PRESSURE IN ENCLOSED FUSES

M.R. Barrault

INTRODUCTION Despite the considerable literature on the subject, the physical conditions prevailing in an enclosed fuse arc column are still ill defined. A good understanding of the arc should allow one to predict the variations in electric field and extension in column length as well as the cut off current and dielectric recovery which follows. Existing calculations based on the charge controlled or similar models fall far short of this ideal largely because they ignore the crucial parameters governing the arcing behaviour. Among these we may list the column geometry, gas composition and pressure, wall temperature, current density and value. In this paper we shall examine some of the factors controlling the pressure, its measurement and evolution.

THE COLUMN PRESSURE The atmosphere in the arc column is derived from the evaporation of the element and also through wall ablation from the internal surface of the surrounding molten filler material (usually silica) tube. This tube is supported by the granular filler which cools the liquid silica thus increasing its viscosity and reducing its flow through the interstitial spaces. As a further consequence of this contact filler grains are melted and their mass added to that of the tube.

The bore of this tube which defines the geometry of the arc column is initially selected by the dimensions of the strip element. Thereafter the melting leads to an increase in available lumen area because of the voids present in the filler either intrinsically or through incomplete packing. For silica sand the ratio τ of the volume of fused silica to that of the original material is approximately 0.66. If a_f is the fully fused fulgurite cross section area t and w the element thickness and width then:

$$\text{Lumen area} \simeq (\tau - \lambda)\ tw + (1 - \tau)\ a_f$$

where λ is the fraction of element material entrapped in the fused section. ($\lambda \approx 1$) and we have neglected the initial set and compressibility of the surrounding material. As a first step we may assume that the quantity of molten fulgurite at a given axial station is proportional to the amount of energy dissipated there.

Combining this with a simple thermal conduction model for an arc of elongated cross section which has an electric field independent of current we find:

$$\text{Lumen area} = \sqrt{\frac{Q(1-\tau)}{\tau}\ \underset{2w}{Cw^{2}} + \text{an initial value}^{2}}$$

Dr. M.R. Barrault, Department of Electrical Engineering and Electronics,
The University of Liverpool, U.K.

Here Q is the charge which has flowed in an arc at that location and the initial value reflects the arc foot and initial filler set processes, C an arc material constant and w the element width.

Silica melts at 1705°C and boils around 2230°C at 1 at pressure, we may therefore expect the outer melted area to be close to 1705°C and the internal lumen wall to be at a temperature corresponding to boiling at the column pressure. A simple model developed along these lines suggests that the internal wall temperature should, at early times vary as QI whilst later on it should depend only on the current. Since QI is a function of axial position it is likely that strong axial flows are established which will average out in some way those variations.

CARTRIDGE WALL PRESSURE The pressure measured at the cartridge wall differs from that in the column because of the mechanical properties of the filler. Most sands will show some shear strength when under compression. As a result in cylindrical geometry:

$$\left(\frac{p_c}{p_a}\right)^{-1} = \left(\frac{r_a}{r_c}\right)^{\gamma - 1}$$

where γ, (< 1) is a constant for the sand p_c, r_c, p_a, r_a the cartridge and arc column pressure and radius. For spherical symmetry, likely to be approximated when the arc length is comparable with the cartridge diameter

$$\left(\frac{p_c}{p_a}\right)^{-1} = \left(\frac{r_a}{r_c}\right)^{2(\gamma - 1)}$$

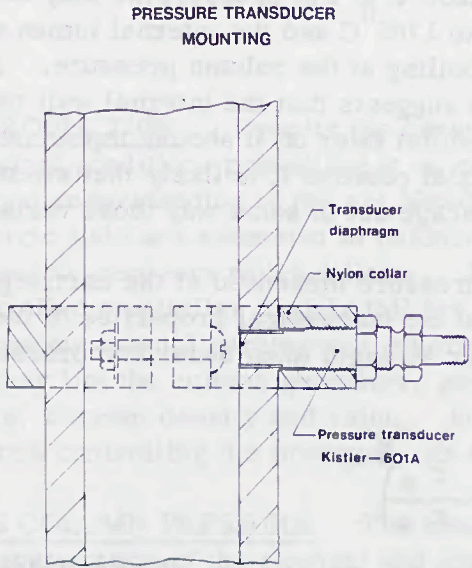
In addition some pressure hysterisis will exist which could introduce a lag at the time when the column pressure is falling.

EXPERIMENTAL RESULTS: The cartridge pressure generated in the assembly described in (1) was measured using a piezoelectric transducer mounted through an aperture in the cartridge wall Figure 1.

A typical trace is illustrated Figure 2. It displays a slow rise reaching a peak well after maximum power and remains fairly constant until extinction. Examination of the fine structure shows that the pressure is able to respond quickly to both upwards or downwards changes in current indicating that hysterisis effects are not serious. Experiments using a thin plastic tube to simulate the silica tube substantiate this observation Figure 3 and shows that $\left(\frac{p_a}{p_c}\right) \simeq$ 2 to 3.

A correlation of peak measured pressure with peak dissipated power Figure 4 leads to broad support of the above considerations.

CONCLUSION: Arc column pressure measurements in the fuse situation are complicated by the transmission properties of the filler material. In particular measurements made with different cartridge diameters (2) not only reflect real changes in column pressure due to changes in initial lumen sizes but also changes in the ratio of $\frac{p_a}{p_c}$ - The considerable delay between the onset of peak pressure and the earlier peak power dissipation underlines the importance of thermal storage in the molten phase.



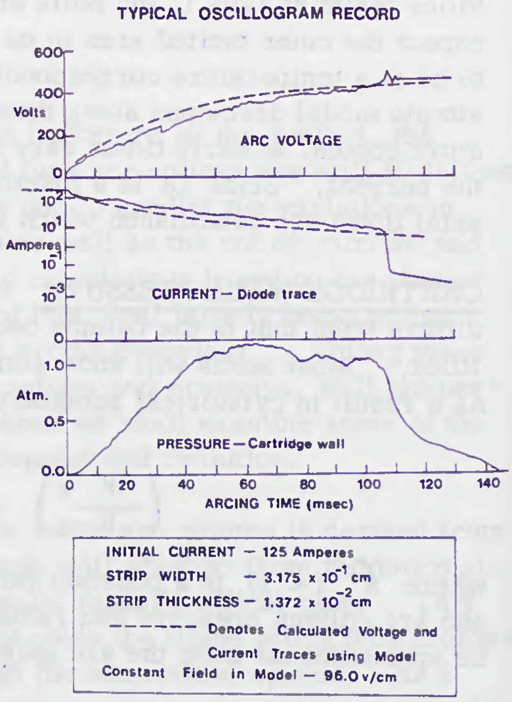
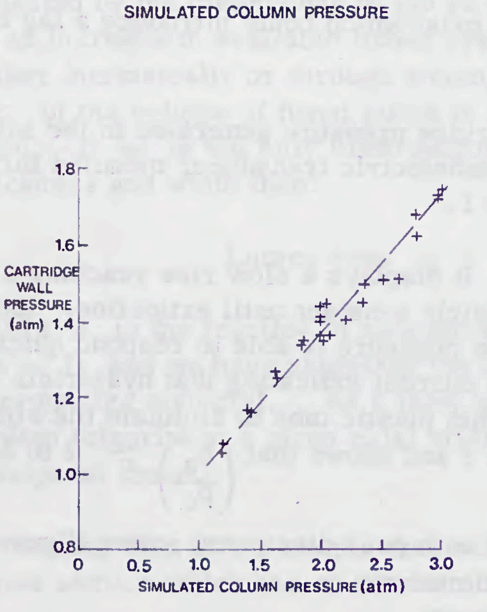


Figure 1

Figure 2



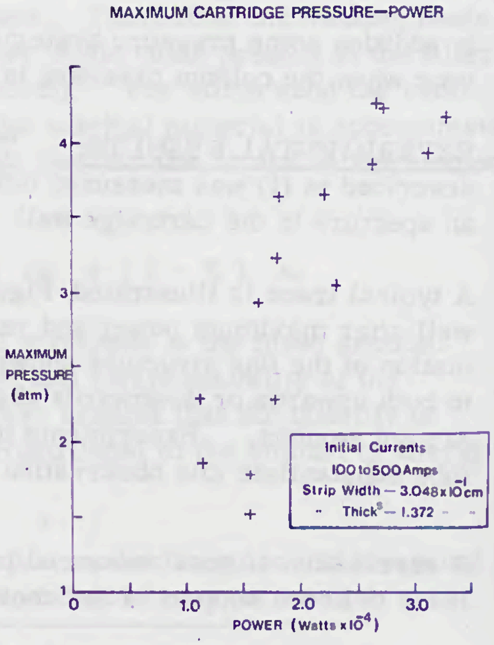


Figure 3

Figure 4

REFERENCES:

(1) Oliver, R. "The behaviour of D.C. overcurrent arcs in cartridge fuselinks"

(2) Baxter, "Electric Fuses" Edward Arnold and Co. 1950