STUDY OF FUSELINKS WITH DIFFERENT t-I CURVES USING A MATHEMATICAL MODEL.

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Abstract: Taking into account that in some applications one requires fusibles with different characteristic curves from those available commercially, we have applied a model to the study of fuse behaviour using different geometric forms with the purpose of verifying and obtaining different t-I characteristic curves. In this study we have seen that the opening time (prearcing time) of the fuselink depends on the geometric form of the fuse element, the possibility of varying the t-I curve through modification in the dimensions of the variable sections of a fuse allows fuses to be obtained for specific customised applications.

I. INTRODUCTION

Fuses have as a goal to act as protection devices for equipment, systems, installations, etc. in the case of anomalous situations or behaviors. The designer of such equipment, installations, etc. studies the limits within which the fuse must act in each case, so that the protected element does not suffer deterioration. Depending on the type of element to protect, a wide range of fuses is needed to suit the various needs. Therefore, one of the objectives of fuse design is to obtain fuses with different t-I performance curves, so that for each specific application the most suitable protection fuse can be obtained. To carry out versatile studies in this field without having to resort to real tests through prototypes, it is desirable to have mathematical models that adequately simulate their real behaviour. Nowadays, to obtain a better characteristic curve, the fuselink has been an evolution towards more complicated geometric shapes, presenting restrictions at regular intervals along their length (Fig. 1). Due to this complicated geometry and to the fact that, as a rule, parameters such as electrical resistivity, thermal conductivity and specific heat vary with temperature, it is not possible to undertake the study using simple analytical techniques and it is necessary to resort to numerical calculations to obtain a theoretically valid model of fuselink behaviour. Several authors [1-8] have developed models for estimating prearcing time for fuselinks. However, these models have some deficiencies, and so, in our work on fuselinks [9], we have developed a mathematical model to obtain t-I fuselink curves taking into account that the electric resistivity of the fuse element varies with temperature and that this is also true for the thermal conductivity and specific heat of the fuse element, the filler and the ceramic body. The heat losses to the filler and ceramic body are also take into account in our model.

In this work, our model is used to study the t-I curves that can be obtained by modifying some of the dimensions that characterize the fusible element. At the same time, it demonstrates the validity of the developed model as a test tool for designers, since the t-I curve for the most adequate fuse for our needs can be calculated without the need for a prototype.

II. DESCRIPTION OF THE MODEL

The model has been described in detail in [9]. The model is based on the solution of the electric potential V (2), current density (1) (J_x and J_y) and heat diffusion (3) equations using the approximation of the partial derivatives by central finite differences. In this model the variation of the different parameters with temperature is taken into account in the equations. Briefly, As the fuselink used for the experimental contrasting of the theoretical model presents the shape shown in figure 1, due to the symmetry, figure 2 shows the element of fuselink that has been used for the solution of equations. To calculate prearcing time it is necessary to solve the heat equation in the fuselink using as the energy source the heat produced by Ohmic losses (4) computed using the current density:

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

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

$$dCp\frac{\partial T}{\partial t}=K\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right]+\frac{\partial K}{\partial T}\left[\left(\frac{\partial T}{\partial x}\right)^2+\left(\frac{\partial T}{\partial y}\right)^2+\left(\frac{\partial T}{\partial z}\right)^2\right]+Qv \quad (3)$$

$$Qv = \rho\left[Jx(i,j)^2 + Jy(i,j)^2\right] \quad (4)$$

where ρ, d, Cp, K and T are, respectively, the resistivity, density specific heat, thermal conductivity and temperature. Qv represents the energy generated in the material per unit of volume and per unit of time.

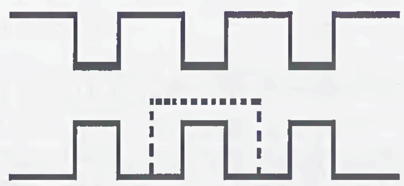

Fig.1: Typical fuselink element

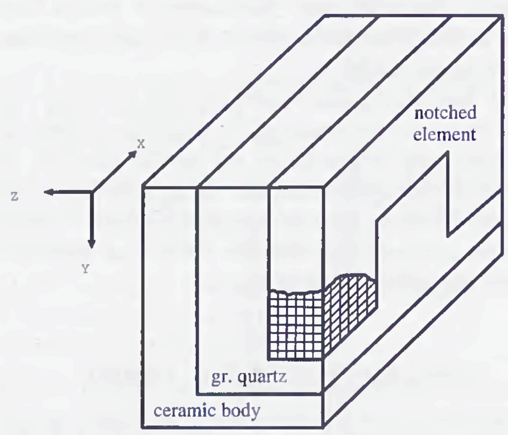

Fig.2: Symmetrical part of an element used in our model and finite-difference mesh.

By using a discretization in the fuselink as shown in figure 2, the approximation of partial derivatives by central finite differences [10] allows us to obtain the electric potential and the components of the current density at each discrete point (i,j).

Taking into account thermal conductivity variation with temperature, the discretization of (3) around central points allows the new temperature T'(i,j,k) at discrete coordinates points (i, j, k) after a discrete time interval Δt to be computed by means of:

$$dCp\frac{T'(i,j,k)-T(i,j,k)}{\Delta t}=K\left[\frac{T'(i+1,j,k)-2T'(i,j,k)+T'(i-1,j,k)}{\Delta x^2}+\right.$$

$$+\frac{T'(i,j+1,k)-2T'(i,j,k)+T'(i,j-1,k)}{\Delta y^2}+\frac{T'(i,j,k+1)-2T'(i,j,k)+T'(i,j,k-1)}{\Delta z^2}+$$

$$+\frac{\partial K}{\partial T}\left[\left(\frac{T(i+1,j,k)-T(i-1,j,k)}{2\Delta x}\right)^2+\left(\frac{T(i,j+1,k)-T(i,j-1,k)}{2\Delta y}\right)^2+\right.$$

$$\left.+\left(\frac{T(i,j,k+1)-T(i,j,k-1)}{2\Delta z}\right)^2\right]+\rho\left[Jx(i,j)^2+Jy(i,j)^2\right] \quad (5)$$

Taking into account that equation (5) is non-linear, in order to be able to use the implicit method [10] in the calculation of the partial derivatives by finite differences, the non-linear terms are estimated at the previous discrete time where the temperatures are known. This has allowed us to obtain a set of linear equations whose unknown quantities are the temperatures at all discrete points (i,j,k) at the moment of discrete time n+1, (the heat generation and temperatures at the previous discrete moment n being known), relating the temperature at a discrete point (i,j,k) with the temperature at the adjacent discrete points. The solution of the set of equations for every discrete time has been obtained using the Gauss-Seidel relaxation method. First, the potential distribution with the temperature existing at the beginning of every discrete time step or iteration is obtained, then, the current density is obtained and is used in equation (5) to obtain the new temperature at every discrete point at the end of the discrete time step. The new temperatures substitute the first ones repeating the process in the following iterations. The process ends when melting temperature is reached in the copper fuse element, thereby determining prearcing time.

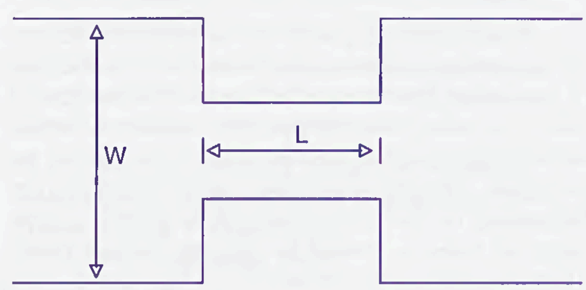

Fig.3: L and W: dimensions of the fuse element modified to study their influence on the t-I curve.

III. RESULTS

The developed model has been contrasted through the results comparison with a real fuse [9]. The objective of this work is to check the versatility of the model to be used in fuse design. Since the real fuse has given dimensions, it is interesting to check how the t-I characteristic curve of the fusible varies when modifying specific dimensions of the same. In this case, the fusible element presents the form in fig.1. For this work, only the length L of the restriction and the width W of the fusible element were modified (fig.3), that is, the width and the thickness of the restriction have been preserved as well as the length and the thickness of the broad part of the fusible.

With the purpose of studying how the increase or decrease of the rectriction length L can affect the t-I characteristic curve of the fusible, the prearcing time of the fusible was calculated using different length L measurements, while keeping the remaining dimensions constant. Figure 4 shows the prearcing time as a function of the r.m.s. current obtained for three different values of the length L of the restriction: 0.5, 2 and 10 mm.

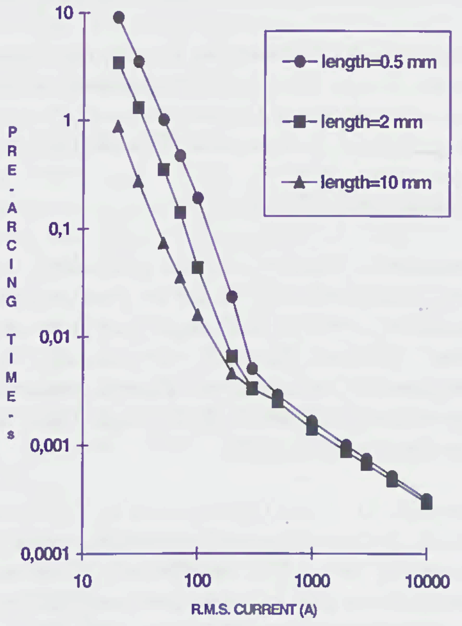

Fig.4: influence on t-I curve of the restriction length.

In this case the real fuse used for the calculations has a thickness of 0.1 mm, a restriction width of 0.5 mm and a restriction length (L) of 2 mm. In this case, resistive short-circuit has been assumed, that is, the current is totally symmetrical. Such as we have already demonstrated in [9], the theoretical values of prearcing time obtained with our model coincide totally with those obtained experimentally. If (theoretically) the length of the restriction is reduced (in our case to 0.5 mm) the prearcing times are increased notably (three times longer), and values that practically coincide with those for the real fuse are obtained solely r.m.s currents over 300 A.

Clearly, the reduction of the restriction to so small a length gives rise to an important part of the heat generated in the restriction being lost through conduction toward the broad part of the fusible, even in spite of the fact that the short circuit r.m.s. current will be increased. If we increase the length of the restriction (10 mm), the opening time is reduced by a factor of 4 with respect to the times obtained for the length of 2 mm, at least for r.m.s. currents with typical overcharge values. As the short-circuit current increases, both t-I curves approach each other, practically coinciding for currents over 300 A. It is clear that the increase in the length of the restriction causes the losses of heat toward the broad part of the fusible to be quite a lot less than for the other cases, therefore affecting to a great extent the prearcing time in the area for overcharge and weak short-circuit currents. For high short-circuit current values the process is practically adiabatic, therefore the prearcing times are not affected by the restriction length.

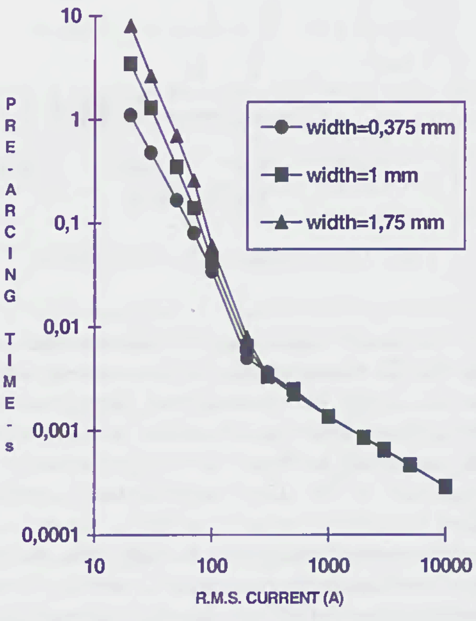

Fig.5: influence on t-I curve of the broad part width.

Figure 5 shows the prearcing time as a function of the short-circuit current for three width values W of the broad part of the fusible. The restriction length measures 2 mm for the three cases. Likewise, the remaining parameters are identical. As can be observed, the t-I characteristic of the fusible depends on the width W, although the effect is greater for typical overcharge currents. This influence is reduced as the short circuit currents is increased. For currents over 300 A, identical prearcing times are obtained for the three widths tested.

The reduction of the broad area of the fusible (with high thermal conductivity) causes the thermal losses to be smaller (low thermal conductivity of the material - sand - in contact with the copper), so the time needed to reach the melting point is reduced. At r.m.s. currents, the melting process is quasi-adiabatic, therefore the reduction in the broad part of the fusible does not affect the time needed to reach melting point. It is clear that, by varying both the reduction of the restriction length and the width of the broad part, quite different t-I characteristics can be obtained.

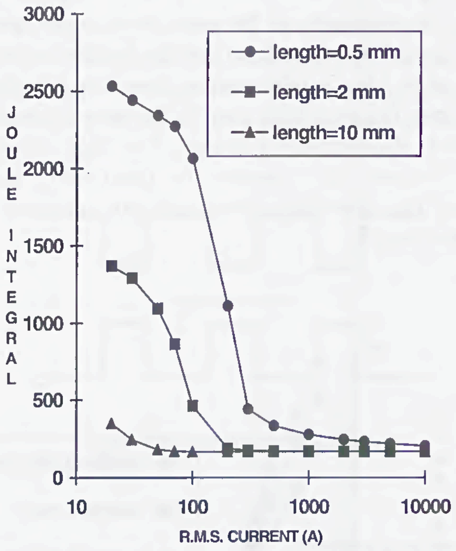

Fig.6: I^2t as a function of the r.m.s. current.

Figure 6 shows the I^2t characteristic of the fusible for the prearcing time values corresponding to Figure 4. As can be observed, the energy needed to reach melting point is a function of the restriction length, according to Figure 4. Energy decreases with the increase of the short circuit current reaching a constant value for currents over 200 A for the case of 2 and 10 mm of restriction lengths. For the given current, the fuse starts to limit the short-circuit current (prearcing time <0.05 s). For the 0.5 mm case, a constant energy value is reached only for current values over 10 kA.

IV. CONCLUSIONS

The studies carried out have permitted us to show that the use of mathematical models in fuse design is a necessary tool that will avoid loss of time and material in prototypes and trials in order to obtain a fuse that is better adapted to the characteristics required by the client. The use of such models will reduce costs, since tests will only be carried out on prototypes once the mathematical model has obtained the sought-after t-I curve.

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