The estimation of the polymer fuses features

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***Abstract*-**The protection of electrical circuits against the overload or short circuits is usually achieved by the single use of blow-out fuses. The paper contains the examining results of the multiple use of polymer fuses. The static and dynamic characteristics of selected fuses are acquired on the test station. Some interesting features of the polymer fuses, not included in datasheets, are carried out. The courses of characteristics in comparison to their technical data with elements of accuracy analysis are discussed.

I. The polymer fuses attributes

Fuses are the basic protection devices used in circuits. Except fuses there are also used bimetallic devices. The first ones break the circuit in the event of short circuit. The second ones provides overload protection. Both devices prevent damage to the connected equipment and cables. The disadvantageous feature of the traditional fuses is their blow-out. In consequence of that there is a break in a circuit and necessity of replacement. The typical bimetallic devices does not need to be replaced. They can back to their idle state. However they can reset even if the fault is not removed. It causes a cycling on and off between the fault event and a protected state which may damage the equipment.
Nowadays above mentioned elements may be replaced by one freed from described problems. It is polymer fuse (PPTC - Polymeric Positive Temperature Coefficient), called resettable fuse [1-14]. It realizes functions like devices above, however it does not need to be replaced and it does not expose the equipment on damage.
The PPTC fuses are constructed with a non-conductive polymer plastic, which can change in two phases. In normal state (without a temperature increase) the polymer has a crystalline or semi-crystalline structure, where the molecules form a regular structure (Fig.1.a).

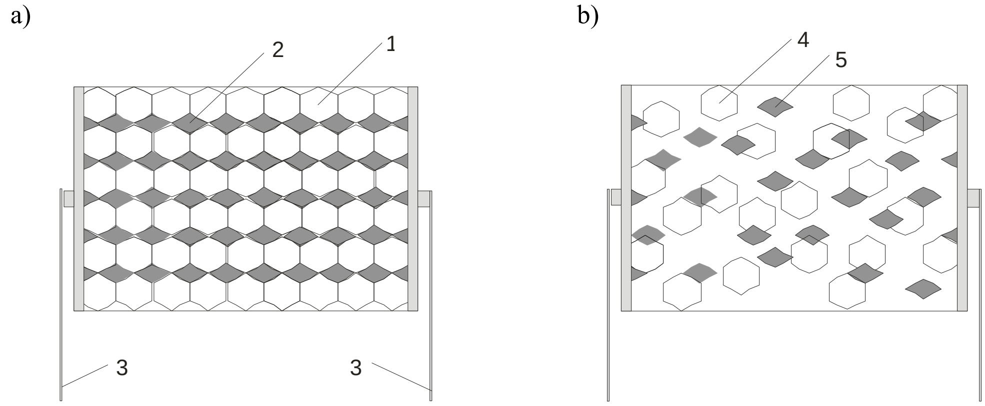

Figure 1. The polymer in two phases with conducting chains of carbon black:
1. Non-conductive polymer in crystalline state, 2. Conducting chains of carbon black molecules, 3. Electrodes, 4. Non-conductive polymer in amorphous state, 5. Broken chains of carbon black molecules

When the temperature increase the polymer comes to amorphous state, where the molecules are aligned randomly (Fig.1.b). There is an increase in volume.
In the structure of polymer a conductive material is combined, it means a carbon black. It forms many conductive paths, causing the resistance of PPTC's become low. There is in a crystalline state of polymer. A current flow through the fuse, causes its heating (I^2R losses). During a small temperature increase, changes are negligible. The structure of polymer is still arranged. The resistance is low. However, if a current increases

enough (and corresponding temperature too) there is a polymer state change to amorphous (it is about 125 °C). The molecules of polymer's and carbon black are broken. The resistance of PPTC's rises rapidly (Fig.2).

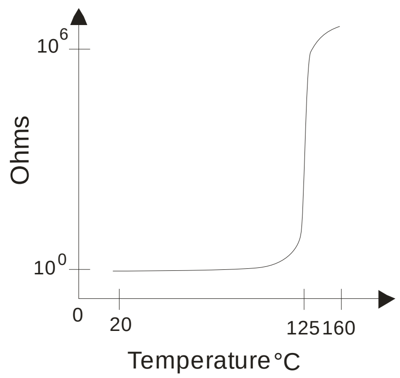

Figure 2. The polymer fuse resistance vs. temperature behavior.

Depending on amount of carbon black the initial resistance acquires the value of miliohms or ohms. After the temperature increase, the resistance reaches a value in megaohms. Current flow is reduced considerably. Only a small residual current is still present. This small trickle current is sufficient to maintain the fuse device in the high resistance state (self-holding state).
The high-resistance state of PPTC is called a tripping state. The fuse remains latched until the fault is cleared or power to the circuit is interrupted. After that the device cools down. When it happens PPTC is self-resetting. Depending on cooling conditions and ambient temperature it takes from a couple of seconds to a couple of minutes. The polymer returns to its crystalline phase. The volume decreases, the carbon black molecules form a new conductive paths. The resistance of the device returns to the extremely low value. The fuse is "resetted" and allows the current to flow through the circuit normally. The fuse and in consequence the circuit is now ready to work again. This operation can be repeated multiple times without a necessity of the fuse replacement by another one.

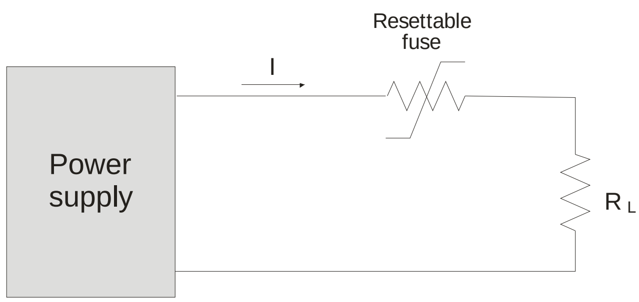

Figure 3. Typical circuit application.

The resettable fuse usually is used in series with load (Fig.3). Its normal resistance (initial resistance) is low, so there is no influence on a working circuit. In circuit shown in Fig.3, the load is protected against short circuit, overload and even overheating (from ambient).
The polymer devices does not need to be replaced. It is the main advantage of this solution. They protect circuits from many fault conditions. The resistance of PPTC's and tripping time are similar parameters like for the typical blow-out fuses.
The resettable fuses are widely applied in transformers (short circuit and winding over-temperature protection), AC/DC adapters, batteries (short circuit and overcharge protection), testing and measurement equipments, computers (interfaces, cards, sockets), security and fire alarm systems, process and industrial controls, micro-electrical machinery, power converters, telecommunication, music equipments, portable electronics, medical electronics, marine electronics, motorcycles and automobiles.
The polymer devices are available in voltage ratings of 16 to 600V AC/DC and current ratings of 20mA to 100A. They usually are packed in radial, axial and surface-mount form.
The subject of testing were three polymer fuses a MF-R series, manufactured by Bourns company: MF-R010: 60V, 200mA; MF-R050: 60V, 1000mA; MF-R185 30V, 3.7A (I_{max} = 40A)

II. The examining procedures and test system

The test station consist of a relatively simple circuit shown in Fig.4. The acquisition system is equipped with adjustable current supplier, PC computer with DAQ PCI-730 card, S relay, R_r reference resistor and R_f examined fuse. During the test the measurement data are acquired and processed under LabVIEW environment. The fuse current and voltage are the measurands. The I_f current is acquired by means of the voltage on the R_r resistor and the U_f voltage - directly from the R_f fuse. The collected data are stored in the file which is accessible by the other applications.
The fuse static characteristics designation is carried on for closed S relay. The supply current is adjusted manually from 0A to the overload of the fuse R_f . Also data acquisition is initiated manually in software (Fig.5).

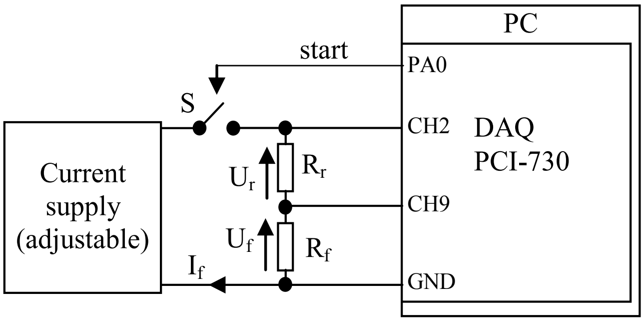

Figure 4. The configuration of the fuse test arrangement.

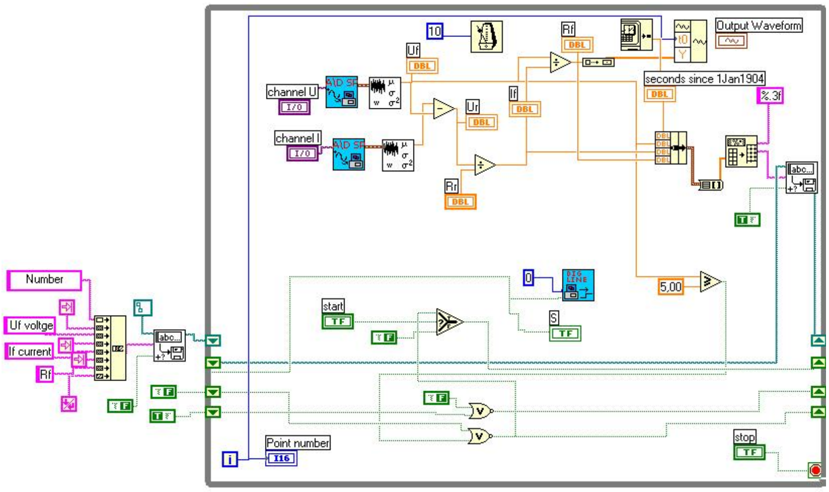

Figure 5. The block diagram of the fuse static characteristics designation procedure.

The exemplary results of static characteristics designation are shown in Fig.6. For presented example, the stored data are processed in Excel.

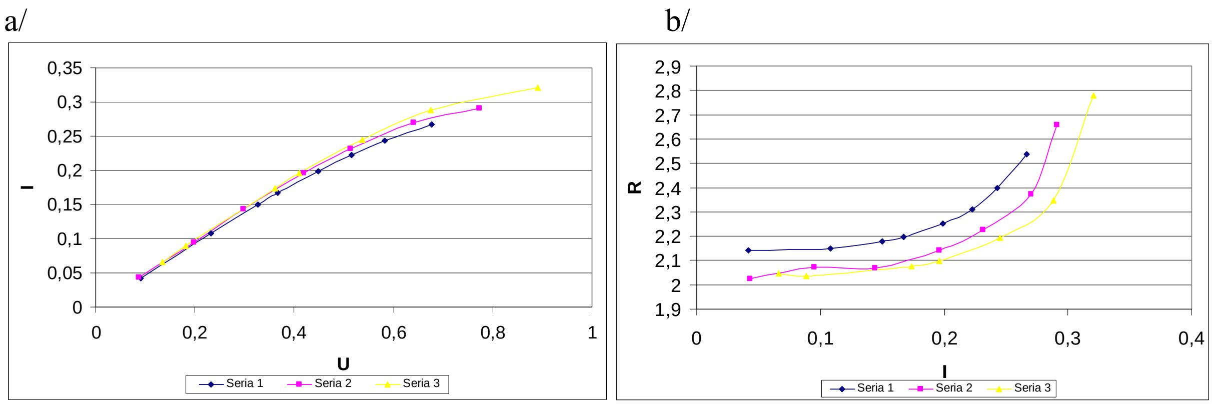

Figure 6. The exemplary results of the MF-R020 fuse static characteristics designation: a/ I_f=f(U_f), b/ R_f=f(I_f).

The dynamic characteristics designation is performed as a response for the step signal generated by closing S relay (Fig.4) for selected the I_f value. The main software sequences of time-to trip designation are shown in Fig.7. The time courses of the U_f fuse voltage and the I_f current responses are registered (Fig.8). The time-to-trip characteristics are shown in Fig.9.

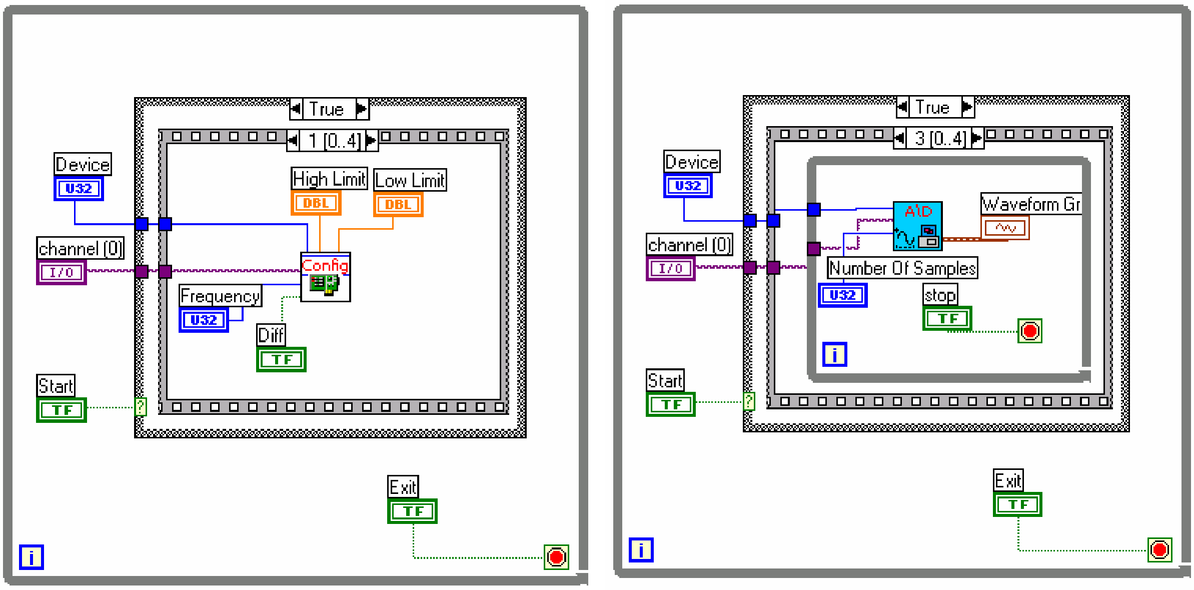

Figure 7. The selected sequences of software controlling the fuse time-to- trip characteristics registration.

a/ b/

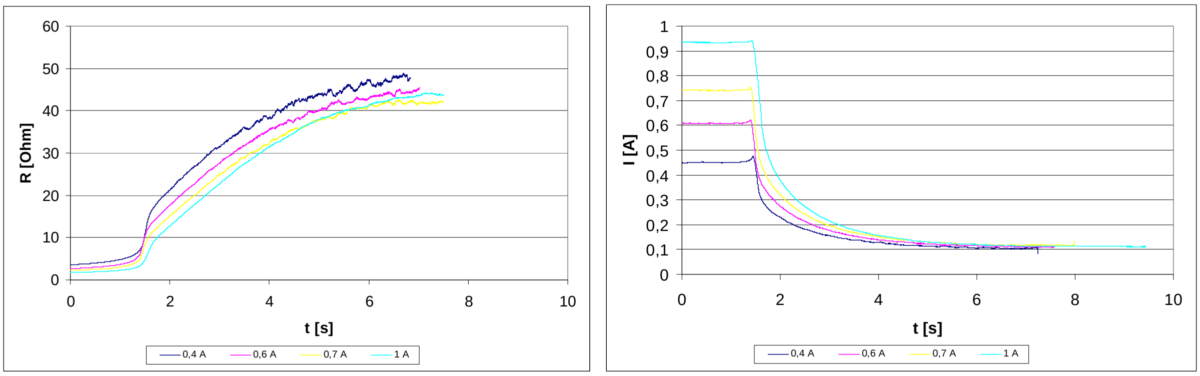

Figure 8. The exemplary results of the MF-R020 fuse time-to-trip characteristics designation: a/ R_f=f(t), b/ I_f=f(t)

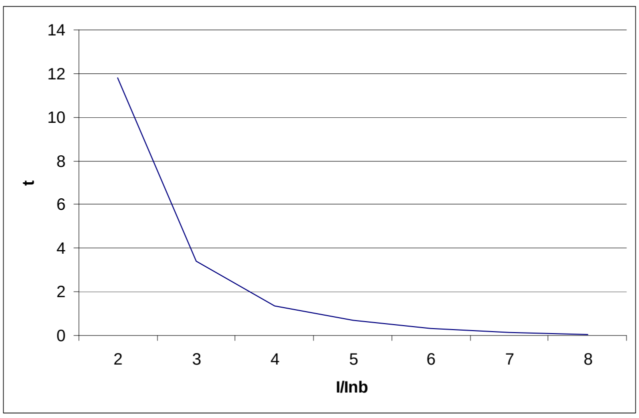

Figure 9. The dependence of time-to-trip in relation to fuse current in ratio to its nominal value (MF-R020 fuse).

The dynamic parameters of the polymer fuse are important for the user. The producers show in their datasheets the fuse time-to-trip values, but they omit the reset-time information. To register this characteristics, the test arrangement was modified (Fig.10). After trip of the fuse, the supplier is switched to voltage stabilization. The S relay is off and the fuse starts cool down.

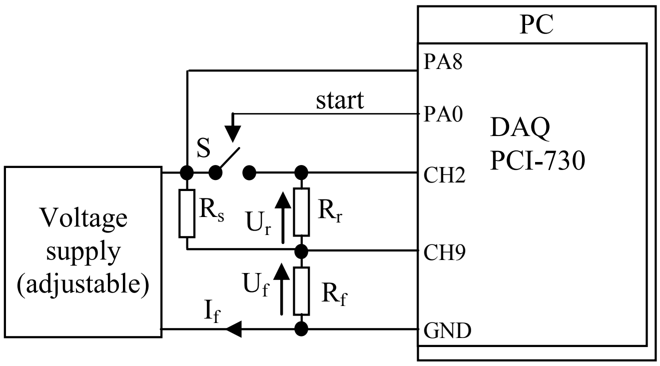

Figure 10. The configuration of the fuse test arrangement for reset-time designation.

The software controls the execution of the sequence of procedures (Fig.11): switch-on of the S-relay (a/), the fuse current supply until its trip (b/), S switching-off (c/), data registration during fuse reset phase (d/). The exemplary characteristics of the fuse reset-time is shown in Fig.12.

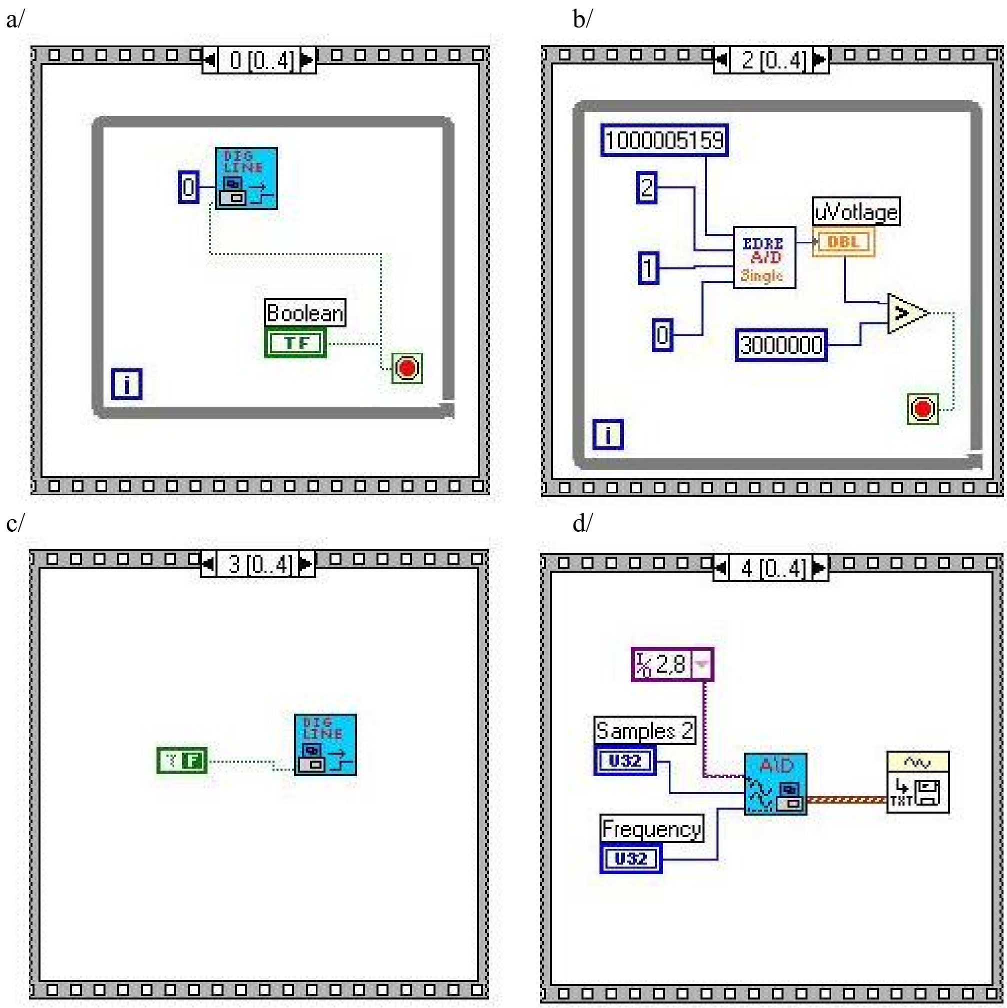

Figure 11. The selected sequences of software controlling the fuse reset-time characteristics registration.

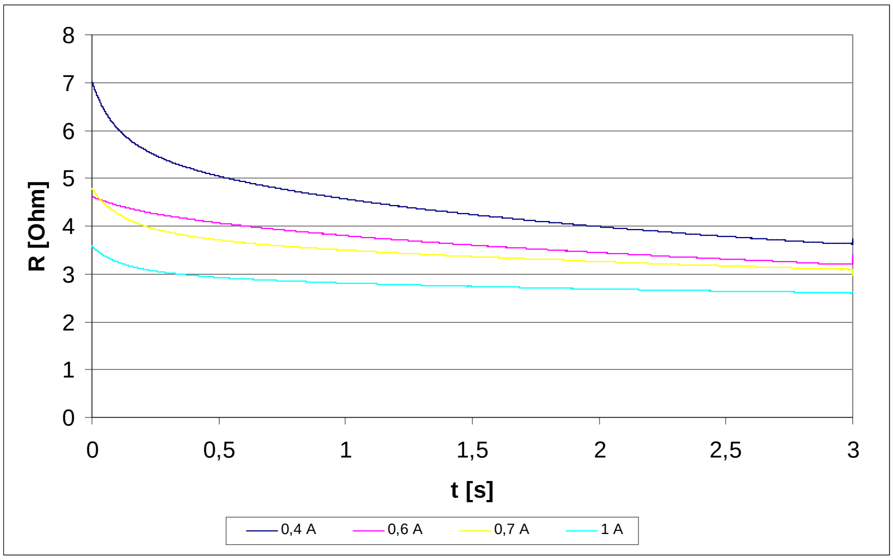

Figure 12. The exemplary results of the MF-R020 fuse reset- time characteristics designation.

The test station, arranged to perform the polymer fuse parameters designation, fully passed the exam. The concurrence of the obtained results to the fuse technical data confirms the propriety of performed operations.

Conclusions

The performed tests show the coincidence of obtained results concerning the switch-off characteristics with the fuse technical data.
The fuse reset time depends mainly on type of the fuse package as well as the ambient temperature and this process takes usually a few seconds. Indeed, it is not critical parameter, taking into account the tasks fulfilled by the polymer fuses.
The main field of applying of polymer fuse are the circuits exposed for short circuits, e.g. output lines of the connectors of interfaces, especially as a short-circuit protection in hot-plugging environment (e.g. USB devices), portable electronics ports, battery packs and so on.
The resettable feature of the fuse is rather not the advantage in case of employment it as a main supply overload protection of the device, because the fuse trip in supply unit is usually the result of some damage in protected circuit. The self-acting return of the fuse to the normal operation can sometimes lead up to the further damages in the device.

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