EXPERIMENTAL STUDY OF A SPARK-GAP

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Abstract

Some experimental results concerning to the resistance of an atmospheric pressure spark-gap, operating in the self breakdown regime are presented. The influence of the energy discharging through the gap on this resistance is discussed.

1. Introduction

Sparks-gaps are elements currently used in a wide class of fast electrical circuits, many of them closely related to experimental Plasma Physics. Therefore, a characterization of its parameters (essentially a time dependent resistance and inductance) can provide useful knowledge for many applications, such as the design of experimental devices with optimal switching action and accurate interpretations of measured signals.

The resistive component of a spark-gap presents a very fast (≈ ns) initial transition from a large (open circuit) value down to a little one, typically smaller than any other impedance in the circuit. This transition constitutes what one expects as the "switching" action, and has been studied in gaseous spark-gaps by Martin [1], and Sorensen and Ristic [2]. More recently, R. Gratton et al. [3], presented measurements of the resistance and inductance of a spark-gap after the transition has taken place, as a function of the gas (air) pressure and gap length. They have found, discharging through the spark-gap a 2.12 nF capacitor, resistance values up to ≈ 600 mΩ, corresponding to gap lengths of 2 mm.

In this work we will present preliminary results of a study on the resistance of a spark-gap similar to the one used by R. Gratton et al., but energized with an order of magnitude larger capacitor, in order to disclose the influence on the resistance values of the energy delivered to the spark.

2. Experimental Setup

A small capacitor (capacity C = 35.5 ± 0.1 nF) is discharged on an air (atmospheric pressure) spark-gap, forming a circuit with a total stray inductance L = 32 ± 2 nH. The condenser is charged via a decoupling resistance R, which allows for a repetitive operation of the device, with a frequency of one shot every few seconds. When the voltage applied to the electrodes (semispheric-shaped cathode, curvature radius 4 mm; plane-shaped anode) is sufficiently high, the breakdown takes place and the current starts to flow. The distance d between electrodes (measured with 0.1 mm accuracy) was varied from 0.4 mm to 4.0 mm, and the corresponding breakdown voltages changed from 2.4 kV to 13.5 kV. The voltage variations on the capacitor, V(t), and the time derivative of the discharge current, dI/dt, has been measured using a capacitive voltage divider and a Rogowski loop, respectively.

3. Results

The breakdown voltage V of the gap was measured as a function of d, and the results are plotted in Figure 1. The data can be fitted by the relationship: $V = a\, d + b\, d^{1/2}$, where a = 25.0 kV/cm and b = 6.4 kV/cm$^{1/2}$. This dependence agrees well with the one given by Meek and Craggs [4] for a plane paralel geometry.

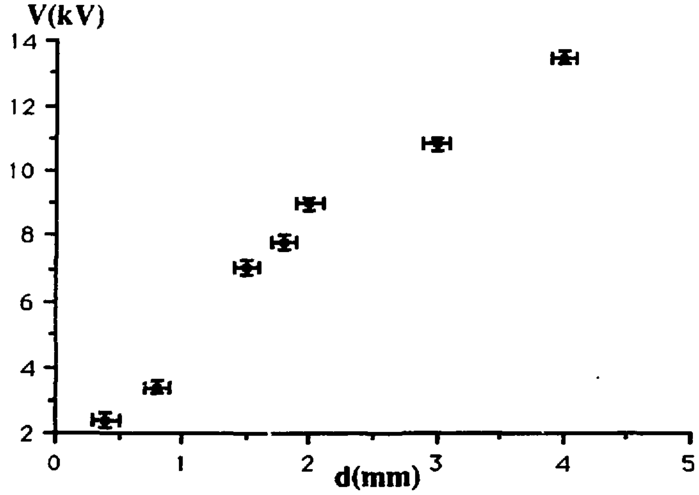
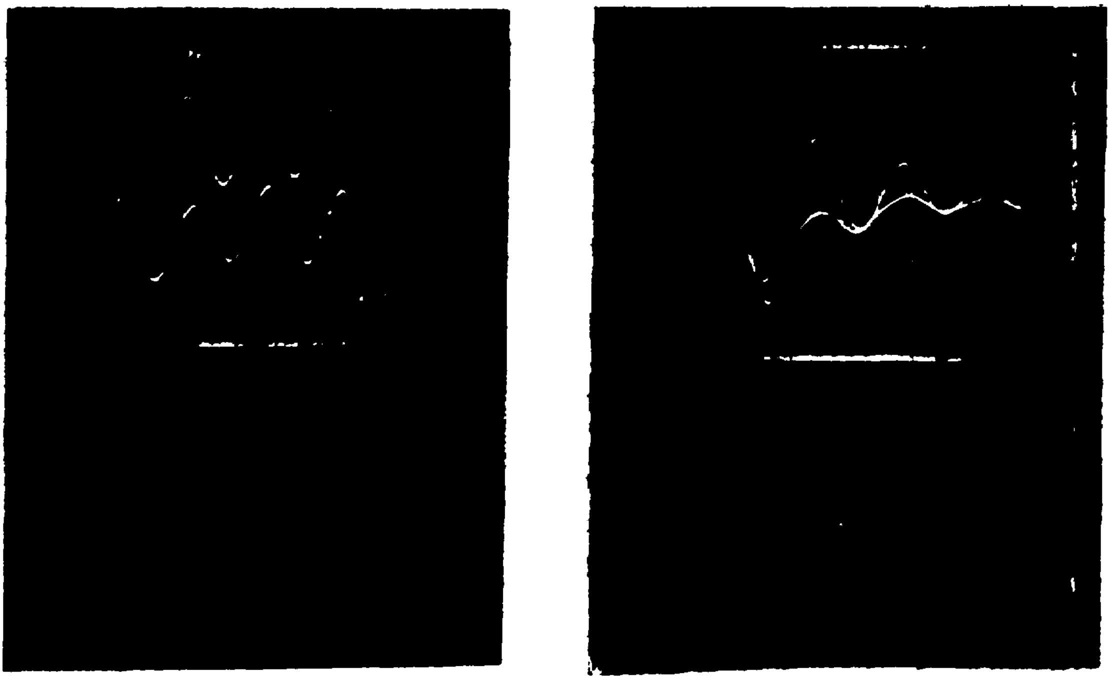


Figure 1: Breakdown voltage as a function of the gap length.



2a)

2b)

Figure 2: a) dI/dt (upper trace) and V(t) (lower) obtained at V = 2.4 kV, and at two different sweeping speeds (100 ns/div upper and 20 ns/div lower): b) The same, obtained at V = 13.5 kV.

Typical waveforms of the measured signals are shown in Figure 2. Fig. 2a) corresponds to the case: V = 2.4 kV (d = 0.4 mm), while Fig. 2b) corresponds to V = 13.5 kV (d = 4.0 mm). In all cases, the upper signals corresponds to dI/dt and the lower ones to V(t). The oscillograms above and below in each Figure differ only in temporal resolution (100 ns/div, above and 20 ns/div, below, respectively). It should be mentioned here that the voltage signals present a spurious long time decay superimposed to the actual V(t) behavior, due to the discharging of the divider's last capacitor (≈ 16 nF) on the 50 Ω termination of the coaxial connecting cable.

The dI/dt signals start growing from zero up to a first maximum with a risetime τ, which increases when increasing V. In Table 1 we give τ as a function of V, and also as a function of the electric field E applied to the gap, $E \approx V/d$.

V (kV)	d (mm)	τ (ns)	E (kV/mm)	τ_r (ns)
2.4 ± 0.2	0.4 ± 0.1	7.2 ± 2	6.0 ± 1.6	7.4
3.6 ± 0.2	0.8 ± 0.1	9.0 ± 4	4.5 ± 0.6	10.9
6.6 ± 0.2	1.5 ± 0.1	12.8 ± 2	4.4 ± 0.3	11.2
9.0 ± 0.2	2.0 ± 0.2	14.0 ± 1	4.5 ± 0.5	10.9
13.5 ± 0.2	4.0 ± 0.2	16.0 ± 2	3.4 ± 0.2	15.8

Table 1: Values of the risetime τ, the electric field E and the resistive time τ_r as a function of the breakdown voltage V and the gap lengh d.

This time should correspond to the so-called "resistive time", τ_r, refered to by Martin [1] with a dependence on the circuit and gap parameters in the form : $\tau_r\,(\text{ns}) \approx 88\,(\rho/\rho_0)^{1/2}\,Z^{-1/3}\,E^{-4/3}$ where ρ is the density of the gas used, ρ_0 the density of air at NTP, Z is the impedance of the driving circuit in ohms and E is in units of kV/mm. As can be seen from Table 1, our results compare well with those predicted by Martin, taking $Z = (L/C)^{1/2}$.

After the initial maximum, the dI/dt signals present a damped sinusoidal behavior. However, we must note that in the highest voltage cases, the curves appear slightly distorted, at least during the first period of oscillation (see Figure 2 b)).

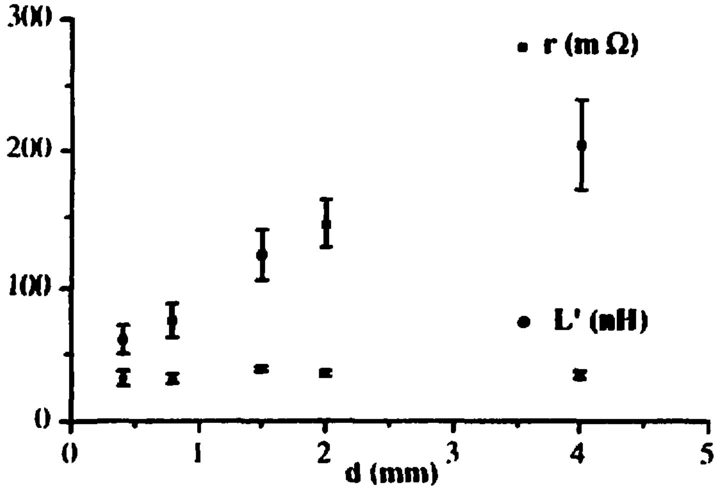


Figure 3: Inductance (L') and resistance (r) in the circuit, as a function of d.

Disregarding by the moment this distortion, we can assume that the circuit contains, in each case, a constant inductance L' and a constant resistance r, which can be evaluated from the dI/dt curves. The results of these calculations are plotted in Figure 3 as a function of the gap length d.

It can be noted that L' is essentially constant, implying that the contribution of the spark to the total inductance in the circuit in our configuration is negligible. On the other hand r increases with d from a value of 44 ± 11 mΩ (the stray resistance of the circuit) up to a value of ≈ 200 mΩ. However the values of r are smaller than those obtained in Reference [3] by a factor of ≈ 3, at equivalent gap lenghs.

4. Final Remarks

Notwithstanding the fact that no detailed calculations of the energies transferred to the spark channel have been done, a comparison between our experimental setup and that used in Reference [3] makes evident that the energy delivered to the spark channel per unit lengh is, in our experiment, much higher than that delivered in the experiment of this Reference. We must conclude then that the lower resistance values found in our measurements are due to the larger energy provided.

The reasons for this result can only be speculated with the data at hand, because any reasonable explanation requires a precise knowledge of the radius of the spark channel. Also, the distortion observed in the initial portion of the dI/dt signals in the highest voltage cases suggest that time dependent resistances should be considered for modelling of the circuit, intead of constant ones.

Aknowledgments

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