# STUDY OF DIFFERENT MATERIALS AS FUSE ELEMENT

C. Garrido and J. Cidras

Dept. of Electrical Engineering, University of Vigo, Phone and Fax nº (34)(86) 812173, Lagoas marcosende 9, 36280–VIGO (Spain)

## 1.– Abstract

A theoretical model to calculate the prearcing time of fuses has been used to study the behaviour of different metals as fuse elements. The model has been experimentally checked and contrasted with data of a real fuse. From the obtained results with the studied metals, we can conclude that, for each metal, there is a thickeness that allows to obtain a only characteristic curve if the same fuse element geometry is used.

## 2.– Introduction

Gauged conductors (fuses) are utilized in the industry to protect equipments and installations against overloads and shortcircuits. The prearcing time–current characteristic curve of fuses is normally obtained by means of essays in the laboratory, being the lost of time and material a consequence of the method.

The previous has motivated that some researchers [1–8] deal to obtain a theoretical model that allows to deduce the characteristic curve of fuses without have to use the experimental tests.

The nominative models, in general, do not take into account the variability with the temperature of diverse factors such as the electric resistivity, the specific heat or the thermal conductivity of the materials that constitutes the fuse.

Recently [9], we have developed a theoretical model that allows to obtain and to optimize the characteristic curve of fuses and considers the variability of the parameters with the temperature.

The experimental contrastation by means of tests in the laboratory and the comparison of theoretical results with the curve of a commercial fuse, have demostrate the validity of the developed model, adjusting perfectly the theoretical prearcing times with the experimental and manufacturer data.

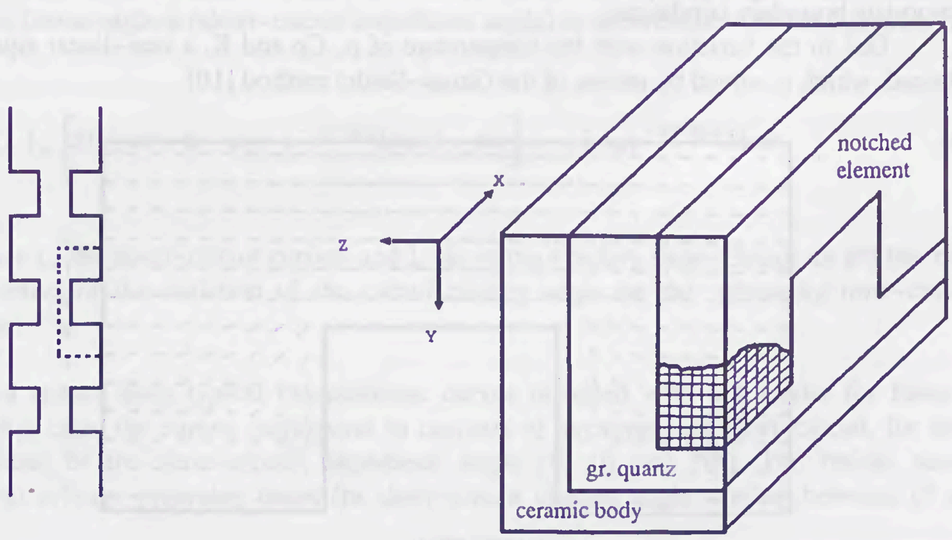



Fig.1: Fuse element geometry, symmetrical part used in our model and finite–difference mesh.

In general, copper is the metal utilized with preference in the manufacture of fuses. In this work, the developed model is utilized in order to study the behavior of other metals as melting element in the manufacture of fuses.

## 3.- Theoretical Model

The model has been described in detail in [9]. Briefly, due to the symmetry of the fuse, in a part of the same (**Fig.1**) it is carried out a partition (finite-difference mesh). We solve the corresponding equations in the partition by means of the approximation of the same by finite central differences [10].

The model is based on the calculation of the current density in each one of the partition points, solving the electric potential (V) and current density (J) equations:

$$\frac{1}{\rho}\nabla^2 V + \nabla\frac{1}{\rho}\nabla V = 0 \,, \Rightarrow \quad \frac{1}{\rho}\left[\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right] + \frac{\partial(1/\rho)}{\partial T}\left[\frac{\partial V}{\partial x}\frac{\partial T}{\partial x} + \frac{\partial V}{\partial y}\frac{\partial T}{\partial y}\right] = 0 \qquad (1)$$

$$\mathbf{divJ} = -\mathrm{div}(\mathrm{grad}\, V/\rho) = 0, \Rightarrow \quad \mathbf{Jx} = -\frac{1}{\rho}\frac{\partial V}{\partial x}, \quad \mathbf{Jy} = -\frac{1}{\rho}\frac{\partial V}{\partial y} \qquad (2)$$

where $\rho$ is the electrical resistivity and Jx and Jy are the components of the current density. Both equations are solved taking into account the appropriate boundary conditions [9].

Once known the distribution of the current density in the fuse element, the time of melt is obtained solving the heat diffusion equation (distribution of the temperature T) in the fuse:

$$d\,Cp\frac{\partial T}{\partial t} = \nabla(K\nabla T) + Qv = K\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] + \frac{\partial K}{\partial T}\left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2\right] + Qv \qquad (3)$$

where d, Cp and K are, respectively, the density, the specific heat and the thermal conductivity of the material where the equation is solved. Qv represents the generation of energy per unit of time and volume due to the Joule effect. The previous equation is solved taking into account the appropriate boundary conditions.

Due to the variation with the temperature of $\rho$, Cp and K, a non-linear equations set is obtained, which is solved by means of the Gauss-Seidel method [10].

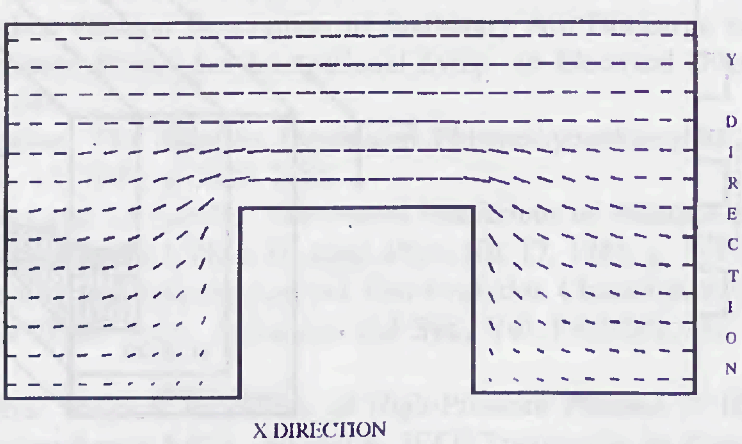



Fig.2: Current density in the fuse element

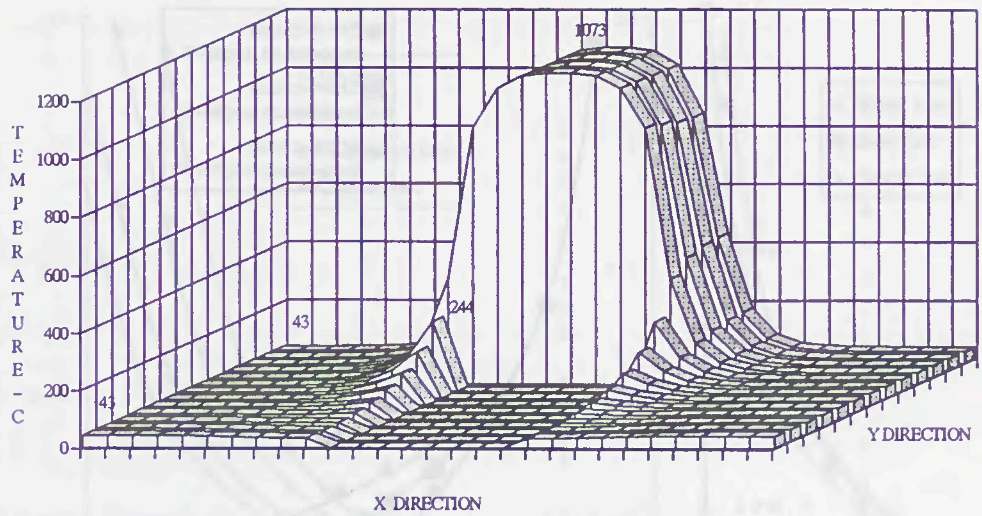



Fig.3: Temperature distribution in the fuse element.

## 4.- Results

**The figure** 2 shows a tipical distribution of the current density in the fuse. The current through the fuse from left to right side. The size of the segment is proportional to the value of the density of current. Due to the abrupt variation of the geometry of the fuse element, it can see as at the begining of the restriction, the current density suffers a high increase as in absolute value as in direction. The corresponding temperature to a determined instant it can be see in the **fig.3.** In this case it shows the temperature for short-circuit current of 1000 A in a real fuse of current nominal 15 A. In the mentioned figure it can be seen as in the wide zone of the element, the temperature rises from 43 ºC at the beginning to 244ºC in the corner of the restriction zone ,while in the restriction zone center it reaches the melting temperature (1073 ºC).

The short-circuit current depends both on the the circuit closing angle θ and the short-circuit power factor angle φ (short-circuit impedance angle) in accordance with the equation:

$$\sqrt{2}\, I_{cc}\left[\mathrm{Sin}(wt+\theta-\varphi)-e^{-wt/tg\varphi}\mathrm{Sin}(\theta-\varphi)\right]+\sqrt{2}\, I_0 e^{-wt/tg\varphi}\mathrm{Sin}\theta \qquad (4)$$

where $I_{cc}$ the short-circuit current and $I_o$ the current before short-circuit. In [9] has been shown the effect of the variation of the circuit closing angle on the prearcing time-current characteristic.

**Fig.4** shows three typical characteristic curves obtained with our model for fuses of copper. In this case, the curves correspond to currents of asymmetrical short-circuit, for three different values of the short-circuit impedance angle (0, 10 and 70º). The results shown correspond to average prearcing times for short-circuit closing angle varying between 0º and 180º.

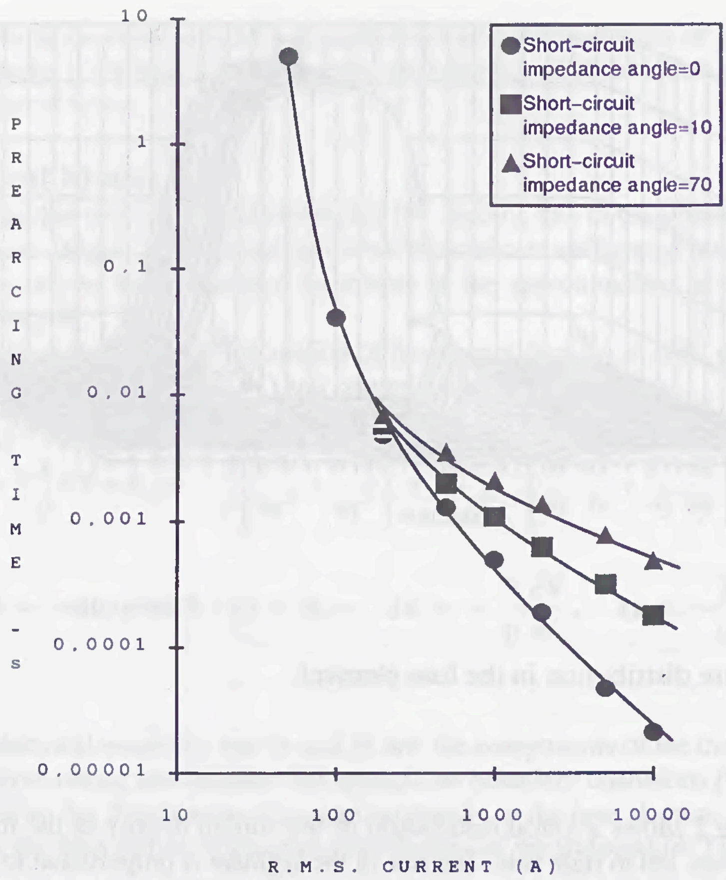


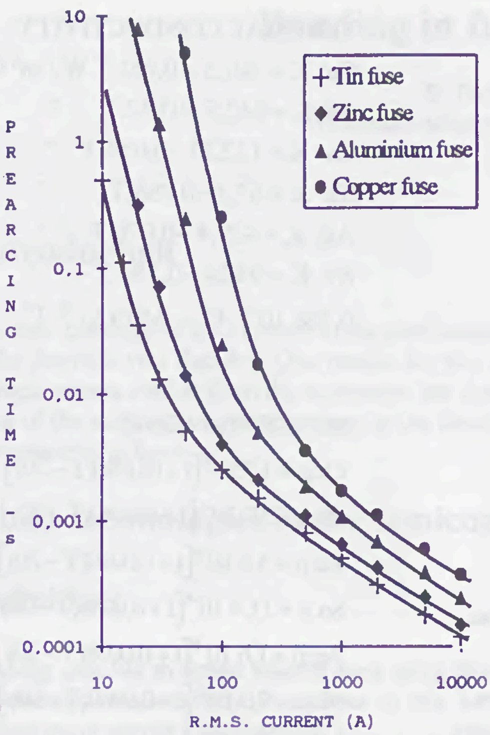

Fig.4: theoretical characteristic curves of a copper fuse for three values of the short–circuit impedance angle.

Such as it is seen, the prearcing times diminish with the short–circuit impedance angle, obtaining the minimum values for a totally resistive impedance of short–circuit. In the case under study (real fuse of nominal current 15 A) the difference in prearcing times is significant only for higher currents to 100 A, obtaining similar values for lower currents to this one . This is due to that with lower currents to 100 A, the prearcing time of the fuse is higher than a semicycle of the signal of current (0.01 s), for which the initial transitory due to the inductance of the circuit does not affect to the prearcing time.

In order to study the characteristic curves of several materials, we have utilized as model a real fuse of copper and whose characteristic curve knows both experimental and theoretically (nominal current of 15 A).

In that same model, with identical measurements, it has been substituted the parameters of the Copper by the parameters of: Aluminum (Al), Zinc (Zn), tin (Sn), Silver (Ag) and Niquel (Ni).

The theoretical curves of prearcing time–current proportioned by our model are shown in the **fig.5 and 6**. The results showed in these figures are in accordance with the values of the electrical resistivity and thermal conductivity of the different metals (**Table 1** [11]) and it should may be concluded that the form of the characteristic curves is different for each metal, if it is considered the difference in prearcing time for low and high currents.



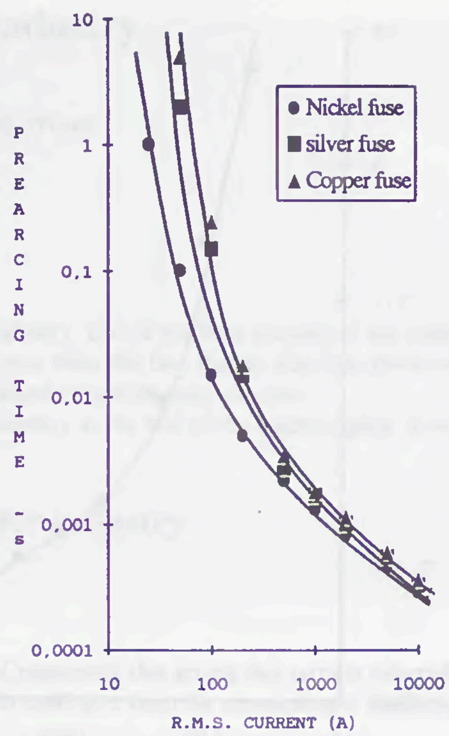




Fig. 5 and 6: theoretical characterisitc curves of different fuses with the same geometry and measurements.

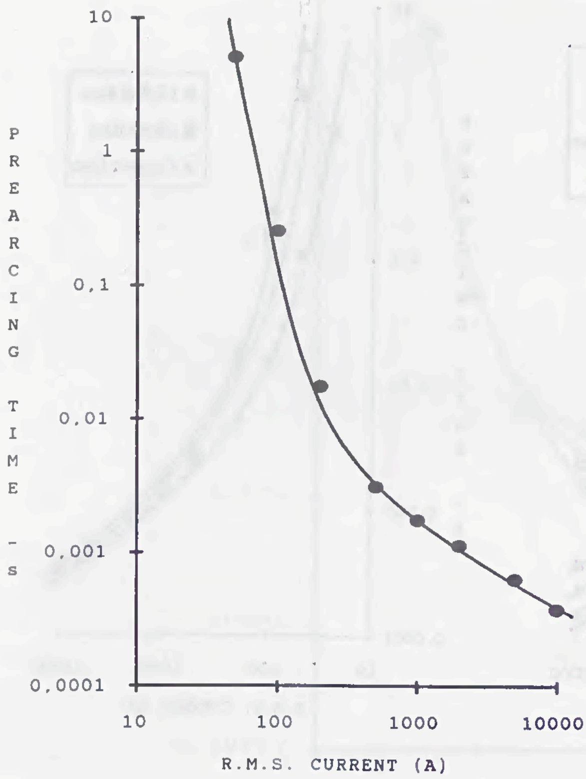
To check that possible difference in the curves, for a current of 100 A, the thickness of the fuse element (Al, Zn, Sn, Ag and Ni) was modified, conserving the remainder measurements, with the objective of achieving a prearcing time equal to the one of the copper fuse for the mentioned current. Once the thickness that verify the condition is obtained, the prearcing times for all currents are calculated.

The process was applied to mentioned metals, obtaining the results shown in **fig.7**. As it can be seen , we have obtain the same prearcing times for all currents and all the studied metals. From this figure it can be easily deduced that, in spite of the enormous difference in the properties of the materials (Table nº1[11]), for each one of them, a thickness exists for which it is possible to obtain the same prearcing time–current characterictic curve.

In our case, the thickness of the copper real fuse is of 0,1 mm, obtaining for the other materials the following thicknesses to obtain the same prearcing time–current curve that the copper one: Al: 0,187 mm, Zn: 0,478 mm, Sn: 0,827 mm, Ag: 0,1075 mm and Ni: 0,215 mm..

## 5.– Conclusions

The theoretical model developed and checked in the laboratory, has been utilized in order to study the behavior of different materials as fuse elements. From the obtained results, it is deduced that for a fuse element with a determined geometric form, a thickness of the element exists such as the prearcing time–current characteristic curve is the same for all the studied materials. This allows us to conclude that, if different characteristic curves are desired, it is necessary to use different geometric forms of the fuse element, since with the same geometry identical curves are obtained without more than modify the thickness of the utilized material.




THERMAL CONDUCTIVITY:

Cu: $K = 401{,}3 - 0{,}061.T\ W / m^{o}C$

Al: $K = 242{,}5 - 0{,}042.T$ "

Zn: $K = 122{,}27 - 0{,}052.T$ "

Sn: $K = 67{,}7 - 0{,}038.T$ "

Ag: $K = 429{,}4 - 0{,}076.T$ "

Ni: $K = 94{,}24 - 0{,}146.T +$ "

$0{,}228.10^{-3}.T^{2} - 0{,}975.10^{-7}.T^{3}$

RESISTIVITY ($\Omega$.m):

$Cu: \rho = 1{,}7.10^{-8}\left[1 + 0{,}0040(T-20)\right]$

$Al: \rho = 2{,}7.10^{-8}\left[1 + 0{,}0040(T-20)\right]$

$Zn: \rho = 5{,}8.10^{-8}\left[1 + 0{,}0040(T-20)\right]$

$Sn: \rho = 11{,}4.10^{-8}\left[1 + 0{,}0045(T-20)\right]$

$Ag: \rho = 1{,}6.10^{-8}\left[1 + 0{,}0038(T-20)\right]$

$Ni: \rho = 7{,}0.10^{-8}\left[1 + 0{,}0060(T-20)\right]$

Fig. 7: Theoretical characteristic curve for all fuses with the same geometry and measurements, except the thickness that is different for each metal

Table nº 1: thermal conductivity and electrical resistivity of metals used in this work.

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