ELECTRIC FIELD AND PRESSURE MEASUREMENTS IN HIGH VOLTAGE FUSES

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Abstract : The aim of this work is to know better the mechanisms which exist in high voltage fuses. In this way, we have chosen to study two physical parameters which are electric field and pressure.

I. INTRODUCTION

In order to model the circuit interruption, we need to determine the electric field and the pressure which exists inside the cartridge fuse. Electric field is measured in six points along the arc column and pressure on the cartridge wall in two perpendicular directions.

II. EXPERIMENTAL SET-UP

II.1 Experimental fuse

To obtain repeated fuse operations, a prototype fuse has been elaborated. The fuse element is a simple silver strip stretched between the end caps, and placed in a Celeron® cartridge.

The fuse element, figure 1, is a pure (99.95 %) silver strip. Its cross-section is 7.5×0.105 mm^2. It has three reduced sections of 0.5×0.105 mm^2.

Figure 1 : Fuse element
length = 70 mm, width = 7.5 mm,
thickness = 0.105 mm

The filler is a silica sand with a 350 µm average granulometry. It contains less than 0.2 % impurities and is compacted at 1.68 by a standard technique.

In order to have similar results as these observed in industrial fuses, from thermal strength I^2t point of view, we use a capacitor bank providing a 3 500 J energy to the fuse. It delivers a 12 ms, 1 800 A pulse. The obtained fulgurite is of about 31 mm long. The experimental set-up is presented on figure 2.

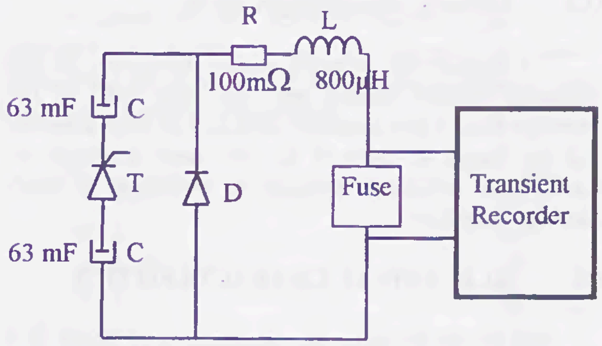

Figure 2 : Experimental set-up.

Current, voltages and pressures are measured by a transient recorder which is compound of two racks 6810 LeCroy (8 channels, f_{emax} = 1 MS/s) and/or of a National Instruments card AT-MIO-16E2 (8 channels, f_{emax} = 62.5 kS/s). Electrical characteristics are presented on figure 3.

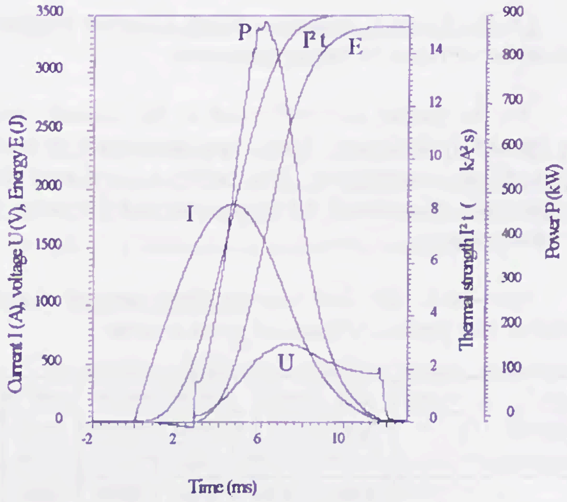

Figure 3 : Electrical characteristics versus time.

II.2 Electric field measurement set-up

To measure the electric field in six points of the arc, the probes are 90 µm diameter tungsten wires. All the probes are referenced to the cathode of the fuse. They are placed on both sides of the notches. We do not observe any difference between fuses with or without probes in the point of view of electrical characteristics U(t), I(t) and in non electrical parameters such as fulgurite dimensions and masses.

II.3 Pressure measurement set-up

To measure the pressure in two directions, we use miniature sensors placed into the inner wall of the cartridge fuse. Their sensitive area is 5.55 mm diameter and the range is from 0 to 250 bars relatively to atmospheric pressure. Pressure is measured at sand-cartridge interface.

III. ELECTRICAL CHARACTERISTICS

For all the 89 tests, the prearcing is of about (2.9 ± 0.1) ms. At the end of the prearc, the energy reaches to 3 J and the I^2t to 2 000 A^2s. Then, arc is established. It starts by a very short explosion phenomena which lasts about 50 µs; this value is in agreement with this of Chikata et al. [1]. They observed that at arc ignition, the plasma consists of ionised silver vapours during about 10 µs, and then the arc burns in silica vapours. Then, the arcing period continues 9 ms. At the end, the energy reaches up to 3 375 J and the total I^2t to 15 400 A^2s.

IV. ARC COLUMN ELECTRIC FIELD

On the figure 4, the total voltage U across the fuse and probe voltages Vi the are presented.

All the probes are referenced to the cathode and are spaced 3 mm apart. They are positioned at both sides of the constriction. The probe 1 is placed on cathode side, the probe 4 on the notches and the probe 7 on anode side.

Burn-back rate and electric field are calculated between two probes. Values are given in table 1.

	v21	v32	v35	v56	v67
v (m/s)	3.40	2.95	2.96	3.09	3.41
u_v (m/s)	0.29	0.38	0.31	0.32	0.21
	E21	**E32**	**E35**	**E56**	**E67**
E (kV/m)	44	38	29	36	45
u_E (kV/m)	4	3	2	3	4

Table 1 : Burn-back rate v and electric field E calculated between two probes.

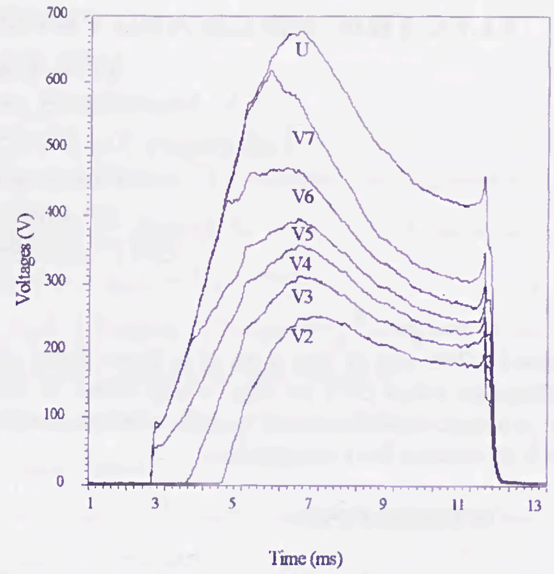

Figure 4 : Voltage U across the fuse and probe voltages V2 to V7 versus time.

For the first 6 mm, here and there of the constriction, the arc seems to go slower than after. This is due to the explosive arc ignition during which the arc spreads out in 3 directions (longitudinal, transversal and vertical ones). Next, during the burn-back phase, arc propagation is essentially a longitudinal one and the rate reaches up to 3.4 m/s.

At the same time, electric field evolution is observed. At 3 mm from the notch zone, electric field is about 29 kV/m, then it regularly increases up to 45 kV/m, 6 mm farther. To know if fuse arc can be considerated as a wall-stabilised arc, arc channel width and thickness are measured. Their values are given in table 2.

	p1	p2	p3,p5	p6	p7
width (mm)	8	9.5	12	9.5	8
thickness (mm)	2.5	3	4	3	2.5

Table 2 : Arc channel width and thickness.

The product of electric field by arc channel width is constant, and this of electric field by arc channel thickness also. So, fuse arc can be treated as a wall-stabilised arc. These observations are in agreement with Ranjan & Barrault [2] and Daalder & Schreurs [3].

V. PRESSURE MEASUREMENTS

Pressure measurements are performed on the inner wall of cartridge with two quartz pressure sensors (KISTLER 601A). Sand thickness between vertical and transversal sensors and fuse element are 10 mm and 6.25 mm respectively (figure 5).

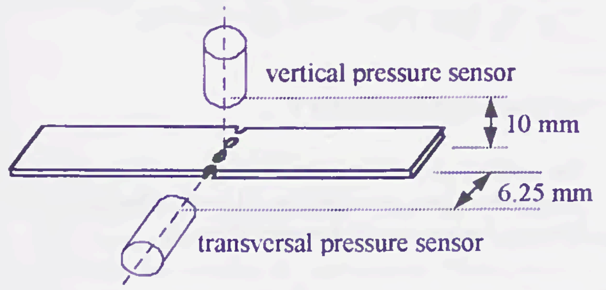

Figure 5 : Location of vertical and transversal pressure sensors.

A typical example of experimental results is given on figure 6.

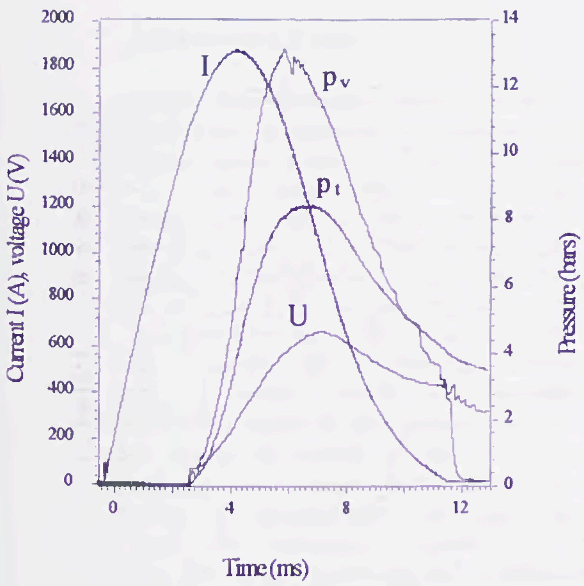

Figure 6 : Vertical p_v and transversal p_t pressures observed, at sand-cartridge interface, for a 1 800 A maximum current pulse.

Vertical pressure maximum is reached about 3.3 ms after arc ignition, its value is (1.5 ± 0.2) MPa. We have observed that vertical pressure maximum and power maximum are simultaneous. Transversal pressure maximum comes 600 µs later and reaches (0.8 ± 0.1) MPa.

Pressure propagation into the sand cannot be obtained from these experimental results because two factors have to be taken in account : the sand thickness is not the same in the two directions and the arc channel has a thickness of about 4 mm in front of transversal sensor while it has 12 mm width in front of the vertical one.

Nevertheless, we can note that the ratio of the vertical pressure to 10 mm (distance between sensor and fuse element) is equal to the ratio of the transversal pressure to 6.25 mm, during the increase.

After arc extinction, a residual pressure of about 0.2 – 0.4 MPa, exists.

A zoom on the pressure during prearcing is presented on figure 7. As we observe the same phenomena on vertical and transversal pressures, only transversal pressure is presented.

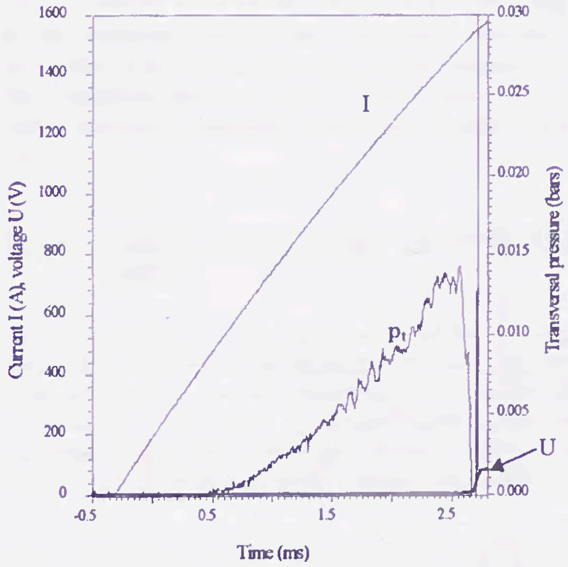

Figure 7 : Transversal pressure versus time, during prearcing.

First, we observe a regular increase of the pressure due to the heating of the fuse element constrictions. Then, 200 µs before arc ignition, the pressure falls. This fall results of a local rearrangement of sand grains.

VI. CONCLUSION

The electric field and pressure values obtained with this experimental set-up are similar to these obtained by other authors [2], [3] and [4], [5]. These values result from validating tests of the experimental set-up and will be used to model interruption circuit.

Especially, the measurement of low pressure existing during prearcing has been done (figure 7) and the meaning of this pressure evolution is given. With this set-up, we will be able to observe phenomena which happen when a critical current I2 is applied to the fuse.

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