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Analysis of the Fuses' Electro-Thermal Field

A. Pleşca
Department of Power Engineering, Gheorghe Asachi Technical University of Iasi,
Blvd. Dimitrie Mangeron, 51-53, Iasi – 700050, Romania, phone: +40 232 278683, e-mail: aplesca@ee.tuiasi.ro

Introduction

At the first sight, the electric fuse manufacture and its working principle don't seen a hardly gain insight into matters, in fact this device operating is very complex, [1-7]. In general, when it studies fuses electro-thermal field, the electric fuses are supposed homogeneous bodies and the equations, which describe their electro-thermal behavior, refer to only fuselink, the main part element. But, with a view to catch better the electro-thermal phenomena of fuses as a whole, it comes out the problem of system heating calculation, system made from "n" element parts, each of them taking part in mutual heat changing and towards environment.

Theoretical study of fuses like an inhomogeneous body

Fuses incorporate one or more current-carrying elements, depending on their current ratings, and melting of these, followed by arcing, occurs when excessive overcurrents flow through them. They can be designed to safely interrupt the very highest fault currents that may be encountered in service, and, because of the rapidity of their operation in these circumstances, they limit the energy dissipated during fault periods. This enables the fuses to be of relatively small overall dimensions and may also lead to economies in the cost and size of the protected equipment.

Because the processes which govern the operation of fuselinks are many and complex, its analysis is very complicated and several simplifying assumptions are required, [8-10] The very complicated situation is that of the prearcing times longer than those which correspond with an adiabatic process, because the current densities in the fuselinks are not constant over their cross-section or along their lenghts due to the presence of the restrictions. In addition, resistivity increases as the fuselink temperature rises, and the effects of various component parts, like fine-grain filler, outer body, end caps, conecting cables or busbars must be considered in temperature distribution analysis, [11-14].

In Fig.1 shows the main element parts of fuse: 1-fuselink from copper or silver; 2-filled material; 3-ceramic body; 4-lateral contacts.

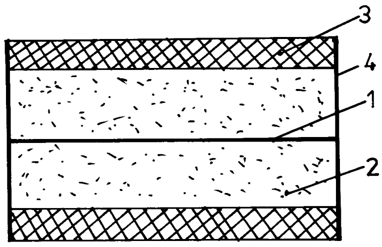


Fig. 1. The main simplified element parts of fuse

To simplify the calculations it can neglect the effect of lateral contacts. Considering that filled material and ceramic body are passively from thermal point of view, these could be equalized with a single one passive element from thermal point of view, with an equalized weight, m_2, given by the sum of both element parts, filled material, m_f and ceramic body, m_c, and an equalized specific heating given by the expression below

$$c_2 = \frac{m_f c_f + m_c c_c}{m_f + m_c}, \qquad (1)$$

where c_f and c_c means the specific heating of filled material and china body, respectively.

Table 1 presents the element parts, which participate in heat changing and the calculus parameters. For a given case, all these parameters must be known.

Table 1. Element parts

Fuselink (active)	Equalized element (passive)	Air
$P_1 \neq 0$	$P_2 = 0$	-
$C_1 = m_1 c_1$	$C_2 = m_2 c_2$	$C_a = \infty$
ϑ_{s1}	ϑ_{s2}	-

Note: P_1, P_2 – dissipated losses because of active elements; C_1, C_2, C_a – heating capacity of element parts and air; $\vartheta_{s1,}$ ϑ_{s2} – stationary overtemperatures.

Making the notation α for thermal transmissivity at giving up surface of heating to environment and S-area of this surface, the parameter

$$D_a = \alpha S, \text{ [W/K]}, \quad (2)$$

means the dissipation intensity of element heating in contact with environment. In this case, the fuselink can not give up directly the heat so, $D_{1a} = 0$, but for equalized element, $D_{2a} \neq 0$.

At stationary conditions, it can calculate the parameter D_{2a} with the relation

$$D_{2a} = \frac{P_1}{\vartheta_{s2}}, \text{ [W/K]}. \quad (3)$$

The mutual heating interrelation among elements is characterized through thermal interaction parameters δ_{mn}, which establish the thermal flux transfer from an element to another. In this case, $\delta_{12} = \delta_{21}$, and they have the relation

$$\delta_{12} = \delta_{21} = \frac{P_1}{\vartheta_{s1} - \vartheta_{s2}}, \text{ [W/K]}. \quad (4)$$

From the above established expressions, it can write the parameters:

$$\begin{cases} D_1 = D_{1a} + \delta_{12}, \\ D_2 = D_{2a} + \delta_{21}, \end{cases} \quad (5)$$

which have only an auxiliary role, without a physics significance.

It considers the transitory thermal conditions, when both two elements have the environment temperature at initial moment, $t = 0$, and so, they have the overtemperatures $\vartheta_1 = \vartheta_2 = 0$. The equations, which give the variation of element overtemperatures of inhomogeneous system during heating transitory period of time, have the expressions:

$$\begin{cases} \vartheta_1 = \xi_1\left(1 - e^{-\frac{t}{T_\xi}}\right) + \eta_1\left(1 - e^{-\frac{t}{T_\eta}}\right), \\ \vartheta_2 = \xi_2\left(1 - e^{-\frac{t}{T_\xi}}\right) + \eta_2\left(1 - e^{-\frac{t}{T_\eta}}\right), \end{cases} \quad (6)$$

where T_ξ and T_η are thermal interrelation time constants, these mean parameters which characterize the system, being independently by power distribution, and the coefficients ξ_1, ξ_2, η_1 and η_2 mean stationary over temperatures.

The parameters T_ξ and T_η can be established indirectly from power balance where it will calculate some helping sizes, σ_a, σ_1 and σ_2, depending on known sizes:

$$\begin{cases} C_1 \frac{d\theta_1}{dt} + D_{1a}(\theta_1 - \theta_a) + \delta_{12}(\theta_1 - \theta_2) = P_1, \\ C_2 \frac{d\theta_2}{dt} + D_{2a}(\theta_2 - \theta_a) + \delta_{21}(\theta_2 - \theta_1) = P_2. \end{cases} \quad (7)$$

Taking into account that except element temperatures θ_1 and θ_2, the other sizes from equations are constants and $\theta_1'(0) = \theta_2'(0) = 0$, the Laplace transforming of system (7) leads to another system which gives the helping sizes:

$$\begin{cases} \sigma_a = C_1 C_2, \\ \sigma_1 = C_1 D_2 + C_2 D_1, \\ \sigma_2 = D_1 D_2 - \delta_{12}^2, \end{cases} \quad (8)$$

which are the coefficients for the next equation

$$\sigma_2 T^2 - \sigma_1 T + \sigma_a = 0. \quad (9)$$

So, the sizes T_ξ and T_η are the solutions of above equation. Also, the equation system (6) for stationary conditions, becomes:

$$\begin{cases} \vartheta_1 = \xi_1 + \eta_1, \\ \vartheta_2 = \xi_2 + \eta_2 \end{cases} \quad (10)$$

and to establish all coefficients, the previous equation system completes with:

$$\begin{cases} \left(\frac{C_1}{T_\xi} - D_1\right)\xi_1 + \delta_{12}\xi_2 = 0, \\ \delta_{12}\eta_1 + \left(\frac{C_2}{T_\eta} - D_2\right)\eta_2 = 0. \end{cases} \quad (11)$$

So, knowing the coefficients ξ_1, ξ_2, η_1 and η_2 and thermal interrelation time constants T_ξ and T_η, it can solve the equation system (6) to establish the functions $\vartheta(t)$ for the element parts from inhomogeneous system.

In Fig.2 shows the heating transitory evolution, solid lines, for copper fuselink, curve #1 and equalized element, curve #2, at a fuse type HBC with rated current, $I_n = 100$ [A], and the same characteristics from experimental data, dashed lines, curve #1' and curve #2', respectively.
The values for dissipated losses in copper is $P_1 = 11.5$ [W] and stationary heatings are $\vartheta_{s1} = 148.3$ [^{0}C] for copper and $\vartheta_{s2} = 42.85$ [^{0}C] for equalized element. Looking at diagrams it can infer some aspects about heating of fuse like an inhomogeneous system.

So, it can see from curve #2, that angle of tangent at curve into origin is zero, because the equalized element is passively from thermal point of view. This element heats slowly at the beginning of transitory process, because of heating capacity much more than active element, the fuselink, $C_2 \gg C_1$, where the specific heating have the values $c_1 = 390$ [J/KgK] for copper, $c_2 = 988.89$ [J/KgK] for equalized element, and weight have the values $m_1 = 0.893 \cdot 10^{-3}$ [Kg] and $m_2 = 0.28$ [Kg], respectively.

The fuselink has a temperature variation speed very high at the beginning of heating process, because it is a heat source from thermal point of view. After initial stage of heating, when the main phenomenon is heating accumulation, it starts to come out the heating exchange among contact elements.

Also, starting from the moment equal with the most bigger thermal interrelation time constant, $T_\xi = 17.23$ [min], the curves #1 and #2 could be plotted, approximately, using the same exponential curve being translated with a certain constant value. All these exponential curves have the same subtangent equal with the most bigger thermal interrelation time constant and so, each element reaches own stationary overtemperature in the same time, although among elements could be a heating exchange.

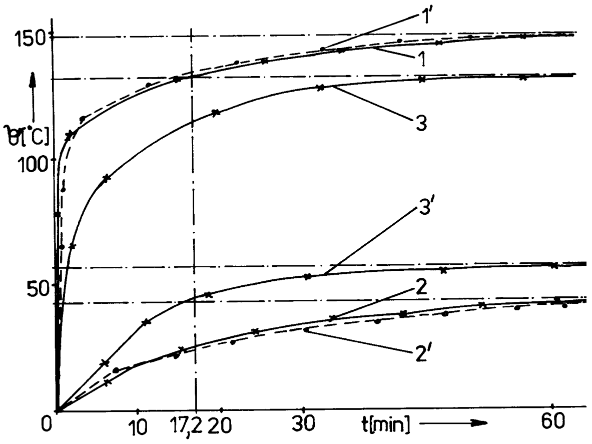


Fig. 2. The heating transitory evolution

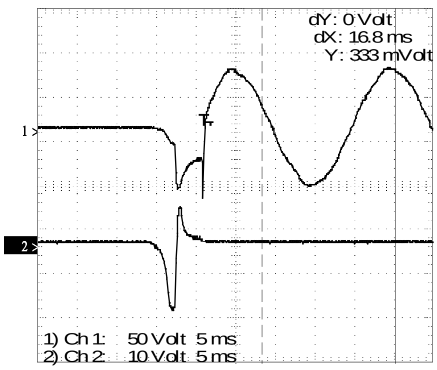
To get an efficiently cooling of fuselink, and so, a more higher life-time and an adequate operating at overcurrents, it can replace the filled material with a new one which have a lower heating capacity. The heating characteristics are shown in Fig. 2, curve #3 for copper and curve #3' for equalized element.

The new filled material has a prevalent composition by silicon carbide unlike quartz sand, the initial one. But, at this kind of replacement it must keep the eyes on the efficiently extinguishing of electric arc, which comes out at the moment of fuse breaking.

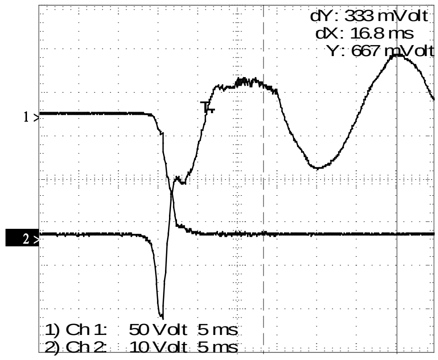
In this case, the silicon carbide proves a good behaviour at fuse breaking as it notices in Fig. 3, where are shown the oscillograms of arc voltages and arc currents (the below waveform on the same oscillogram record), in the moment of fuse breaking, with quartz sand (Fig.3 (a)) and silicon carbide (Fig. 3(b)) comparatively.

The filled materials for HBC fuses, but not only, has to fulfill two criteria: an adequate cooling of fuselink and an efficiently extinguishing of electric arc.

From the above recorded waveforms it can be noticed that in the case of silicon carbide like filled material for the fuse, the arc voltage doesn't present any overvoltages during fuse operating but there is a small peak value for the overcurrent.



a)



b)

Fig. 3. The waveforms of the voltage arc and current arc in the case of quartz sand (a) and silicon carbide (b)

Conclusions

From all theoretical study and experimental results it can be outlined the following conclusions:

- for a correct study of fuse electrothermic field, it must analyse the fuses like an inhomogeneous body made from "n" homogeneous element parts each of them with own heating characteristic;
- from the moment equal with the most bigger thermal interrelation time constant, all heating curves can be plotted, approximately, using the same exponential curve, being translated with a constant value;
- the filled material from fuses plays an important role as regards an adequate cooling of fuselink, but it must keep the eyes on the efficiently extinguishing of electric arc;
- the overcurrent's protection using fuses, depends on kind and geometry of fuselink, but also, very important, on filled material specific features.

Acknowledgements

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A theoretical study of electro-thermal field, which comes out at fuses type HBC (High Breaking Capacity), but not only, is shown in this paper. This study is achieved considering the electric fuse like an inhomogeneous body as a whole, the experimental data confirming the theoretical assumptions made initially. Also, on the basis of theoretical study, it stands out the influence of filled material upon fuses behaviour. Ill. 4, bibl. 14, tabl. 1 (in English; abstracts in English, Russian and Lithuanian).

А. Плесща. Исследование электротермического поля предохранителей // Электроника и электротехника. – Каунас: Технология, 2010. – № 8(104). – С. 85–88.

Предложен теоретический анализ электротермических полей устройств HBC. Теоретический анализ потвержден экспериментально. Ил. 4, библ. 14, табл. 1 (на английском языке; рефераты на английском, русском и литовском яз.).

A. Pleşca. Saugiklių elektroterminio lauko tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 8(104). – P. 85–88.

Atliktas HBC tipo (ir ne tik) saugiklių elektroterminio lauko teorinis tyrimas. Šiuo tyrimu siekiama atkreipti dėmesų į elektros saugiklius. Atliktas teorinis rezultatų įvertinimas, pagrindžiantis ekperimentų rezultatus. Il. 4, bibl. 14, lent. 1 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).