CHOICES FOR THE PRESENTATION OF FUSE MELTING CURVES.

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Summary.

Fuse manufacturers generally present time-current characteristics which are guaranteed within 10 % (of the current). This paper shows experimental results with a considerable stronger spread, in the case of asymmetrical currents. The increased spread is in agreement with expectations from former computer simulations using a thermal model for the fuse. The experiments show a reduced influence of the switching angle, when the melting time is plotted as a function of the so called virtual current (the expanding RMS current). Purpose of this study was to present an experimental justification for the use of virtual currents for fuse melting curves. The method can be of help in the case of sharp coordination studies, or for non sinuous currents.

1. Introduction.

For operating times above about 100 ms, the pre-arcing-behaviour of fuses can usually be represented by time-current characteristics, where the pre-arcing-time is plotted as a function of the RMS- value of the prospective current. For faster pre-arcing-times, graphs are used where the pre-arcing Joule integral I^2t is plotted as a function of the RMS- value of the prospective current. This I^2t stands for the time integral of the square of the instantaneous current passing through a fuselink between the instant when a circuit fault occurs and the instant t_m of arc initiation :

$$I^2t = \int_0^{tm} i^2 dt \tag{1}$$

The preference for I^2t curves is based on the assumption that, at a particular prospective current I_p, different wave shapes can lead to a range of melting times, but are coupled with the same Joule integral. In fact, this assumption only holds, when the heat loss from the fuse strip is the same for any current shape.

Equivalent to the Joule integral, also a quantity is used, termed virtual time, defined as the I^2t value divided by the square of the value of the prospective current :

$$t_v = \frac{\int_0^{tm} i^2 dt}{I_p^2} \tag{2}$$

Fuse manufacturers generally supply graphs of virtual times and Joule integrals, both as a function of the prospective RMS current.

Although it has been warned even in basic textbooks on fuses[1] that the values of Joule integrals (or virtual times) not only depend on the current level, but also on the shape of the prospective current , the latter is often not taken into account in practice.

Especially for fuses with elements on a substrate such simplifications can lead to faulty fuse coordinations. Purpose of this study was :

- to determine experimentally the influence of the current asymmetry on the spread of virtual time (or Joule integral) curves,
- to justify experimentally the alternative presentation of time current characteristics, using 'virtual currents'. This method was introduced formerly, only on the basis of computer simulations[2,3,4].

2. Definition of virtual currents.

As an alternative for the Joule integral I^2t or the *virtual time* t_v we suggest to choose for the *virtual current* $I_v(t)$.

For any momentary current $i(t)$, a virtual current $I_v(t)$ can be defined similarly to the prospective RMS current I_p, with the difference that the integration is not limited to time periods (for instance 10 ms for a 50 Hz current). In formula :

$$I_v(t) = \sqrt{\frac{\int i^2 dt}{t}} \tag{3}$$

In fact, the *virtual current* $I_v(t_1,t_2)$ can be considered as a measure for the average heating power per unit of resistance, for the time difference between moments t_1 and t_2. Only one time parameter is left, when $t_1 = 0$ for fault currents.

With a voltage source :

$$u(t) = U_p\sqrt{2}\sin(\omega t+\psi) \tag{4}$$

the general expression for an asymmetric current after $t = 0$ is given by :

$$i(t) = I_p\sqrt{2}\,[\sin(\omega t + \psi - \phi) - e^{-Rt/L}\sin(\psi-\phi)] \quad (5)$$

with :

- t : time
- $i(t)$: momentary ac current
- I_p : prospective RMS current
- ω : angular frequency
- $\cos\phi$: power factor of the circuit
- ψ : phase angle of the voltage source at t=0
- U_p : RMS voltage
- R : circuit resistance
- L : circuit inductance
- α : current switching angle, with= $\psi - \phi$
- τ : circuit time constant with $\tau=L/R$

The virtual current $I_v(t)$ related with $i(t)$ can be determined by integration :

$$I_v(t) = I\,[\,1 - \frac{1}{\omega t}\sin\omega t\cos(\omega t+2\alpha) + \frac{\tau}{t}\sin^2\alpha(1-e^{-2t/\tau}) - \frac{4\sin\alpha\,\sin\phi}{\omega t}\{\sin\psi - e^{-t/\tau}\sin(\omega t+\psi)\}]^{0.5} \quad (6)$$

The use of virtual currents was already suggested by Hulsink[3] and Takach[4] for transformer protection applications. Also the IEC Technical Committee 32 considered its relevance[5] but preferred the use of virtual times. As a main critic they judged the virtual current method difficult to use. This argument has become weaker during the last twenty years because of the increased possibilities of personal computers. The committee did not recognize the less spread in the characteristic for the case of short time constants of the fuse element. A stronger negative point of virtual times was not considered by the TC : what to do with transformer inrush? The common analogy with 25 I_n at 10 ms is weakly motivated, while the translation to virtual currents is performed easily.

3. Experiments.

For the thermal tests, a low voltage circuit was chosen (Figure 1).

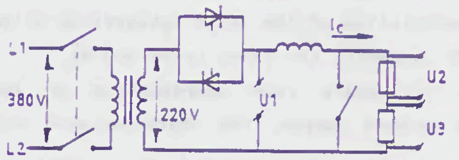

Figure 1. *Test circuit for the determination of current-time characteristics.*

The RMS value of the current (I = 10-100A) and the power factor ($\cos\Phi$ = 0.1) of the circuit were realized with air coils.

The switching angles (Ψ = 0, 30, 90, 150^0) were accurately established with thyristors. Commercial high voltage fuses (12 kV, 40A) served as test objects. These fuses consist of 15 parallel strips. For reasons of economy and test set up requirements, the strips were tested individually (deviations between the behaviour of the total fuse and individual strips were only expected in the low current range).

The experimental results are plotted in Figure 2 (virtual time t_v as a function of prospective RMS current I), together the manufacturer curve.

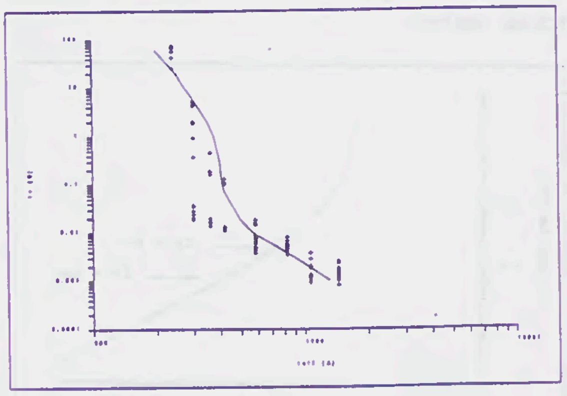

Figure 2. *Comparison of the manufacturers curve with experimental values of the virtual melting time t_v as a function of the RMS current, for several switching angles.*

From Figure 2 it is evident that the virtual time can hardly be presented by just one single curve. The manufacturer curve is in closest agreement with the experimental points for ψ = 90^0. Obviously, the manufacturer's test was performed with symmetrical currents. The observed spread of results is not typical for this particular type of fuse, for instance Cranshaw[6] reported similar results for semiconductor fuses.

A reduction in the spread of the experimental results can be reached, by presenting them in Figure 3 (real melting time t_m as function of the virtual current I_v). This observation is in accordance with former computer simulations[2]. Together with the experimental points, the manufacturers curve is plotted in Figure 3. This curve (tm, Iv) can consist of the original curve (tv, Ip) without translation, which simply can be realized by changing the axis *names*[2]. Figure 4 illustrates this similarity.

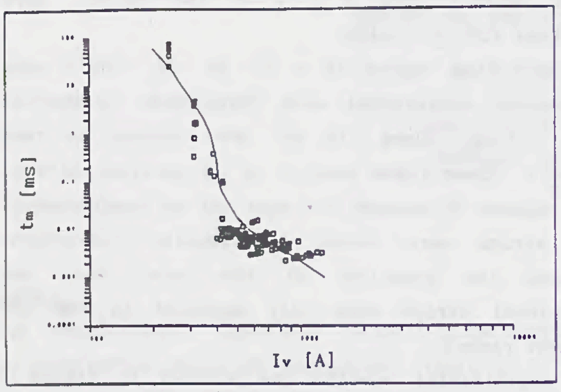

Figure 3. *Comparison of the manufacturers curve with experimental values of the real melting time t_m as a function of the virtual current I_v, for several switching angles.*

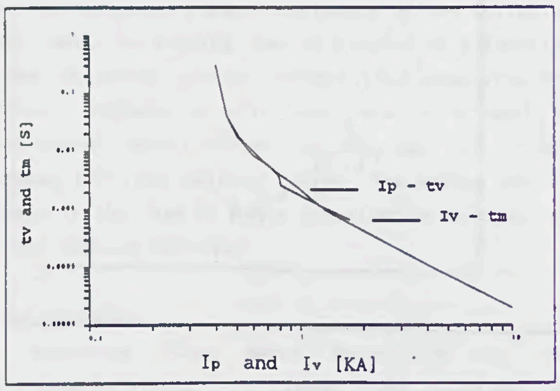

Figure 4. *Original manufacturers curve (virtual melting time versus RMS current) and translated version (real melting time versus virtual current).*

This fortunate possibility is understandable from Figure 5 : the virtual current of a symmetrical sinus reaches the prospective value within about 5 ms. This is short enough for nearly adiabatic heating (so $I_p^2 t_v = I_v^2 t_m$), while later on $I_v = I_p$.

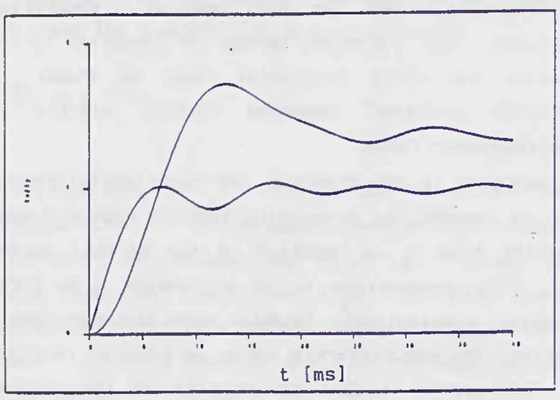

Figure 5. *The virtual currents $I_{v1}(t)$ and $I_{v2}(t)$, belonging to an almost symmetrical (ψ=90°) and an asymmetrical momentary current (ψ=0°) with the same prospective value and cosϕ = 0.1.*

4. Application example of the virtual current method

The practical use of the virtual current method for fuse coordination is illustrated in Figure 6.

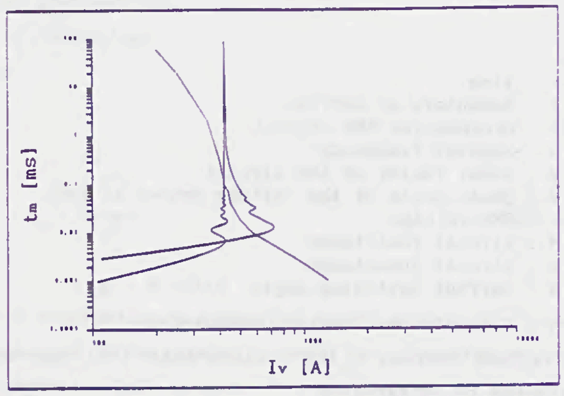

Figure 6 *Manufacturers fuse melting curve for 40 A, presented for virtual times and RMS currents, together with the transformed curve for real melting times and virtual currents.*

In Figure 6, the conventional manufacturers curve (tv, Ip) is plotted without changes in the t, Iv graph. To determine fuse functioning for a current with prospective value I_p = 420 A, with symmetric and asymmetric current shape, their virtual patterns are plotted in Figure 5. From the intersections, fuse functioning for t = 100 ms and 10 ms is found, for symmetrical and asymmetrical shapes. This is in accordance with the experimental values of Figure 3 (96 ms and 8 ms respectively). It is clear that the conventional method with virtual times would result in the value 100 ms for both wave shapes.

Other examples of virtual current applications are described elsewhere for transformer inrush[2,8] or fuse selectivity[7].

5. Conclusion and recommendations.

As a result of this and former studies it can be stated, that for the every day use of fuses, it is advisable to choose :

- characteristics of the real melting time as a function of RMS currents, for times above 100ms.
- characteristics of the Joule integral as a function of RMS currents, for times below 100 ms.

However for **sharp fuse coordination** or for **non sinuous current shapes**, the characteristic with the real melting time as a function of virtual current offers a more reliable instrument for the fuse application specialist. This characteristic can be considered identical to the available conventional virtual time characteristic, if the latter is **determined for symmetrical sinus currents.** One has to keep in mind that the virtual current method is also an approximation, it offers however a time and cost saving alternative to computer simulations or real experiments.

Acknowledgement.

The authors want to thank Mr. P.Klijn for the construction of the experimental setup and Mr. R.VanBezooyen for the assistance during the measurements.

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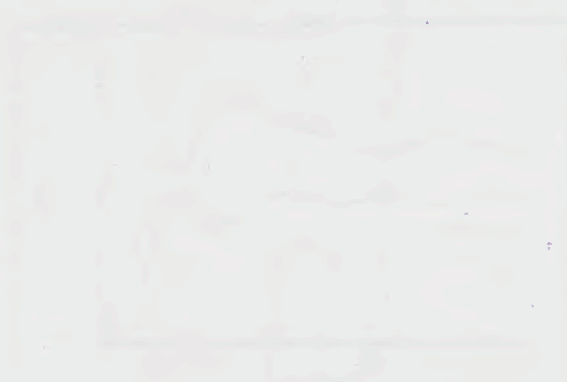

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