Current Sheath Structure in Miniature Plasma Focus

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Abstract – Current sheath dynamic is an important parameter for good focusing in a Plasma Focus (PF) device. The structure of the current sheath from breakdown to the pinching phase has been studied by developing small scale (50-160J) plasma focus facility. The analysis of current sheath structure was possible by using several fast diagnostic techniques. The current sheath layer buildup time around the insulator sleeve has been analyzed for different gas filling pressure. The filamentary structure of current sheath was found at high gas filling pressure although the electrical signal showed good focusing signal at around 380 ns, after the breakdown of the gas. The spot size duration analyzed by time resolved images has been correlated with the electrical signals. The spot position at the tip of anode has been found at low pressure on the circular solid part of the anode and at high gas pressure, the bright spot indicates that the electrons striking deep in the hole of the anode.

1. Introduction

From last four decades, Plasma Focus (PF) devices with different dynamics and input energies have been used as sources of various radiations, charged particles and neutrons with potential applications in many different areas [1-3]. Some critical drawbacks for large facilities [1-3] are the low repetition rate, high cost of experiments, and require more time and manpower to carry out an experiment. Recently, due to the advancement in pulse technologies the research on miniature PF devices has attracted the attention of the plasma research community. This is due to a fact that the small scale facility has smaller size of capacitor bank of tens to hundreds of joules in comparison with banks of kilojoules, in this way it would be easier to operate the device in a repetitive regime of Hz to kHz, and due to the smaller transference of load in spark-gaps, thus diminishing its erosion. Also the cooling of the system would be easy due to lesser average power of the device.

P. Silva *et al.* [4] have observed the pinch in a deuterium-filled plasma focus operating at 50 and 67J. They reported about the typical dip in the current derivative signal and the typical peak in the voltage signal associated with pinch compression usually observed in several kJ PF devices. The structure of the electrodes consisted of a 29 mm long, 6 mm diameter copper tube anode and an outer cathode of eight 5 mm diameter copper rods uniformly spaced on a diameter of 27 mm. The size of their device was in the order of 25cm × 25cm × 50cm.

More recently, Soto *et al* [5] have observed current sheath structure and the evidence of pinching in electrical signals in their ultra miniature device (nanfocus: NF) of 0.1J. The total size of the NF device is 20cm × 20cm × 5cm. They obtained a current peak of 4.5 kA during a discharge in hydrogen at 3 mbar by using an anode of 0.21 mm of radius.

In this article, the current sheath dynamics as well as the evidence of pinch formation in a Mather-type PF device have been reported by operating with 58-160J of capacitor bank energy. The size of the device, which includes the capacitor bank, pseudospark switch and the focus chamber, is of the order of 22cm × 22cm × 38cm, smallest in the range of tens to hundreds of Joules PF devices. Several diagnostic tools are developed and employed simultaneously to confirm the occurrence of pinching in this miniature PF device and to get the optimum pressure range for hydrogen as the working gas.

2. Experimental Setup

The schematic of miniature plasma focus is shown in figure 1. It consists of a coaxial electrode assembly - a tapered inner electrode that acts as an anode and made of copper with a 9.5 mm diameter at the closed end and 6.5 mm diameter at the tip, and a cylindrical outer electrode of stainless steel, having inner diameter of 48 mm that acts both as a cathode and the chamber wall. An insulator sleeve of Pyrex glass, with a break down length of 14.6 mm is placed between the anode and the cathode. Sixteen coaxial cables (length ~ 0.5 m) are used in parallel to connect the input flanges of the focus assembly to pseudospark switch, which is connected with parallel four capacitors (0.2μF, 30kV each) to give final capacitance of 0.8μF with maximum operational voltage of 30kV. A pseudospark switch TDI1-150k/25 is connected in a compact layout which transfers the energy stored in all four capacitors of the capacitor bank to PF electrode system. The open end of the electrode assembly is attached with a KWIK-FLANGE (KF) of size NW50 (50 mm outer diameter, 100 mm length) to act as a vacuum chamber. The glass blanking plate is attached at the other end of KF to act as an optical view-port. This allows the radiation to come out from the chamber and makes the optical diagnostics possible for different experimental studies.

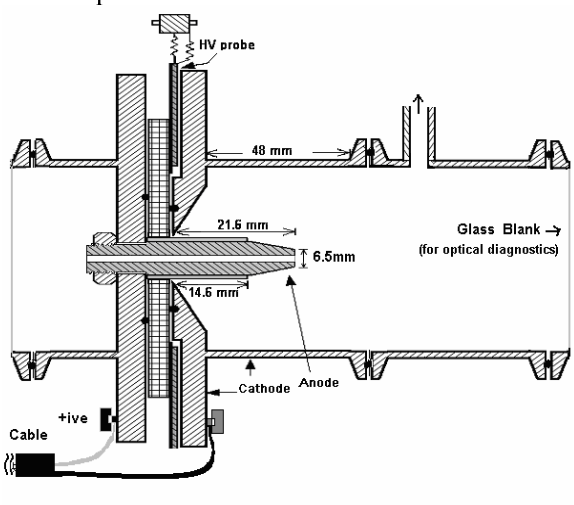

Figure 1: Schematic of PF device.

3. Imaging of the current sheath

Time-integrated optical imaging: The time integrated images were obtained by using Canon camera EOS 300D in axial direction of the discharge along with the electrical signals. In figure 2, the effects of pressure on the plasma column can be seen clearly in these images. Initially, at low pressure ~ 1 mbar, the experiments show uniformly diffuse volume discharge plasma filling the inter-electrode space, which extends later towards the electrodes open end. But after 6 mbar gas pressure, the images show asymmetric plasma structures which probably are due to radial filamentary discharges initiated at high filling gas pressures. Such radial filamentary structures of current sheath at high pressure are also reported by Bruzzone *et al* [6].

The evidence of pinching is also obvious as a bright spot in the figure 2. Some sign of focusing can be seen at low filling gas pressure as a bright region but no evidence of pinch was observed in electrical recorded signals. It may be interesting to note that the bright center spot which indicates focusing phenomena was seen to observe at higher filling gas pressures ($p \geq 11$ mbar) even though the discharge do not look very symmetric, this indicates to the fact that symmetry of the plasma discharge is not so crucial to the final focus formation. The size of the bright spot varies with the filling gas pressure and it is minimum nearly 1 mm (i.e. focusing is at its best) at 12 mbar gas filling pressure. This simple diagnostic is very useful in giving us initial information about the possible working gas pressure range where the focusing can probably be obtained.

Time-resolved optical imaging: The ACTON 750 spectrometer was used as a time resolved optical imager with images being captured at central maxima (zeroth order) with the input slit wide-open to let the image go on to the ICCD plane with magnification of 0.12. The resolution of the imaging setup is limited by the intensifier resolution to about 0.5 mm on the object plane. This gives the optical images of the current sheath evolution from break down phase to radial collapse pinch phase with different delay time starting from 100ns to 1μs with respect to the plasma focus breakdown was used with a 20ns exposure time. A time-derivative trigger signal derived from the Rogowski coil was fed to the Programmable Pulse Generator PG-200 of Princeton Instruments to introduce suitable pulse delay to trigger the ICCD camera at the desired timing instant to scan the entire range of current sheath dynamics with suitable adjusted pulse width of 20 ns that controls the exposure time of the ICCD camera. All cables were timed and calibrated to obtain accurate data.

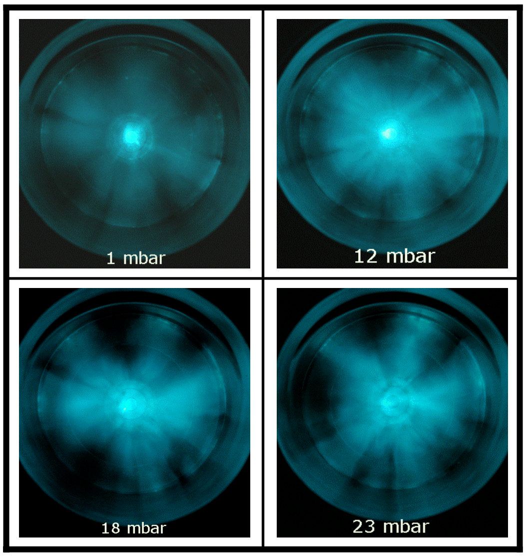

Figure 2: Time integrated images at different gas filling pressures.

Figure 3 shows some of the images obtained by gated ICCD-camera of ACTON 750 spectrometer at different gas pressures of hydrogen at the time instants of 110 ns and 380 ns, after the gas breakdown. The images taken at time 110 ns show the current buildup around the insulator sleeve as images before that were too faint to be recorded on the CCD with 20 ns exposure time. To get clearer picture about the dimension of the current sheath four circles are drawn on the image of the 12 mbar gas pressure.

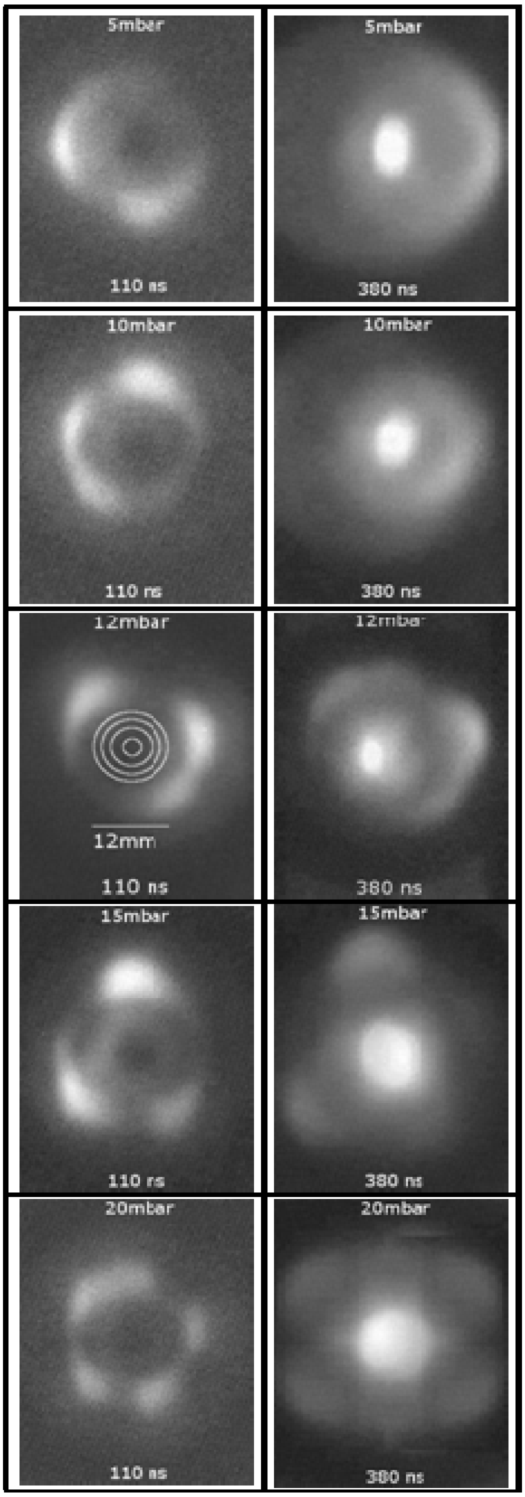

Figure 3: Time-resolved images.

The outermost circle represents the insulator sleeve outer diameter ~ 12 mm and the smallest circle represents the 3 mm hole in anode. The circles in-between the two extreme sizes, as mentioned above, are drawn to represent the anode outer diameter ~ 9.5 mm and the anode diameter ~ 6.5 mm at top or open end. The solid anode appears dark in the images taken at the 110 ns after breakdown and more prominent in low pressures due to the lesser plasma around the insulator sleeve. These images show that the current sheath is still at the lower closed end of the focus tube which is evident from the big dark circular region in the center of the image. At high gas filling pressure the structure of the current sheath becomes more filamentary but the evidence of pinching as a bright spot at the top of the anode is more prominent at 380 ns in 12 mbar image despite the non-uniformity of the current sheath.

4. Electrical Information

In most of the PF devices, the simple resistor divider is usually served as a voltage monitor to give information about current sheath dynamics like the breakdown of gas and the successful pinch formation at the tip of the anode. However, it is noted that the response time of such voltage measurement probe is slower than the voltage rise time of the radial collapse phase of miniature PF. The measured response time of our resistive voltage divider was about 15 ns which is not fast enough for the detection of radial collapse phase of miniature plasma focus which we expect to be around 10 ns as the expected duration of initial breakdown and axial acceleration phase is about 250-350 ns. The expected time estimate for the axial phase is based on typical axial speed of 3 - 7 cm/μs for most of the Mather-type plasma focus devices all around the world.

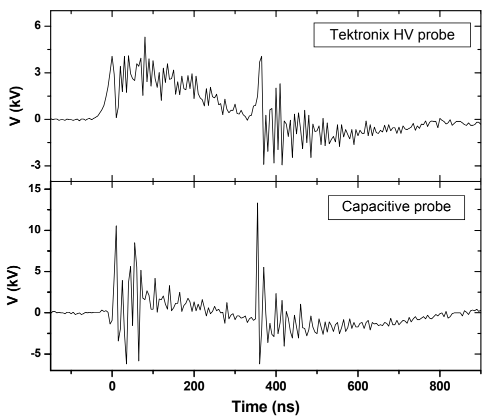

Figure 4: Typical HV signals at 12 mbar gas pressure of hydrogen.

It has also been noted that for a typical Mather-type PF device the duration of radial collapse phase is around 1/30 of axial phase duration. Based on these arguments, the duration of the radial phase of miniature PF was expected to be around 10 ns which could not be observed by resistive voltage probe and hence a fast capacitive voltage probe, made of copper sheet, was developed and used to measure the voltage across the electrode system as shown in Fig. 1. It consists of a circular copper disc of diameter 55 mm and the thickness 0.5 mm. A hole in the centre of radius 26 mm makes this disc possible to place near the cathode plate. The opposite side of the disc is connected with a resistor divider consisting of 5 pieces of 2 kΩ resistors in series with a shunting resistor of 50 Ω at the end. These resistors are placed in a copper tubing of having BNC round socket. The whole construction is carefully insulated to avoid high voltage breakdowns which can cause health hazards or damage the oscilloscope. The output signal is further attenuated at the oscilloscope end. The waveform observed in the oscilloscope display is expected to be 2000 times smaller than the input voltage.

The time response of new HV capacitive probe was compared to a standard Tektronix high voltage probe (P6015A) by recording typical high voltage signals of the miniature plasma focus as shown in figure 4. These signals were captured at gas filling pressure of 12 mbar in hydrogen at charging voltage of 16 kV. By comparing the two oscillograms, it is obvious that the detection of capacitive voltage probe is much faster than the standard Tektronix probe, and offers a much better solution for measuring the high voltage of miniature plasma focus device. The pinching is seen to occur at 380 ns and the current sheath buildup time is around 80 to 110 ns after the initial breakdown of gas.

5. Conclusion

The current sheath structures have been studied in a miniature plasma focus by employing simple diagnostic techniques. It gives the possibility to use the small scale facility for the basic research and applications. The experimental research with this miniature PF device would allow extension of the existing theoretical models to the low energy region The discharge current in the optical studies reveal the filamentary structure in the miniature plasma focus other than the pinch formation. The relation between the initial current sheath status and the pinch formation needs further detailed investigation.

Acknowledgement

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References

[1] S.Lee, P.Lee, G.Zhang, X.Feng, V.A.Gribkov, M.Liu, A.Serban and T.K.S.Wong, IEEE Trans. Plasma Sci. **26,** 1119 (1998)

[2] M.Zakaullah, K.Alamgir, M.Shafiq, S.M.Hassan, M.Sharif and A.Waheed, Appl. Phys. Lett. **78,** 877 (2001)

[3] A.Szydlowski, M.Scholz, L.Karpinski, M.Sadowski, K.Tomaszewski and M.Paduch, Nukleonika **46,** S61 (2001)

[4] P.Silva, L.Soto, W.Kies and J.Moreno, Plasma Sources Sci. Technol. **13,** 329 (2004)

[5] L.Soto, C.Pavez and J.Moreno in *AIP Conf. Proc.: 6th International Conference on Dense Z-Pinch* ***808,*** 2006, pp. 211-214

[6] H.Bruzzone and R.Vieytes, Plasma Phys. Control Fusion, **35**, 1745 (1993).