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Multiple focus formation in a Mather gun device

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Abstract. Along with the normally produced pulses of dI/dt, x-ray, optical emission, neutrons and ions by a Mather type plasma focus gun, one more set of pulses were observed to be generated by a low energy device at Trombay, a few 100 ns after the first set of pulses, in majority of the discharges. In a small number of discharges even three or more sets of pulses were observed. Signals from pick-up probes placed in the run down region of the device suggest formation of more than one sheath which subsequently may form more than one focus which in turn is responsible for the second and subsequent sets of pulses.

Keywords. Plasma focus; Mather gun; thermonuclear fusion.

1. Introduction

A number of laboratories investigating Mather type plasma focus devices (Mather 1971) have observed that the devices emit x-rays in two pulses, each lasting for few tens of ns and separated by a few tens of ns. Similarly the optical emission, neutrons and ions were emitted predominantly in a single pulse lasting for $\sim$ 100 ns

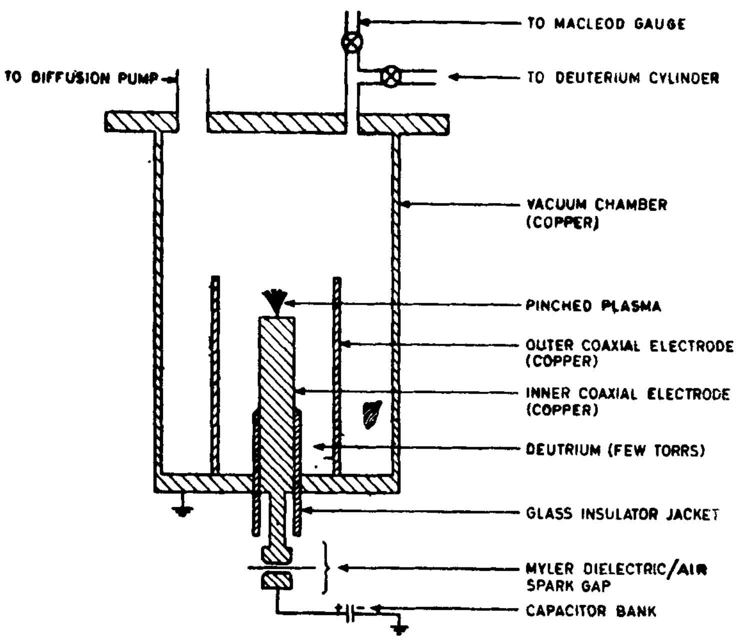

Figure 1. Mather type plasma focus device.

(Krompholz *et al* 1980; Peacock *et al* 1971). However a low energy plasma focus under investigation in our laboratory has different and unusual emission characteristics, which are described here.

2. Experimental set-up

The Mather type plasma focus device (figure 1) on which experiments were conducted had central anode and outer cathode diameters as 2·2 and 7·2 cm. The length of the anode was 11·8 cm and the corning glass sleeving on its one end was 3.8 cm long. The device was studied by a capacitor bank having 16·8 μF capacity and 40 nH series inductance. The circuit with the load had a ringing period of 6·8 μs. The experiments were conducted in the (charging) voltage range of 6 kV to 16 kV (100 to 230 kA, peak currents). There was no observable variation in the time resolved characteristics of the device (except for intensities) with the change in the bank voltage.

The characteristics (of this plasma focus) investigated were x-ray, optical, neutron and accelerated ion emissions, the current and time derivatives of current (dI/dt) through the device and through the current sheath in the run down region. All the experiments were conducted with hydrogen as the filling gas except in the case of neutron emission, where deuterium was the filling gas.

3. X-ray emission

X-rays were detected by a plastic scintillator (NE 102A, 5 cm thick) mounted on a photomultiplier (PM) tube (Philips 58 AVP). The signal was recorded on a Tektronix 7834 storage oscilloscope. The system displayed a pulse of 5 ns (FWHM) when a single ^{60}Co gamma was incident on the detector.

Figure 2 shows a typical x-ray signal from plasma focus discharges viewed through a 6 mm perspex window. A peculiar feature of these signals is that in about 60% of the discharges, apart from the usual two x-ray (primary) pulses, a second set (auxiliary) of pulses of similar duration, also appeared a few 100 ns after the first pulse. In about 5% of the discharges more than two sets of pulses were observed in a span of about 1 μs.

The temperature of the plasma emitting these pulses (Podgorny 1971) at 13·5 kV (185 kA) charging voltage, was (2·7 $\pm$ 0·3) keV and (3·1 $\pm$ 0·3) keV for primary and auxiliary pulses respectively. The primary as well as auxiliary pulses also contained hard x-rays. These had maximum intensities (Bernard 1978) at (45 $\pm$ 5) and (30 $\pm$ 5) keV energies for primary and auxiliary pulses respectively.

4. Optical emission

Optical emission was detected by a PM tube (Philips 58 AVP) covered with a blue green filter (4500 to 5500 Å) with 10^{-4} attenuation. The detector was so collimated, that it viewed only the central 1 cm^2 area of the inner electrode of the plasma focus vertically.

The optical signal observed was of $\sim$ 200 ns (FWHM) duration and it consisted of a

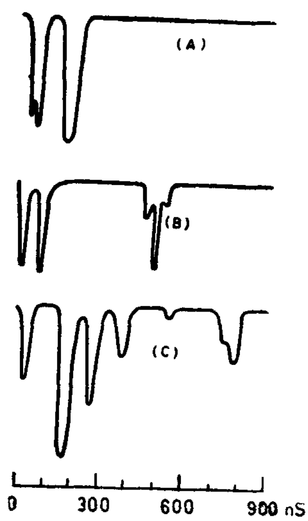

Figure 2. C. R. O. patterns of X-rays A. Only primary focus formed occurrence 35% B: Primary and auxiliary focus occurrence 60% C: Multiple focus formation occurrence 5%.

number of overlapping narrow pulses. In 10% of the discharges an auxiliary pulse was also observed above the background. As in x-ray emission this pulse also appeared a few 100 ns after the primary pulse. However, unlike the x-ray pulses, it was much smaller in amplitude as compared to the primary ones (figure 3d).

5. Neutron emission

Neutrons were detected by the same plastic scintillator used for x-ray detection; in addition it was covered with 6 mm of lead to shield the x-rays from affecting the detector. The detector recorded no signal above the background when the plasma focus was operated with hydrogen as filling gas, thus confirming its insensitivity to x-rays.

It was observed that bulk of the neutrons were emitted in a pulse lasting for about 100 ns but this pulse was followed by a number of smaller 'secondary' pulses and the total emission lasted for about 500 ns. The auxiliary pulse in this case was however observed only in 7% of the discharges. It is quite likely that this pulse may have been emitted more often but was indistinguishable from the secondary pulses. Figure 3G shows a signal in which this pulse is clearly observable above the secondary pulses.

The total neutron yield emitted in a single discharge was measured by a silver activation counter. The device emitted $(5 \pm 2) \times 10^7$ neutrons when 185 kA ($\sim$ 1·4 kJ) current was discharged through it. This yield is comparable to the yields obtained in other focii (Bruzzone *et al* 1976) operating elsewhere in this energy range.

6. Accelerated ion emission

The accelerated ions were detected by an ion collector (Young *et al* 1977) biased at (—) 300 V to separate the low energy electrons from the ion beams. It also had a

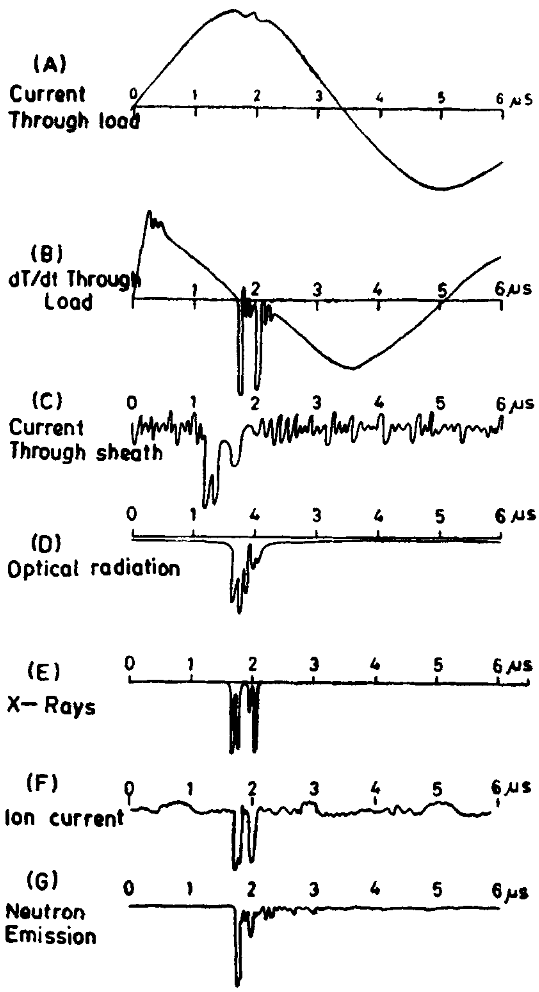

Figure 3. C. R. O. patterns of plasma focus diagnostics.

1 mm diameter pinhole in front of it to prevent saturation. The collector was held 5 cm away from the tip of the central electrode, this distance was sufficient to stop (at 5 mb pressure) any ion below 10 keV to reach it, thus preventing the plasma debris from affecting the detector. The detector recorded no appreciable signal above background when it was covered with 12 μm of mylar, thus ascertaining its insensitivity to x-rays and electrical noise.

Ions were observed to be emitted in single pulse (with a forked peak) of 100 ns duration. In about 50% of the discharges an auxiliary pulse was also observed after a few 100 ns (figure 3F). This auxiliary pulse was of approximately same duration and amplitude as the primary pulse.

7. Plasma focus dI/dt signal

The dI/dt signal as measured by a Rogowsky coil is shown in figure 3B. The pulse consisted of a main pulse of 100 nsec duration and it was followed by a number of smaller secondary pulses of much smaller amplitude. As in case of various plasma focus emissions, in about 50% of the discharges, this primary pulse was followed by an auxiliary pulse which was of about the same amplitude and appeared, as expected, a few 100 nsec after the primary pulse. In 5% of the discharges more than two pulses were also observed.

8. Auxiliary focus

The various auxiliary pulses observed in x-ray, light, neutron and ion emissions and the dI/dt signals, a few 100 ns after the primary pulse are unlikely to be produced by some delayed action phenomenon in the primary focus. One of the plausible explanations of this phenomenon is the formation of two (or more in case more pulses are observed) current sheaths in plasma focus gun. These sheaths may form subsequently, two separate focii one after another. To check on this hypothesis a small probe was kept in the plasma focus run down region. It was a three-turn coil of 1 mm radius and was placed 1 cm below the tip of the central electrode. (The placing of this probe had no effect on the focus performance, this was ascertained by measuring the other characteristics of the device with and without probe placed inside it). The integrated output signal obtained from this probe (figure 3C) also had an auxiliary pulse appearing a few 100 nsec after primary pulse. In some discharges signal having more than two pulses was also observed. These results suggest the formation of multiple currents sheath in our plasma focus which probably results in multiple focii.

9. Conclusion

It has been observed that in a plasma focus device not all bank current is utilised for pinching. Experiments (Decker *et al* 1980) suggest that as high as 50% of the bank current continues to leak along the glass insulator at the time of pinching and thus does not contribute to neutron production. This current can launch a second plasma sheath if sufficient gas pressure exists ($>$ 0.01 mb) after the first sheath snplow the gas. Generally in plasma focii the pressure is not sufficient after the snplow, therefore only one sheath is launched. However in our device, there is a gap between the inner electrode and glass insulator. The gas trapped in this gap fills up the inter electrode space to sufficient pressure for a second, and in certain cases subsequent sheath propogation. Since the multiple focus formation utilises insulator leakage current which otherwise is wasted, these can be used to enhance the neutron yield from the device. In the current experiments reported here, the neutrons yield by second sheath is small. However we believe that it is mainly due to low pressure during the second sheath formation as the gas quantity introduced is very small. If this quantity can be increased the yield may be enhanced. We plan to do this by making the gap between the inner electrode and insulator large. Further experiments are in progress.

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