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X-Ray Emission from Dense Plasma Sequential Focus Device

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Abstract

The Sequential Dense Plasma Focus (DPF) under investigation is a 3.3 kJ device having a coaxial electrode assembly with a modified central electrode surrounded by six outer electrodes in squirrel cage fashion. In conventional DPF device, one or two compression phases are generally observed. In sequential dense plasma focusing device more than two compression phases (i.e. multiple focusing) have been achieved. Sequential focusing of current sheath was achieved on DPF device using a modified form of central electrode. The sequential focusing was optimized by taking different electrode designs for different filling gas pressures of argon. The observation of multiple spikes in the voltage probe signal confirmed the sequential focusing. We have observed the X-ray emission characteristics from the best-optimized Sequential DPF device. The time resolved X-ray signals from Sequential DPF device have been taken using one of the channels of five channel Diode X-ray Spectrometer. Multiple X-ray spikes corresponding to different voltage spikes at different instants have been observed indicating thereby the possible use of Sequential DPF device for fast X-ray cinematography.

Keywords:

Plasma focus, Sequential focusing, X-rays, Diode X-ray spectrometer, voltage spike

1. Introduction

Sequential dense plasma focus has its importance in X-ray cinematography and neutron radiography. Lee *et al* [1] were the first one to observe the formation of second focus at the target disc placed above the central electrode of DPF device and thus predict the possibility of development of Sequential DPF device. Subsequently, Lee [2] proposed a theoretical model for sequential focusing. Nisar *et al.* [3] reported the experimental evidence of Sequential DPF by having target disc hanged by two off centered insulating support instead of single axially centered support used by Lee *et al.* [1].

Earlier, DPF device has been developed as a fusion device with most of its studies being done in hydrogen and its isotopes. Since DPF is also a source of X-rays, energetic ions and relativistic electrons it has founds its applications in other areas too. Energetic ions from DPF have recently been used for material processing [4-7] and deposition of thin films [8,9]. The relativistic electrons of this device have been used for microlithography [10]. The DPF device also emits soft X-rays during pinch and subsequent phases. Presently, the problem is no longer that of reducing the radiation losses from plasma focus but is that of increasing the total X-ray yield in certain region of spectrum. This is due to increasing potential application of plasma X-ray

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sources in X-ray spectroscopy, microfabrication, microscopy, laser pumping and high-density microelectronic lithography [11-14].

Recently, we have attempted to optimise the sequential DPF by modifying the central electrode design with variable radius copper cylinders attached with the central electrode by single or double support [15]. It has been found that a decreasing radii type of cylindrical attachment at the top of the central electrode by single support gives strong sequential focusing action. Nisar *et al.* [3] have claimed the sequential focusing in their focus by observing two spikes in their voltage probe signal as well as in neutron pulses. A conventional DPF device many times shows two or three spikes in voltage probe signal and therefore the result reported by Nisar et al does not confirm sequential focusing. In present paper, we report the time resolved X-ray emission characteristics of sequential focusing DPF device with central electrode design optimized earlier [15] for strong sequential focusing. This is to explore the possibility of developing plasma sequential pulsed X-ray source.

2. Experimental Setup

The DPF device used in this study is a 3.3kJ Mather type device whose schematic is shown in figure 1. The modified central electrode is used to obtain the sequential focusing. The modified central electrode is the one in which two cylinders of decreasing radii are carved on the top of it. The outer electrode consists of six copper rods whose design is same as that of conventional focus device. The device is operated with argon as the filling gas in the pressure range of 50 to 150Pa. The device is powered by a low inductance 30 μf capacitor bank charged up to 14kV. The voltage probe and X-ray diode spectrometer signals were recorded using Tektronix TDS 784 digital storage oscilloscope. The best sequential focusing is indicated by strong multispike voltage probe signal for the central electrode with cylindrical attachment of decreasing radii with single support as shown in inset of figure 1.

The X-ray signals are detected by a multichannel diode X-ray spectrometer (DXS) [16]. The diodes used in the DXS are planar silicon PIN photodiodes (BPX 65) without glass windows, housed in a modified TO-18

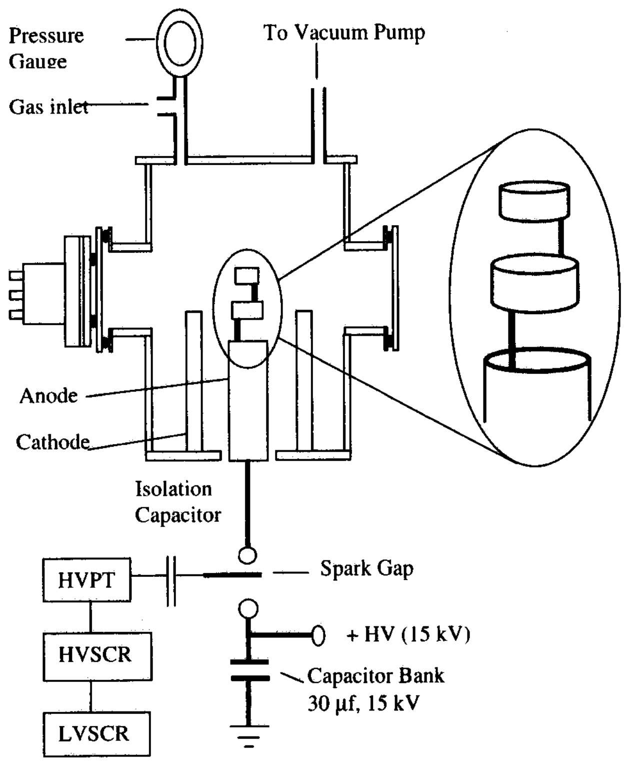

Fig. 1 Schematic of experimental set up with the inset showing modified central electrode design for sequential focusing.

case. Each diode of DXS is reverse biased to 45 V and is connected to the oscilloscope through a resistor capacitor combination.

3. Results and Discussion

The typical voltage probe and DXS signals at 60, 100 and 120 Pa filling gas pressure of argon are given by (a), (b) and (c) of figure 2, respectively. The X-ray signals shown in figure 2 are taken using the channel of DXS in which the PIN diode window is covered by 149 μm aluminized mylar. Each of the voltage probe signals posseses multispike structure which clearly indicates sequential focusing in device. Majority of voltage probe signals contain four to five voltage spikes. The first peak corresponds to the first compression at the top of the main part of the anode. This is followed by one or two small peaks, separated by 100–150ns, which is seen even in conventional plasma focus. The next peak is stronger and occurs about 600–650ns after the first peak which corresponds to second focus at the first cylindrical attachment. The third peak which occurs at the second cylindrical attachment is about 300–350ns after the second focus. The time gap between second and third focus (300–350ns) is less than time gap between the first and second focus (600–650ns) because of the shortened support as well as the smaller width of the second cylindrical attachment. As can be seen from figure 2, no X-ray emission corresponding to first voltage spike is observed. This is possiblly due to the fact that the first focus is occuring little too early because of the shortening of the main part of the anode. Therefore not nearly the peak discharge current is flowing through the first focused plasma column and thus the plasma is not hot enough to radiate in X-ray regime. The first X-ray spike starts approximately at the peak in the second spike of the voltage probe signal. It is also apparent from figure 2 that the second spike in the voltage probe is always most intense and has smallest FWHM of about 50–60ns. The third and fourth voltage spike are relatively less intense with more half width. The second and third X-ray peaks in DXS matches well, in a similar fashion, to third and fourth voltage peaks, respectively. The second X-ray spike was always more intense in comparison to the fisrt one and the third peak was the weakest in all DXS signals at different filling gas pressures. In some of the DXS signals we have noticed more than three peaks with the first the first three similar to normal one and the later ones being even lesser in magnitude with more half width as seen in figure 2(b).

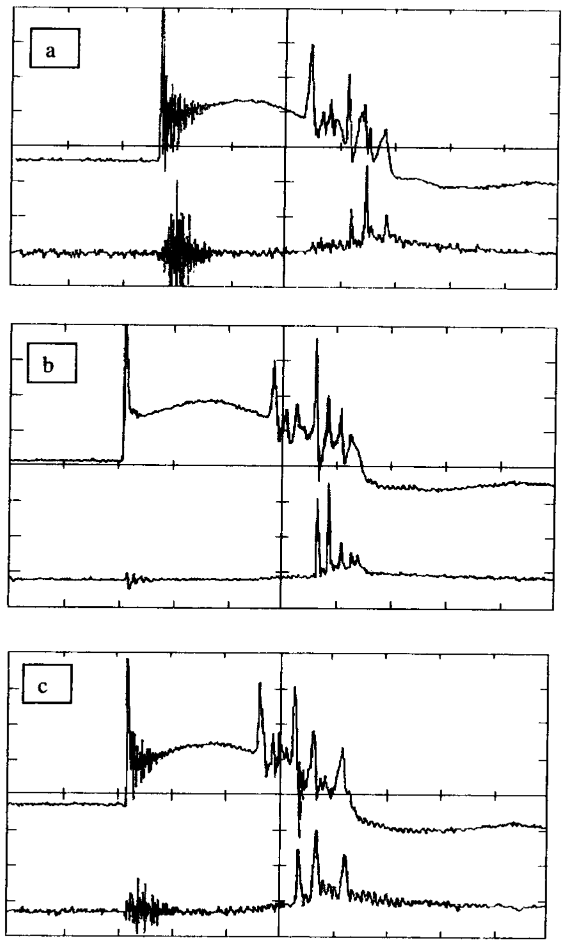

Fig. 2 Typical voltage probe (upper trace) and DXS (lower trace) signals at different filling gas pressures of (a) 60 Pa, (b) 100 Pa and (c) 120 Pa with time base of 1 μs/div and voltage base of 1V/div.

4. Conclusion

This study clearly establishes Sequential DPF as a source of sequential X-ray pulses as well. This device thus can find suitable application in the field of X-ray cinematography.

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