Analysing experimental research data with the help of numerical derivative

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A lot of research data is generated during carrying out experiments like for example in case of oscilloscope records. In this huge amount of information a lot of it is irrelevant. Therefore finding the useful information can be difficult. The influence of closing a short-circuit current with an electromagnetic relay on its contacts was tested. During those tests a large amount of data, recorded by oscilloscope, was created. Only a small portion of this information was useful. The problem was to find specific information in all of the gathered data. This article presents the usage of scientific software designed to solve this issue. It also describes the usage of numerical derivate for finding a specific time range of collected waveforms .

KEYWORDS: numerical methods, derivative, electrical contacts

1. Derivative and its numerical interpretation

Derivative of a function $f(x)$ at point x_0 is a limit defined as:

$$f'(x_0) = \lim_{\Delta x \to 0} \frac{\Delta f}{\Delta x} = \lim_{\Delta x \to 0} \frac{f(x_0 + \Delta x) - f(x_0)}{\Delta x} \tag{1}$$

When $\Delta x \to 0$ then $P_1 \to P_0$ and secant k becomes tangent to curve $y = f(x)$ at point $P_0(x_0, f(x_0))$ then $f'(x_0) = tg\ \alpha$ [1] (Fig. 1).
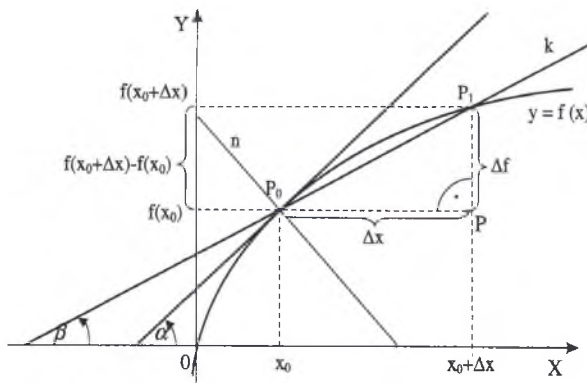

Fig. 1. Graphical definition of derivative [1]

Numerical derivative is based on the Taylor series [2]:

$$f(x) = f(x_0) + (x-x_0)f'(x_0) + \frac{(x-x_0)^2}{2!}f''(x_0) + \dots$$
$$+ \frac{(x-x_0)^n}{n!}f^{(n)}(x_0) + \dots \tag{2}$$

The explication of Taylor series f_{k-1} in the neighbourhood of point x_0 gives us two point equation for numerical derivative [2]:

$$f'_k = \frac{f_{k+1} - f_k}{h} \tag{3}$$

where $h = x_{k+1} - x_k$ and $f_k = f(x_k)$.

Derivative of a function $y=f(x)$ informs about rate of change of the function y depending on the rate of change of the argument x. Greater the change in value of function y the grater the change in its derivative.

2. Experimental data problem

Experiments regarding switching on short circuit current with an electromagnetic relay where conducted. Tests were done in circuit shown on Fig. 2. Current limiting resistor R was used to set peak current. Circuit was protected by a miniature circuit breaker *FI*, type B and nominal current same as the electromagnetic relay *ER* under test. Short circuit current and voltage between electromagnetic relays contacts was measured with the use of current *CP* and voltage probes.
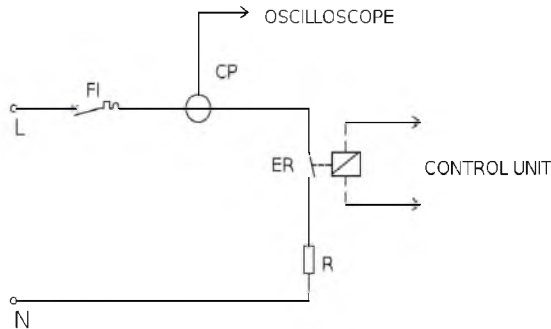

Fig. 2. Test circuit: FI – miniature circuit breaker, CP – current probe, ER – tested electromagnetic relay, R – current limiting resistor

At each test the current flowing through the contacts and voltage between them where recorded (Fig. 3). During those tests a large amount of raw data was gathered which needed to be processed and analysed.
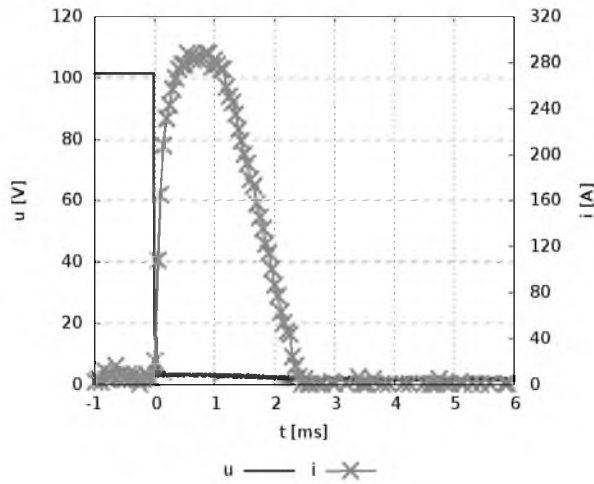
Fig. 3. Example graph presenting current and voltage between contacts

These experiments focused on the study of contact welding during the closing operation of electromagnetic relay. This welding could have been influenced by micro-arcing phenomena [3] and it takes place in a short time at beginning of the closing operation. This time can vary between 20 to 100 μs. When the electrical contacts are at the end of closing operation a rise of electrical current can be observed together with a voltage drop between these contacts (Fig. 4). This voltage drop reaches a value of about 16 volts and it is related to the presence of electrical arc. This arc phenomena can soften electrical contacts surface or even melt it, in a result creating an electrical weld [4].
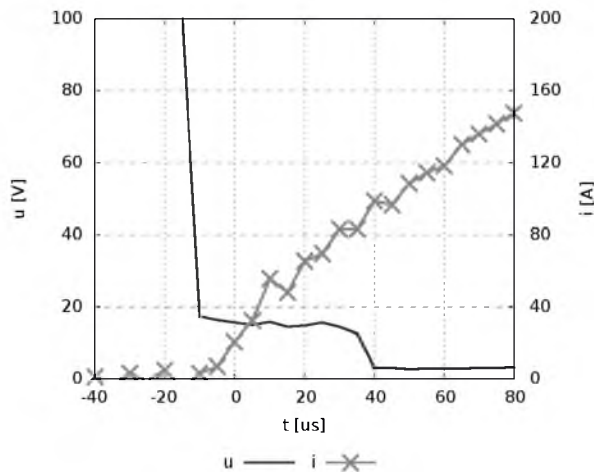

Fig. 4. Micro-arcing recorded during a closing operation of electromagnetic relay

Because all experiments resulted in similar way a single solution could be developed. By analysing the data two significant points were noticed. First when the voltage dropped from its maximum value and the current started to rise. Second point when the voltage dropped to almost zero. Best way to find this two points was by using a derivative.

3. Numerical derivative as a solution

A script was created in Scilab [5], an open source software for numerical computation. Its goal was to automatically read all the acquired data recorded by oscilloscope, find the correct part of a waveform and calculate all the necessary variables. Original waveform used in the calculations is shown on figure 3. Result of calculating the numerical derivative is shown on Figure 5. The main window shows the entire numerical derivative value of voltage over time. The search part of the waveform is presented in the smaller window inside Figure 5.
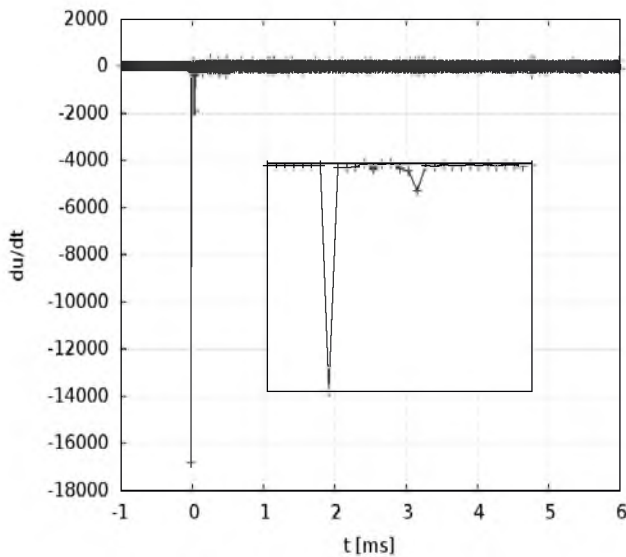

Fig. 5. Numerical derivative of experimental data

There are two visible peaks that show where the voltage drops from its maximum value and later on when it reaches zero. Those two points create a range, based on which the time duration of the micro arc and its energy are calculated.

Aligning voltage time curve and its derivative on a single chart, as presented on Figure 6, shows that those two peaks represent beginning and end of the electrical arc.
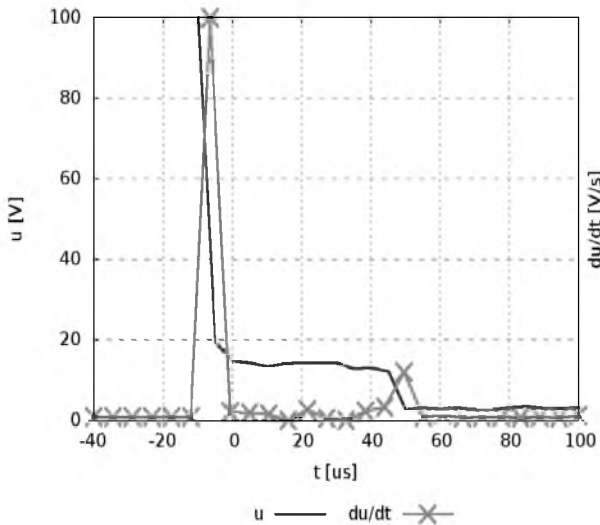
Fig. 6. Voltage time curve and its numerical differential

Part of the script responsible for finding the micro-arcing time frame during contacts close operation is presented on Figure 7. The numerical derivative as defined by equation 3 is realized by the command *diff(volts)/tz*, where *diff* computes the difference function, *volts* is a waveform recorded by the oscilloscope representing the voltage between the electric contact and t_z is time interval (equal to *h* in eq. 3).

```
[vmax, vstart] = max(abs(diff(volts)/tz))

vend = size(volts,'r');

tvolts = volts(vstart+1:vend);

[vmax, vend] = max(abs(diff(tvolts)/tz))
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Fig. 7. Searching for beginning and end of interval (part of Scilab script)

Furthermore the *vmax* represents the maximum value of waveform and *vstart* represents the point in vector at which *vmax* occurred. Next *tvolts* a temporary vector used to find the next maximum value which represent the second searched point. The *max* function is used to find the maximum value in matrix and point at which it occurred, *abs* function returns the absolute value of argument.

Results of the calculations include information such as electrical arc time of burn, peak current and the Joule's energy. Other data can be acquired as needed. Complete results and their analysis is not described in this paper.

4. Conclusion

Analysing experimental data could pose a problem, especially when large amount is collected. A solution to this problem may be the use of special scientific software, like Scilab, that is capable of processing all kinds of experimental research data. This software allows the use of all kinds of mathematical tools, for example the derivative of a function. With the proper algorithm it is possible to create a script that automatically searches through gathered data, processes it and calculates the necessary values, on which a researcher can work later on.

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