MINIMUM BREAKING CURRENT OBTAINING IN FUSES

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Summary:

In this report it has been developed a method for the time-current characteristics obtaining referring to all kinds of fuses, using for that techniques of finite elements analysis. We reach to obtain the necessary model for each rated current without the previously needing of know the melting time value. The methodology used allows to know in each instant the temperature along all the fuse element points, having the possibility to prospect which will be the minimum breaking current value (I_3).

1. Adiabatic model.

When the fuse is submitted to currents with values equal or near to the breaking capacity, the melting time values don't use to be above half millisecond. During this time and taking into account the big difference of the thermal conductivity between the fuse element (.400 W/m°C) and the sand (0.4 W/m°C), there is no heat transmission from the fuse element to the sand, and the melting process is considered as adiabatic. Making these considerations, only is modelized the fuse element, which in several cases uses to have the shape shown in figure 1. (Due to the existing symmetries, we only will simulate the quarter of the fuse strip.)

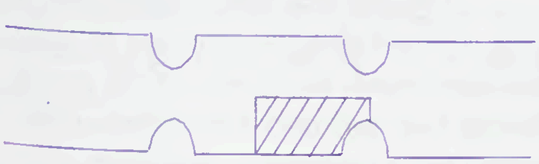
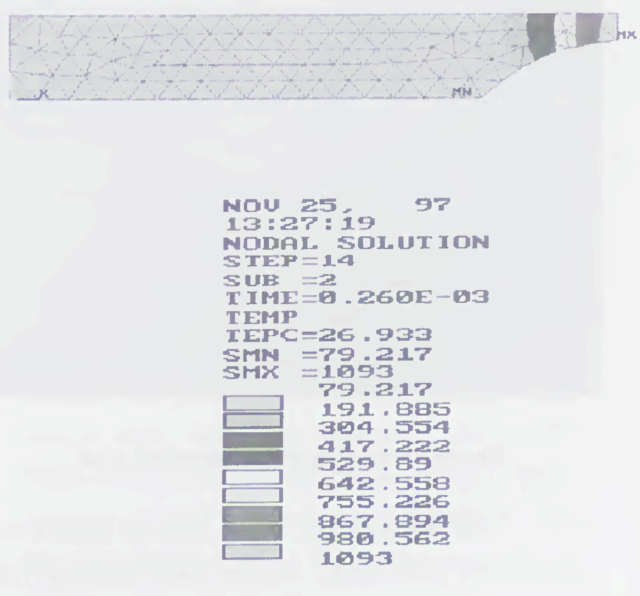


Figure 1. Fuse strip. Lined area (simulated zone).

Model characteristics:

- Three-dimensional simulation.
- The model has real dimensions.
- Adiabatic behaviour.
- Using of only ¼ strip.
- Temporal evolution of the current.
- Prospective error at the simulation 6.25%.

During the simulation has to be considered the temporal evolution of the current. The obtained results for a prospective current with value 20.000 A, with power factor 0.1 and making angle of 60° is the one shown in figure 2 .



Initial temperature 20°C

Figure 2. Model and simulation at current I_1

On figure 2 it can be observed that it has been reached the melting at the neck, while the wide zone only has suffered a thermal step of about 60°C, due mainly to its own heating and not to the heat transmission from the narrow zone to the wide zone.

While the current diminishes, the melting time increases and the established model for I_1 leaves to be reliable. It has to be needed to begin to consider the sand influence, but because the melting time values are still small, the sand thickness which takes place is also very small and besides it can be assumed that the heat transmission is done in radial direction. Even now, exist the difficulty to know or to sense the melting time to have the possibility to choose the correspondent model.

2. Definitive models.

In front of this fact we decided, taking the base of the adiabatic model, to increase progressively the sand thickness which takes part as the current is diminishing.

The sand thickness has to have its dimensions in accordance so that the last sand layer will not surpass the temperature of 20° C, which is the initial temperature of the simulation process.

In case of melting times above five milliseconds, the used models have to count with the sand layer. In all the simulations made inside the high currents range (from I_1 to 20 times the rated current), is the neck that one which generates the enough heat to cause the fuse melting. As the current diminish, it can be proved how the entire fuse element goes reaching the same temperature.(wide zone and narrow zone). This fact indicates that it's been reaching the current value I_3 (corresponding to the minimum breaking current assured by the manufacturer, and which comes imposed by that one). (figure 4.).

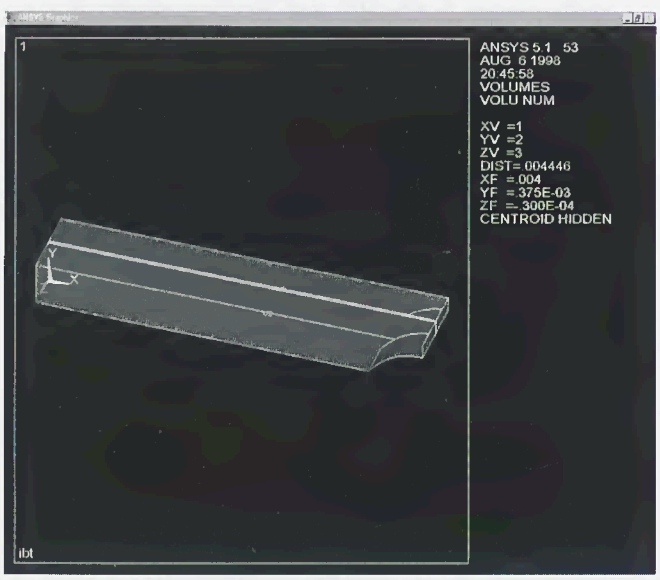


Figure 3 Fuse strip with surrounded sand.

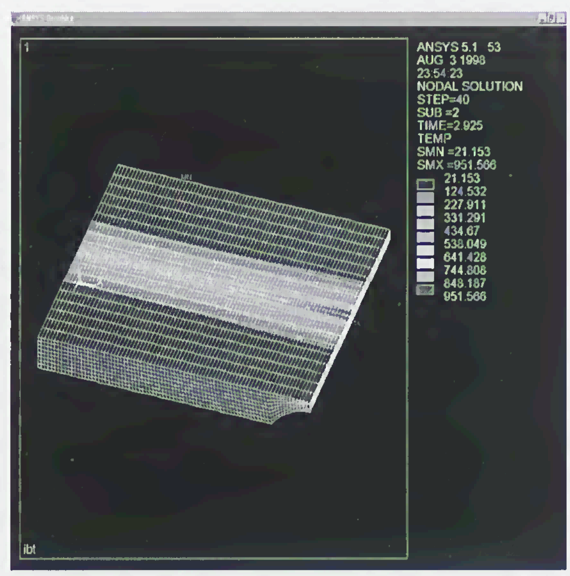


Figure 4 Simulation at $4I_n$

On figure 3 the silver strip is placed on the central zone (blue) and the sand volumes (red and violet) will be increasing, as the current will be diminishing.

The volumes which are placed at the front and at the rear of the strip (fuse element) have the mission to transmit the generated heat into the fuse strip (pre-arcing) towards the external part, and to absorb the generated energy in the arcing phase.

The generated heat is transmitted in axial direction along the strip and in radial direction towards the external. Being proved how the fuse strip (placed at the centre of the model) has a temperature distribution quite homogeneous (thermal gradient of 100 ºC), due to the great difference of thermal conductivity values between the sand and the silver.

Model characteristics:

Three-dimensional simulation.

- Using of ¼ strip.
- Using of the current prospective value.
- No utilisation of the convection phenomena.
- Simulation estimated error 6.25%.

The obtained melting time is 2.925 sec.

Using these models, the time-current characteristics are obtained, which range is between the breaking capacity to four times the rated current. The results are shown on the [1]table 1

J $(A/mm^2)_{wide\ zone}$	Sand thickness (mm)	$T_{melting}$ (ms)
222222.22(20000 A)	0	0.14
4055.55(365 A)	0.25	3.8
2222.22(200 A)	0.4	6
1666.66 (150 A)	0.4	12
1555.55 (140 A)	0.5	20
1111.11(100 A)	0.7	70
1000(90 A)	0.8	100
888.88(80 A)	0.9	140
777.77 (70 A)	1	220
555.55(50 A)	1.5	820
444.44 (40 A)	3.5	3000
252(252 A)	5	4500

Table 1. Melting time for some current density values.

The method explained before has been applied one time more to a new geometry, where have been maintained the same materials used before. Now we vary the fuse strip length, keeping constant the thickness and the rest of the neck dimensions.

The obtained results are the following ones:

J $(A/mm^2)_{wide\ zone}$	Sand thickness (mm)	$T_{melting}$ (ms)
222222.22(20000 A)	0	0.14
4055.55(365 A)	0.25	3.8
2222.22(200 A)	0.4	6
1666.66 (150 A)	0.4	12
1555.55 (140 A)	0.5	20
1111.11(100 A)	0.7	70
1000(90 A)	0.8	100
888.88(80 A)	0.9	140
777.77 (70 A)	1	220
555.55(50 A)	1.5	700
444.44(40 A)	3.5	2475

Table 2. Melting times for some current density values.

On tables 1 and 2 is used the current density value which allows to make independent current that circulates along the fuse from the number of fuse elements and its dimensions. We have calculated two current density values, but we choose the one obtained from the wide zone of the fuse element because it has much more length and has a bigger contact surface with the refrigerating element (sand). It has been observed that exist a direct relation between the current density mentioned before and the necessary thickness to make the simulation (figure 5). sing the relation found and knowing the strip geometry, the current density (expressed in A/mm^2) is calculated. It's introduced the datum into figure 5, obtaining the sand thickness necessary for the simulation. In this way is avoided the needing, exposed in all the bibliography, of to know previously the melting time to can choose the appropriate model.

The explained method has been applied to a fuse composed by four strips with different dimensions than the previous ones. Table 3.

[1] Strip geometry is not included due to be considered as manufacturer privacy.

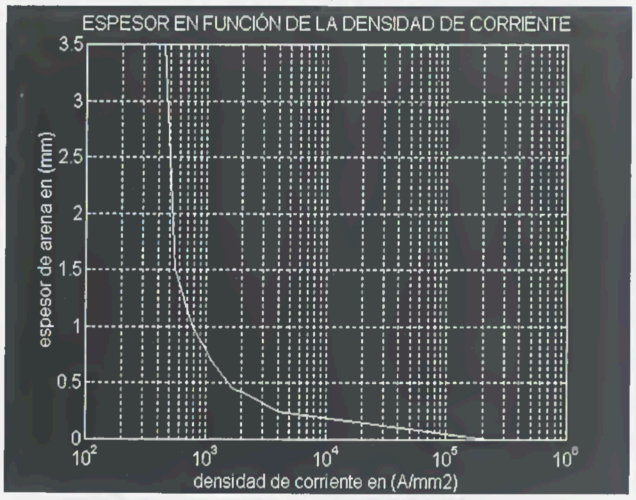


Figure 5. Thickness in function to the current density.

Prospective curren (A)	Current density (A/mm^2	Needed sand thickness (mm)	Melting time obtained in simulation (s)	Experimental time (s)
1000	1400	0.5	0.018	0.015
800	1111	0.7	0.03	0.025
600	833	0.9	0.152	0.14
500	700	1.1	0.31	0.25
400	555	1.5	1	0.9
300	416	5	3.5	3.3

Table 3 . Melting times obtained with the described model.

When very high melting times are reached, at very low currents (near to three times the rated current), the three-dimensional model begins to bring process times very long (rounding the 24 hours). The heat has time enough to reach the porcelain, transmitting itself to the external environment fundamentally by convection and the fuse element reaches a

uniform temperature. In these conditions the previous model is not valid. Due to that we will adopt a model with axial symmetry (figure 6 with two dimensions) where the fuse element is considered with uniformly section and winded in spiral round the star core. Its dimensions (high and width) are exactly the same than the ones belonging to the fuse strip and has an electrical resistance equivalent to one helix step of the original strip. The obtained results can be shown on the simulation of figure 7.

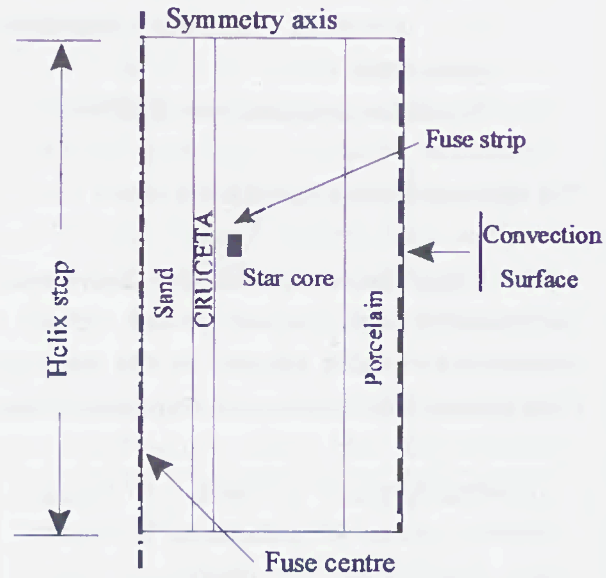


Figure 6. Two dimensions model.

It can be checked that the hottest zone is the internal zone (left part of the figure) and the heat flows towards the external part (right part of the figure) where exist a convection surface.

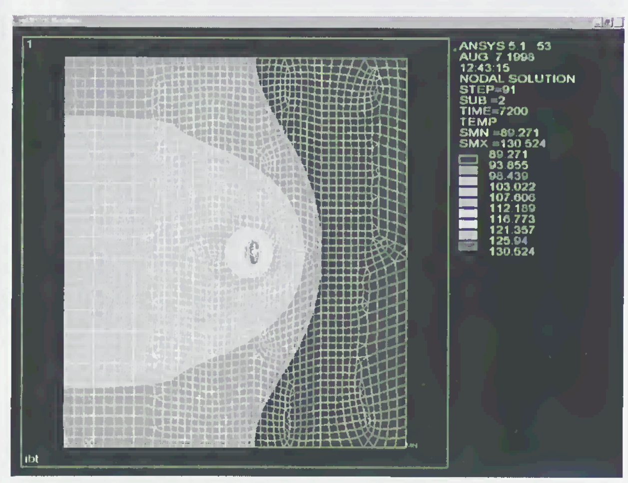


Figure 7. Simulation at rated current

At figure 7, the simulation devises the situation of the fuse behaviour at the rated current.

The exhibited method allows to obtain the melting times for every current with a maximal error of 6.25% (in calculation), using only two models:

1. Three-dimensional model
   - Adiabatic for currents with values near to the breaking capacity.
   - Sand contribution for currents until four times the rated current.

2. Two-dimensional model
   - Currents from three times the rated current to the rated current.

3. Minimal breaking current determination.

In the exhibited methods it can be observed that there is a limit current between the three-dimensional model and the two-dimensional one. The lowest current that causes a secure breaking can be obtained from the melting phase analysis.

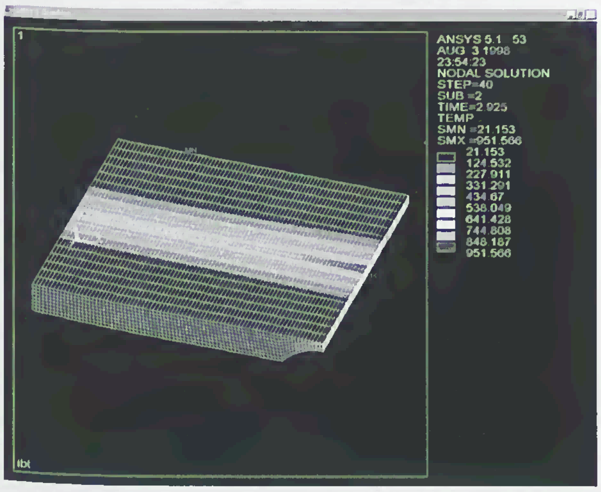


Figure 8. Simulation at four times the rated current. High rated current fuse.

The temperature distribution belonging to the simulation exhibited on figure 8 shows that it has been reached the melting point at the neck and also that at the wide part of the fuse strip exist a temperature near to the melting point (round 800 ° C). This fact indicates that the arc will appear in a simultaneous way at all the necks, giving place to a secure functioning. The current that won't cause this fact will give place to a random appearance of arcs in position and in time, for which it can't be assured the correct fuse functioning.

4. Summary.

As more important conclusions for the time-current characteristics determination we can conclude:

1. Using of only two kinds of models.
2. Elimination of the previous needing to know the melting time corresponding to the simulated current.
3. Real temperatures obtaining at any place of the fuse, allowing to know perfectly which are the conditions of the surrounding sand at the place where will appear the electric arc (neck).
4. Minimum breaking current determination without needing of tests.

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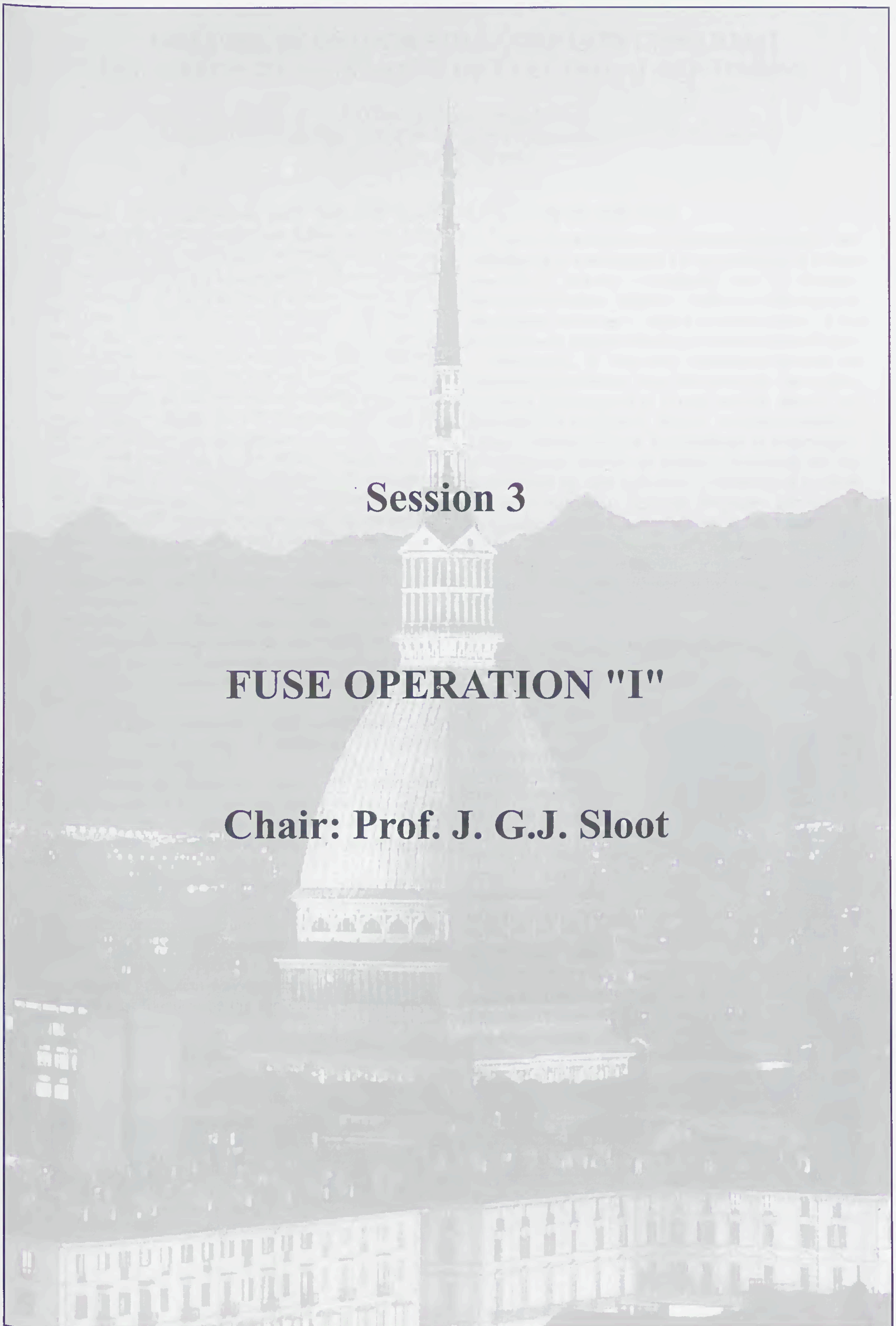

Session 3

FUSE OPERATION "I"

Chair: Prof. J. G.J. Sloot