,017  | 3,220        | 11,3     | 108,4   | 9,6                 |      |      |          |                |  |  |  |
| 4  | 1400 | 1265 | 220 | 1700 | 1437 | 296 | 51,9          | 0,019  | 3,516        | 12,3     | 119,2   | 9,7                 |      |      |          |                |  |  |  |
| 5  | 1450 | 1301 | 234 | 1750 | 1461 | 311 | 46,4          | 0,022  | 3,855        | 13,5     | 130,9   | 9,7                 |      |      |          |                |  |  |  |
| 6  | 1500 | 1331 | 247 | 1800 | 1479 | 324 | 42,0          | 0,024  | 4,191        | 14,7     | 142,8   | 9,7                 |      |      |          |                |  |  |  |
| 7  | 1550 | 1361 | 260 | 1850 | 1496 | 337 | 37,6          | 0,027  | 4,622        | 16,2     | 157,3   | 9,7                 |      |      |          |                |  |  |  |
| 8  | 1600 | 1389 | 272 | 1900 | 1513 | 350 | 33,5          | 0,03   | 5,127        | 17,9     | 174,0   | 9,7                 |      |      |          |                |  |  |  |
| 9  | 1650 | 1414 | 283 | 1950 | 1528 | 362 | 29,8          | 0,034  | 5,677        | 19,9     | 192,6   | 9,7                 |      |      |          |                |  |  |  |
| 10 | 1700 | 1437 | 296 | 2000 | 1539 | 374 | 26,6          | 0,038  | 6,295        | 22,0     | 213,4   | 9,7                 |      |      |          |                |  |  |  |
| 11 | 1750 | 1461 | 311 | 2050 | 1550 | 387 | 23,4          | 0,043  | 7,062        | 24,7     | 240,9   | 9,7                 |      |      |          |                |  |  |  |
| 12 |      |      |     |      |      |     | Rст =         | Rт(Mu(U1-U2))/(Ml(I2-I1))-1)                           |              |          |         |                     |      |      |          |                |  |  |  |
| 13 |      |      |     |      |      |     | Rдин =        | (dE/dJ)L/S L - толщина образца; S - площадь электродов |              |          |         |                     |      |      |          |                |  |  |  |
| 14 |      |      |     |      |      |     | beta =        | Rст/Rдин   |              |          |         |                     |      |      |          |                |  |  |  |
| 15 |      |      |     |      |      |     | Rт -          | величина сопротивления токового резистора (Rт = 1 Ом)  |              |          |         |                     |      |      |          |                |  |  |  |
| 16 |      |      |     |      |      |     | Для           | массштаба напряжения                                   |              |          |         | Для                 |      |      |          | массштаба тока |  |  |  |
| 17 |      |      |     |      |      |     | 2000          | 1229   | пикселей     |          |         |                     | 1700 | 1501 | пикселей |                |  |  |  |
| 18 |      |      |     |      |      |     | 2000          | 423  | пикселей     |          |         |                     | 1700 | 288  | пикселей |                |  |  |  |
| 19 |      |      |     |      |      |     | Масштаб       | напряжения =   |              |          |         | 0,12407 В/пиксель   |      |      |          |                |  |  |  |
| 20 |      |      |     |      |      |     | Масштаб       | тока =   |              |          |         | 0,004122 А/пиксель  |      |      |          |                |  |  |  |
| 21 |      |      |     |      |      |     | 1632          |  |              |          |         |                     |      |      |          |                |  |  |  |
| 22 |      |      |     |      |      |     | 1690          |  |              |          |         |                     |      |      |          |                |  |  |  |
| 23 |      |      |     |      |      |     | 1632          | Нуль тока =  |              |          |         | 1632 пикселей       |      |      |          |                |  |  |  |
| 24 |      |      |     |      |      |     | 1679          | Нуль напряжения =                                      |              |          |         | 1685 пикселей       |      |      |          |                |  |  |  |
| 25 |      |      |     |      |      |     | Масштаб       | времени =  |              |          |         | 0,02353 мкс/пиксель |      |      |          |                |  |  |  |
| 26 |      |      |     |      |      |     | 1310          | 684  |              |          |         |                     |      |      |          |                |  |  |  |
| 27 |      |      |     |      |      |     | 2160          | 684  |              |          |         |                     |      |      |          |                |  |  |  |
| 28 |      |      |     |      |      |     | Начало        | отсчета времени =                                      |              |          |         | 525 пикселей        |      |      |          |                |  |  |  |
| 29 |      |      |     |      |      |     | Измерительный | интервал времени =                                     |              |          |         | 17,6 мкс            |      |      |          |                |  |  |  |
| 30 |      |      |     |      |      |     | Время         | до начала измерительного интервала =                   |              |          |         | 18 мкс              |      |      |          |                |  |  |  |

Figure 2 – Template of Microsoft Excel for the processing of data obtained after scanning raster images of voltage and current oscillograms

Array of scanned data for inputing into the template is represented as a two-dimensional array of 10 rows and 6 columns. Array of scanned data for input to template represents as a two-dimensional array of 10 rows and 6 columns. In Fig. 2 the columns of this matrix are denoted as  $t_1$ ,  $I_1$ ,  $U_1$ ,  $t_2$ ,  $I_2$ ,  $U_2$ . The template columns  $J$ ,  $1/J$ ,  $dE/dJ$ ,  $R_{dyn}$ ,  $R_{st}$ ,  $beta$  use formulas to ensure calculation of  $J$ ,  $1/J$ ,  $\rho_{dif} = dE/dJ$ , dynamic and static resistance  $R_{dyn} = (U_1 - U_2)/(I_1 - I_2)$ ,  $R_{st} = (U_1 + U_2)/(I_1 + I_2)$  and the nonlinearity coefficient of varistor  $beta = R_{st} / R_{dyn}$ . According the template columns  $1/J$ ,  $dE/dJ$  we can built the dependence (1) in Microsoft Excel. The option "Add trend line" is used for the construction of this dependence. It provides carrying out a straight line through the data points by the method of least squares. This line needs to perform linear extrapolation in determining the value of  $\rho_g$ .

The window of Microsoft Excel after plotting the dependence (1) is shown in Fig. 3. If to select on a straight line two points with coordinates  $\rho_{1dif}$ ,  $1/J_1$  and  $\rho_{2dif}$ ,  $1/J_2$ , one can perform the calculation of  $\rho_g$  by the formula:

$$\rho_g = \rho_{1dif} - 1/J_1 \cdot \frac{\rho_{1dif} - \rho_{2dif}}{1/J_1 - 1/J_2}. \quad (5)$$

This formula for the template shown in Fig. 3 is used in the cell, which is preceded by the words "Расчет удельного электрического сопротивления зерна". After substituting in the formula of the above coordinates, Microsoft Excel provides input the grain resistivity  $\rho_g$  into this cell of template.

In this paper the scanning of raster images of oscillograms for getting the original dataset was performed with a step 25 pixels along the time axis (interval  $3 \mu s$ ). For calculation of differential resistance  $\Delta U/\Delta I = (U_1 - U_2)/(I_1 - I_2)$  the points of voltage and current, spaced at an interval of 75 pixels along the time axis were used.

The pulse is used for measurement causes heating of the varistor's sample. The overheating temperature  $\Delta T$  at any time  $t$  can be found from bitmaps of voltage and current oscillograms. Their scanning, from the time of the pulse with a given time step  $\Delta t = t_i - t_{i+1}$  allows to obtain the arrays of voltage  $U(t_i)$ ,  $U(t_{i+1})$  and of current  $I(t_i)$ ,  $I(t_{i+1})$ . These arrays allow us to calculate the overheating temperature of the sample, taking into account that for the duration of the short pulse ( $\tau$  no more than  $350 \mu s$ ), the heat do not dissipate, ie all power generated by electric current goes to heating the sample.

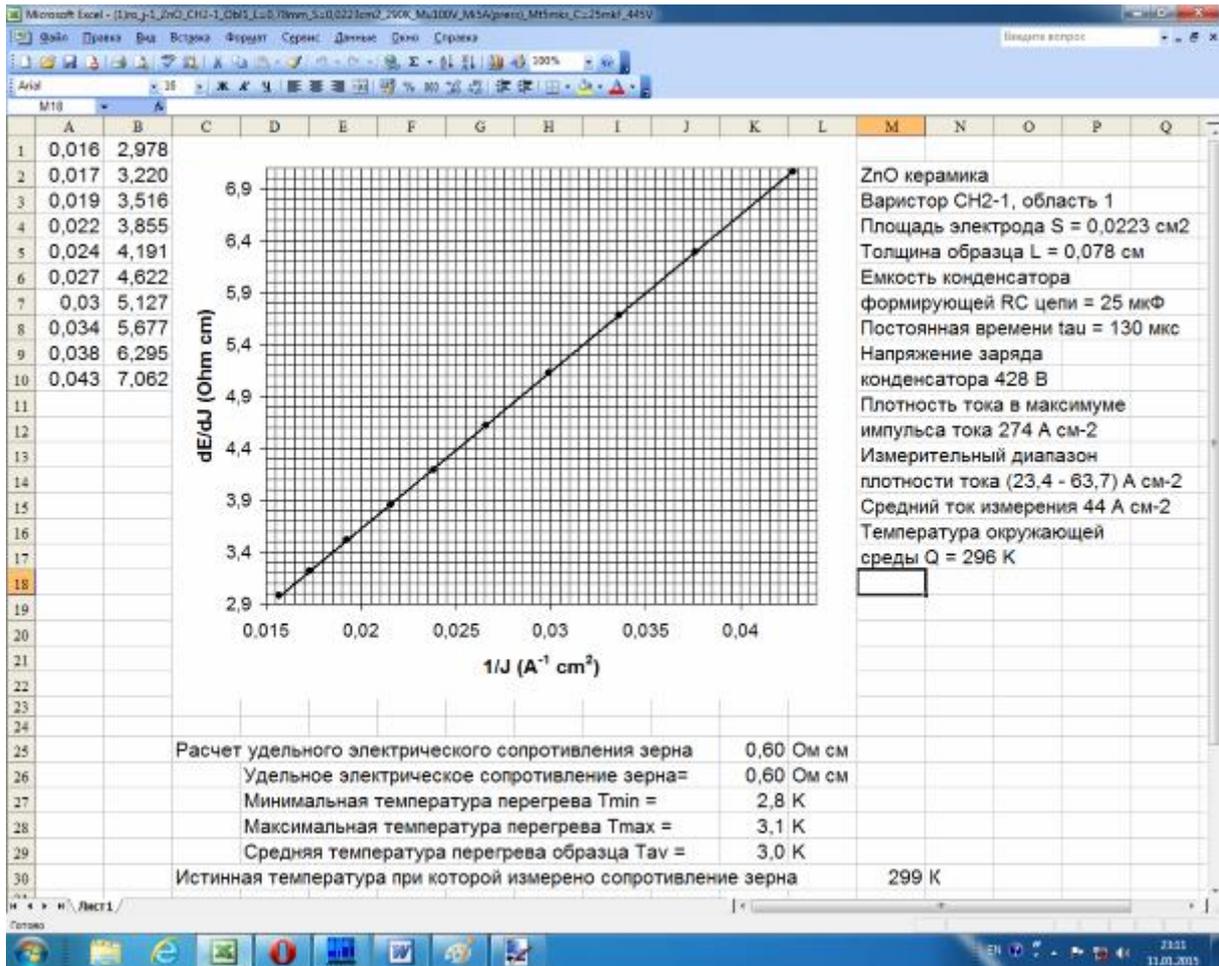


Figure 3 – Template of Microsoft Excel for plotting the dependence

$\rho_{dif} = f(J^1)$ . Building performed on the data presented in Fig. 2

If the instantaneous current and voltage have the values  $I(t)$  and  $U(t)$ , then for an infinitesimal time interval  $dt$  in the sample has dissipated the energy  $dW(t) = U(t) I(t) dt$ , which increases its temperature on

$$d \Delta T(t) = \frac{U(t)I(t)dt}{c_T d_m SL}, \quad (6)$$

were  $c_T$  и  $d_m$  are specific heat capacity and density of the varistor's ceramics.

If the equation (6) to integrate by time then one can be found the superheat temperature of the sample  $\Delta T(t)$  at time moment  $t$ :

$$\Delta T(t) = \frac{1}{c_T d_m SL} \int_0^t U(t)I(t)dt. \quad (7)$$

Integral in the equation (7) is calculated by trapezium method using arrays of voltage  $U(t_i)$ ,  $U(t_{i+1})$  and of current  $I(t_i)$ ,  $I(t_{i+1})$ . Estimated relationship for the superheat temperature  $\Delta T$  at time  $t$  in this case has a view:

$$\Delta T(t) = \frac{1}{2c_T d_m SL} \sum_{i=1}^N (U(t_{i+1})I(t_{i+1}) + U(t_i)I(t_i))(t_{i+1} - t_i), \quad (8)$$

were  $N = t/\Delta t$ ,  $\Delta t = t_{i+1} - t_i = \text{const}$ .

For getting the arrays  $U(t_i)$ ,  $U(t_{i+1})$ ,  $I(t_i)$ ,  $I(t_{i+1})$ , the scanning with a step 25 pixels was performed. Processing was carried out in Microsoft Excel using the menu option "sum"  $\Sigma$  for calculating the sum in expression (8).

Arrays of the scanning data in pixel for the time, current and voltage are inputed into the columns of template  $t_i$ ,  $I_i$  and  $U_i$ . In the template columns  $t_i$ ,  $P_i$ ,  $dT_i$  apply formulas that by scale and array elements  $t_i$ ,  $I_i$  and  $U_i$  calculate the instantaneous value of the time  $t_i$ , power  $P_i = U(t_i)I(t_i)$  and the change of temperature  $dT_i = (U(t_i)I(t_i) + U(t_{i+1})I(t_{i+1}))(t_{i+1} - t_i)/(2c_T d_m SL)$ .

To calculate the superheat temperature of the sample  $\Delta T(t_{i+1})$  at time  $t_{i+1}$  the column of template  $dT_i$  subgroup is copied up a time  $t_{i+1}$ . To this subgroup is used menu option "sum"  $\Sigma$ . Performed the summation of the increments of temperature, which gives the desired value  $\Delta T(t_{i+1})$ . In Fig. 4 the maximum overheating temperature of varistor's sample in the measurement of  $\rho_g$  is obtained by summation of all values in a column  $dT_i$ . This temperature one can be seen after a line of text "Максимальная температура перегрева =".

If copying the different subgroups of values in the array  $dT_i$  and applying to them the option "sum"  $\Sigma$ , we can construct a time dependence of the overheating temperature begin from the time activity of the voltage pulse. In Fig. 5b such dependence is shown for varistor CH2-1.

As can be seen (Fig. 5b) the temperature  $\Delta T$  changes most strongly in the interval of time close to beginning of the pulse voltage (the reference time  $t = 0$ ). Over time, the rate of  $\Delta T$  change decreases and superheat temperature reaches a constant value corresponding to the maximum overheating temperature of varistor's sample under the influence of the voltage pulse.

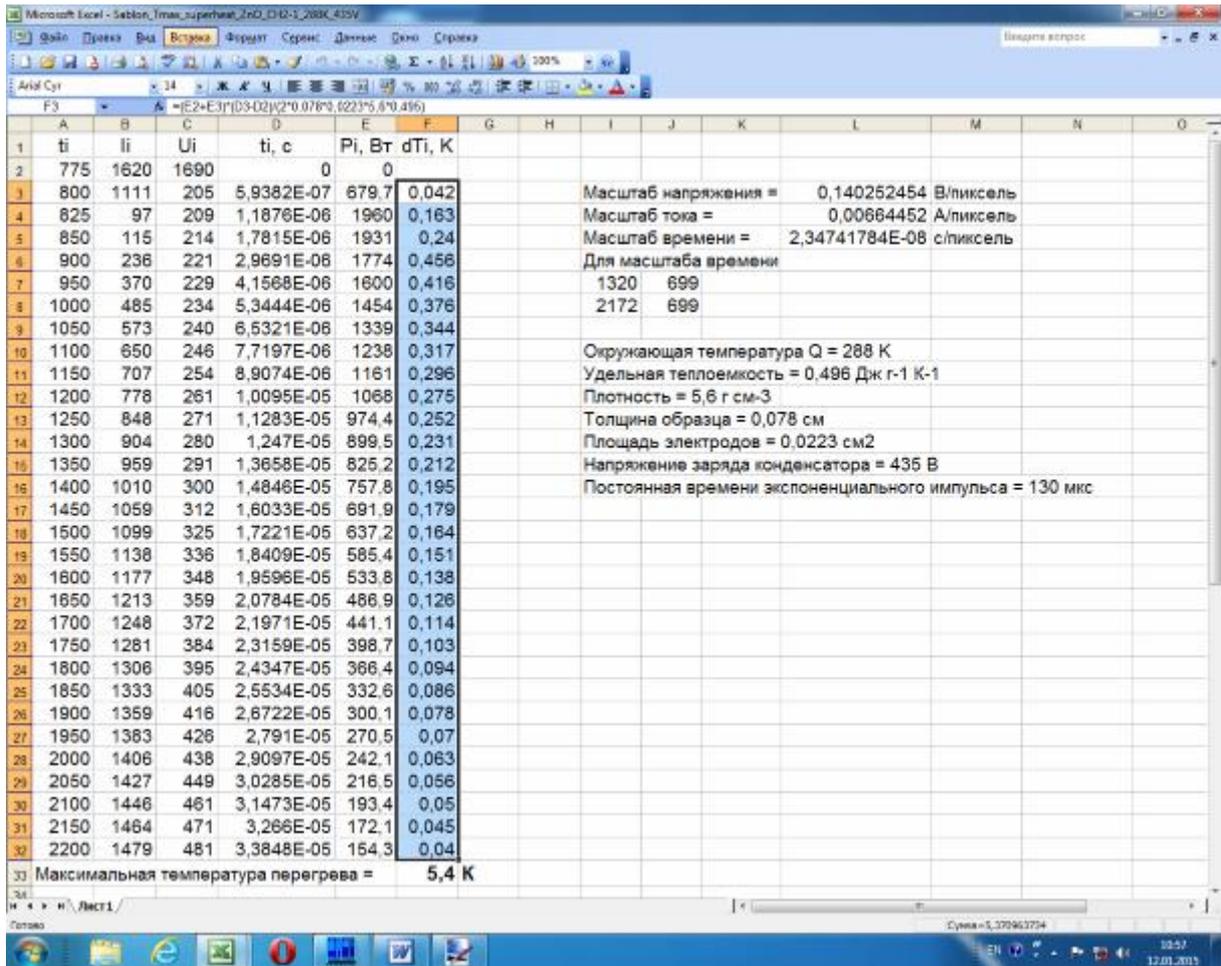


Figure 4 – Template for calculating of the superheat temperature of the varistor’s sample

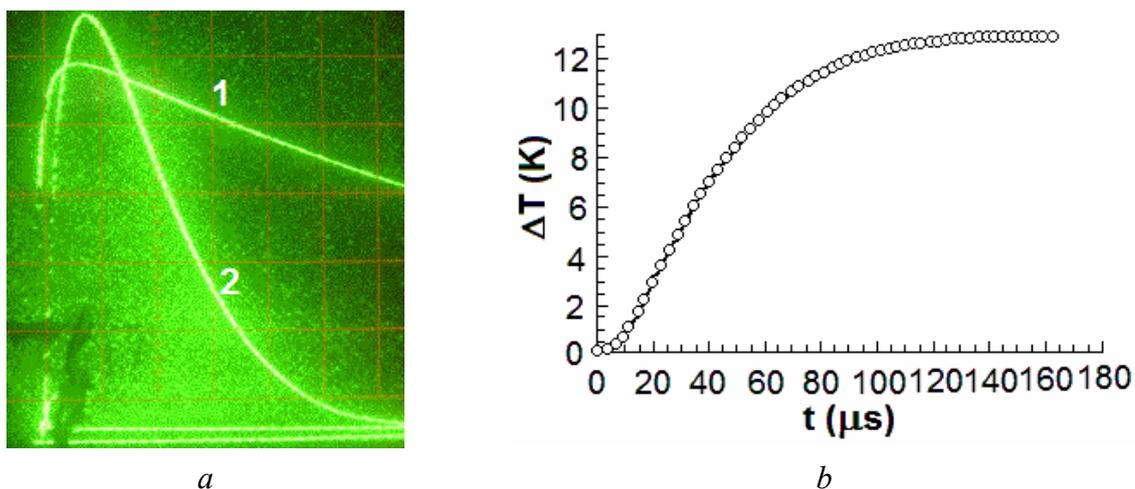


Figure 5 – The bitmap image of oscillograms - a (1 - voltage, 2 - current) and built using it the dependence of superheat temperature from time for varistor CH2-1 -b. Scale: time – 0.1163  $\mu\text{s}/\text{pixel}$ ; voltage – 0.1395 V/pixel; current – 0.0034 A/pixel. Geometry of a sample:  $L = 0.78$  mm,  $S = 0.0231$  cm<sup>2</sup>. The time constant of the exponential pulse voltage  $\tau = 340$  ns.

Ambient temperature 297 K.

**Conclusion.** Create the templates for program Microsoft Office Excel, to simplify and expedite the processing of the data obtained by means of scanning the bitmap images of oscillograms of analog oscilloscopes. Templates are designed for use in oscillographic method of determining the specific electrical resistivity of grains in varistor materials. The possibility of determining superheat temperature of varistor’s sample under the influence of voltage pulse by means of oscillograms was shown. The template of Microsoft Excel to calculate the superheat temperature was developed.

## REFERENCES

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