BEAM AND HOT SPOT FORMATION IN A LOW IMPEDANCE DRIVEN VACUUM SPARK.

H. Chuaqui, M. Favre, L. Soto, and E. Wyndham
Facultad de Fisica, Pontificia Universidad Catolica de Chile,
Casilla 6177, Santiago 22, Chile.

Abstract

Observations of a vacuum spark discharge plasma when driven by a 1.5 Ω, 120 ns switched coaxial line at 60 kV open circuit voltage. A comparison of behaviour is made when a Nd:YAG laser over a range of energies is focussed either onto the anode or onto the cathode surface. A significantly different behaviour is seen if the line gap is shorted out allowing the sinusoidal voltage from the Marx to be applied to the electrodes. Hot spot formation with associated anode plasma are seen in this last case.

1.– Introduction

The vacuum spark has become a popular and fruitful subject of experimental and theoretical research in the last two decades. The dynamic behavior has been treated with some success by the theorists[1], but observational techniques still have much ground to gain. Extensive reviews are available[2,3]. The great majority of results have been obtained in low inductance capacitor bank circuits but very few results have been published[4] when using a low impedance switched coaxial line as a driver. Although peak currents for the typical voltage used will be lower when using a line, it has the advantage that for the time scale of the current dips ($\simeq$ 50 ns) Z can be significantly lower than the impedance associated with the LI product of a low inductance spark. In this paper we present preliminary results for the vacuum spark discharge when driven from a 1.5 Ω line at a fairly low voltage. These results are also compared with the results obtained with the line gap shorted–out and significant differences are found.

2.– Experimental Configuration.

A 400 kV, 25 nF Marx generator is coupled to a water dielectric coaxial line with a double transit time of 120 ns and impedance of 1.5 Ω. A self–breakdown gap is placed at 3/4 of the way to the chamber. Measured current rise times are 15 ns forming a well–controlled square pulse. The vacuum spark discharge is formed in the typical geometry of a conical anode and a plane cathode. Figure 1 shows the two schemes used to trigger the discharge using a 30 ns Nd:YAG laser at energies of 18, 90 and 180 mJ. In the first scheme (a) the laser light passes through a 3 mm diameter cathode aperture and is focussed onto the copper anode. The second scheme (b) passes the laser light through a hollow conical anode and focusses the laser light onto a slightly recessed central cathode region which is 3 mm

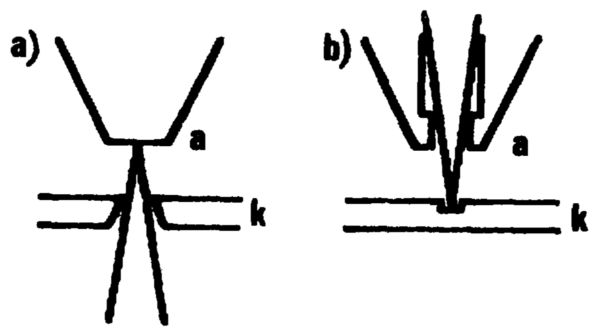

Figure 1: different schemes used for laser triggering. a: anode, k: cathode.

wide by two 2 mm deep. The diagnostics used were an X–ray pin–hole camera, filtered with 3 μm Al and 5 μm Mylar. Temporal resolution of the X–rays was observed with a PIN diode sensitive between 8 and 40 keV. An aluminium cathode XRD filtered with 5 μm Mylar detects soft X–rays at 200 eV and between 600 to 2000 eV. Both these detectors see side–on emission. The operating voltage of the line was 60 kV. When the line gap is shorted out a sinusoidal voltage with a quarter period of 450 ns is obtained. However due to the characteristics of the line, during changes in the load which are shorter than 120 ns the driver will be resistive and not inductive.

3.– Experimental Results

a) Line Gap Operating: with direct anode illumination (Fig. 1–a) no X–ray emission is observed unless the laser preceeds the applied voltage by more than (Δt) 250 ns, even though a apreciable current of order 40 kA flows in the discharge. X–ray emission is a maximum for Δt between 450 and 800 ns for all laser energies. The emission of hard X–rays is very similar at 90 and 180 mJ laser energies but is approximately 1/3 at 18 mJ. Under no conditions are soft X–rays seen. Strong signals are seen from the PIN diode for maximum discharge current between 20 and 33 kA. The onset of X–ray emission is identified with the reduction of $\dot{I}$ from its large positive initial value at the begining of conduction. For illumination at 180 mJ the X–ray pulse takes essentially the same form as the current. At lower illumination the X–ray emission accurs as a narrow pulse for Δt < 400 ns, at later times, the pulse follows the current. X–rays pin–hole photographs show strong emission from the anode electrode surface. Figure 2 shows typical current and X–rays traces for Δt = 685 ns. In the case of direct cathode illumination (Fig. 1–b), we find the same general temporal relation for X–rays and current. The differences are: even for a 180 mJ illumination a maximum current of only 22 kA is observed with a correspondingly lower X–ray emission, the PIN diode signal has more structure (multipeaked form) and the overall pulse width is narrower. The $\dot{I}$ value is notably lower

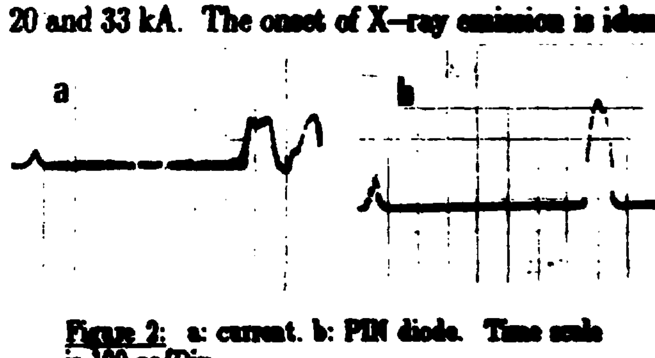

Figure 2: a: current. b: PIN diode. Time scale is 100 ns/Div.

than for direct anode illumination. Figure 3 shows a composite resume of the X–ray signal amplitude and the current at 180 mJ illumination for both schemes.

b) Line Gap Shorted–Out: this scheme was tried for direct hollow cathode illumination only. It was found necessary to use 180 mJ illumination for a fast breakdown and for X–ray production. With a slow sinusoidal voltage applied the laser pulse comes at different times and therefore different anode–cathode voltages. It was found that the time delay of 170 ± 20 ns from laser pulse to electrical breakdown is independent for an applied voltage above 8 kV. An XRD signal begins with the laser pulse and ends at the start of appreciable conduction (> 2 kA) and at the start of the main PIN diode signal. Hard X–ray emission at low intensity begins shortly after the laser pulse but the main pulse is clearly identifiable with a step on the rising current edge. Remarkably the value of the current at which the step occurs is independent of the applied voltage and occurs at a current of 10 kA. After the emission of hard X–rays starts to fall the current increases to its maximum value. Fig. 4 shows in three successive shots three current traces and the hard X–ray signal, XRD and voltage behaviour. Pin–hole photographs show a string of somewhat diffuse hot–spots (d ≃ 700 μm) along the axis. There is also evidence of an X–ray emitting plasma projecting from the anode, as may be seen from Fig. 5.

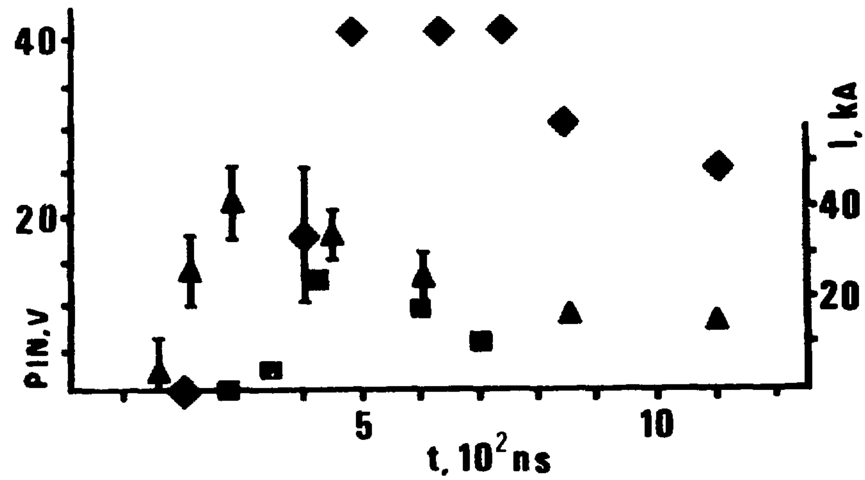

Figure 3: composite resume of X–ray signal amplitude and current at 180 mJ. Scheme 1–a: ▲ = I, ◆ = PIN diode. Scheme 1–b: ■ = I.

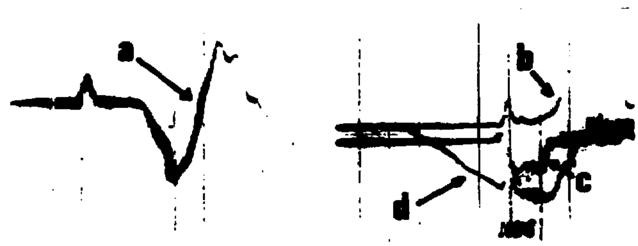

Figure 4: signals in successive shots at 100 ns/Div. a: I, b: PIN diode, c: XRD, and d: V.

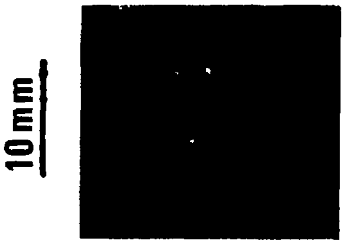

Figure 5: X–ray pin–hole photograph.

4.– Discussion

In contrast with the results from Zakharov[4], who used a similar driver, no evidence of plasma points, loose or tight[5], have been found. The emission of X–rays is from an electron–beam–bombarded anode. However, this is not surprising as the currents in this preliminary experiment are well below the value normally taken as necessary for the formation[2] of hot–spots. It is unclear at present what is the mechanism of beam current limiting and the $\dot{I}$ disruptions. The different experimental results when a sinusoidal voltage is applied is probably related to the formation of a plasma in the cathode recess. The apparent independence of breakdown time and the first part of the current pulse as well as soft X–ray emission all suggest hollow cathode or pseudospark[6] processes. With this class of processes we would expect a far higher inter–electrode plasma density, which should allow easier formation of hot–spot or their precursors.

5.– Conclusion

A number of interesting properties have been found in a low current vacuum discharge, particularly in relation to the voltage wave–form applied to the elctrodes. The laser power is apreciable lower than used in other laser–initiated vacuum spark discharges[4,7], but the main features observed by these authors are present. There is clear evidence of different physical processes occurring when a slowly varying voltage is applied. Future experiments at current discharges of 80 kA should prove conclusive.

6.– Acknowledgements

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7.– References

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