Ion beam measurement using Rogowski coils in a hundred of joules dense plasma focus device.

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Abstract. In present work an effort has been made to measure the ion beams generated during experiment with PF-400J plasma focus device, using an array of two Rogowski coils with time of flight analysis. It was found that the coils measure the signals of beam for a particular range of operating pressure. The beam signals were recorded at 20, 15, 12, 10, 9,8,7,6 and 5 mbar filled pressure of hydrogen gas. The optimized pressure range for good plasma column formation for this device was found about 9 mbar. At 15 mbar no or very weak beam signals were observed by Rogowski coil which was kept relatively far from the top of the anode and at 20 mbar there were no beam signals observed in both of the coils. The calculated beam energy is found to have maximum value at 9 mbar of filled hydrogen gas pressure.

1. Introduction

Dense plasma focus devices (DPF) are well known to emit different kind of radiations as well as particles and particle beams [1-3]. Since the generated beams might have various applications, it is desirable to characterize the emitted beams. It is believed that the X-rays and beams emission from DPF devices takes place because of presence of the induced electric fields, generated due to different instabilities in pinch phase [4-6]. In fact the m = 0 instability is considered as one of the most strong candidate to induce the high electric field during plasma column formation. However the charged particle acceleration mechanism, which creates beam, is still under active investigation for more clear understanding. Intensive experimental investigations on beam generation from DPF devices have been carried out by many researchers [7-8].

The conventional diagnostic techniques (Faraday cup and/or Thomson parabola on CR-39 plastics) are active and charge particle interaction with the detector provide beam signal. Also pinholes, which usually have dimensions less than the plasma column, are used before the beam detectors. The beams may be generated at any place in plasma column and there might be difficulties to align pinhole with the beam originated place. Moreover, there are chances that high energetic charge particles which may arise during axial shock phase [9] mimic the beam signals by making interaction with Farady cup and leaving tracks on CR-39 plastics.

In this work we propose a passive non intrusive diagnostic technique using Rogowski coil in order to get information about beams. The choice of Rogowski coil is advantageous over the other diagnostic techniques in a way that it senses change in magnetic flux induced by beam current and does not perturb the measuring beam. Also the change in magnetic flux induced by the non-beam charge particles will not be able to produce a strong signal in Rogowski coil, thus the measured signal has the large chances to be a beam signal generated in plasma column. Also use of Rogowski coil does not demand pinhole arrangement and the beams which are generated at any place in plasma column can easily be detected. A more advantageous use of Rogowski coil is that the beam signal will not be lost and can be used further.

In following section 2 we will describe ion beam measurement using Rogowski coil and calculations for beam energy estimation. Results are discussed in section 3 and the work is concluded in section 4.

2. Experimental arrangement

In figure 1 a schematic sketch of experimental arrangement for PF-400J [10-11] is presented. The central electrode (anode) is made of stainless steel has diameter of 12 mm. The anode length covered by an insulator (alumina) is ~20.5 mm and the effective length was ~8.0 mm. The anode is surrounded by 8 copper cathode bars of diameter ~4.7 mm. Two Rogowski coils separated by 4.50 cm were placed in a drift tube at the top of the anode. The coils were designed by winding a thin copper wire on RG-58 co-axial cable. The coil nearer (designated as RC5) to the anode consist 45 turns and the coil farther (designated as RC1) from the anode has 20 turns. Both of the coils have similar inner diameter ~2.9 cm. The dissimilarity in number of turns will only make difference in the rate of increment or decrement in current derivative signal but the start time of signal in both the coils should not be affected by the number of turns**.**

The experiment was performed for different pressures (20, 15, 12, 10, 9, 8, 7, 6 and 5 mbar) of hydrogen gas. During the experiments 15 discharges for each pressure have been performed in dense plasma focus device PF-400J. The distance between the two coils (4.5 cm) is divided by the differences of time of appearing the current signals at two different positions in Rogowski coils (time of flight analysis). This estimation of beam speed is used to calculate the beam kinetic energy.

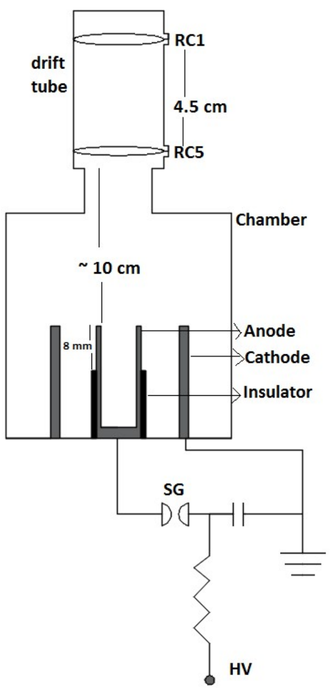

Figure 1. Schematic representation of plasma focus device PF-400J with Rogowski coil arrangement for beam measurements.

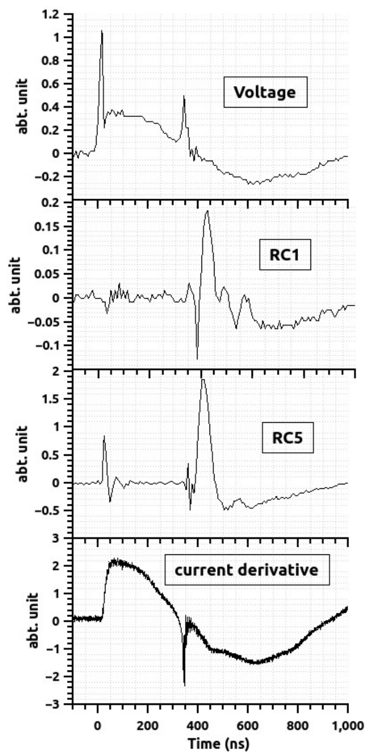

Figure 2.Various signals obtained during the experiment.

3. Results and discussion

Typical plasma focus discharge signals obtained during the experiments with plasma focus device PF-400J are presented in figure 2. It is clearly visible from figure 2 that the ion beam and X-rays emission take place after plasma column formation, which is indicated by a dip in current derivative signal of plasma discharge. During the experiments more than one signal were detected by the Rogowski coils. In the present study the only signal (appears first) which is indicated by an arrow in figure 3 is analyzed. Here we made an assumption that this signal is produced by proton beam (filled gas is hydrogen). In true sense, apart from the proton beam signals, more than one signal can be produced by impurity ions, which may arise from the electrode material erosion during and after the plasma column formation. But due to their mass these signals should appear at later times than the proton beams. However further analysis is needed in order to understand the origin of the signals which appear at later time. The obtained beam signals (current derivatives in arbitrary units obtained from two Rogowski coils RC5 and RC1) at different pressures-12, 10, 9, 8, 7, 6 and 5 mbar of hydrogen gas are shown in figure 4 (we did not find the beam signals in RC1 at 15 mbar and in both the coils at 20 mbar). Two signals of the same beam in two different Rogowski coils, which are separated by a distance of 4.50 cm, are clearly visible. This distance between the coils is divided by the time (start of signal) taken by the beam to reach from first coil (RC5) to the second coil (Rc1) to estimate the beam speed and later this speed is used to estimate the kinetic energy of beam.

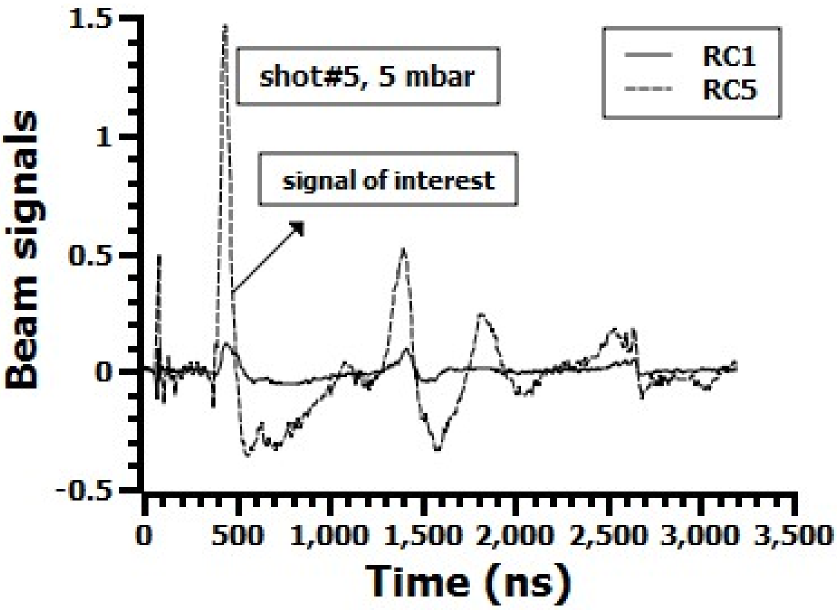

Figure 1 Experimentally observed beam signals using Rogowski coils RC5 and RC1. Only the first signal is taken in to account in order to calculate the proton beam energy.

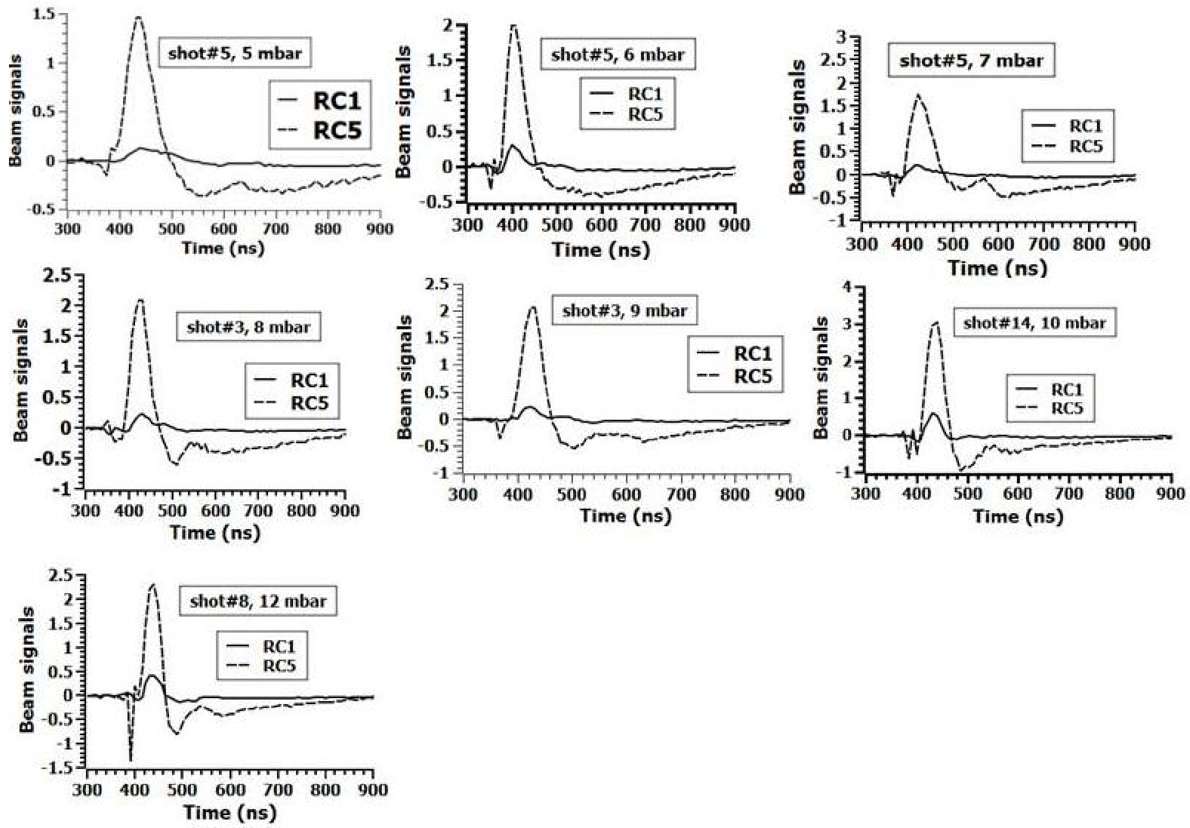

Figure 2 Beam signals at various pressures. The difference of appearing time in two Rogowski coils was used to calculate the beam speed. Later this speed is used to calculate the kinetic energy of beam.

Figure 5 shows the variation of kinetic energy of proton beam with pressure. The trend of this variation shows maximum kinetic energy of proton beams at 9 mbar. Nonetheless, the kinetic energy obtained at 8 mbar is out of trend. The plasma focus devices have an optimized range of working pressure for a good pinch, 7 – 12 mbar in case of PF-400J for hydrogen gas, there is a possibility that the maximum kinetic energy of proton beams may oscillate within this range if repeating the experiments several times. At this point we can only say that the energies of proton beam measured by the Rogowski coils are 28.55 ± 6.54, 40.81 ± 20.31, 79.10 ± 12.36, 48.0 ± 12.37, 98.42 ± 48.23, 53.32 ± 10.78, 35.27 ± 5.97 keV for the pressures 5, 6, 7, 8, 9, 10 and 12 mbar respectively, of hydrogen gas in PF-400J plasma focus device.

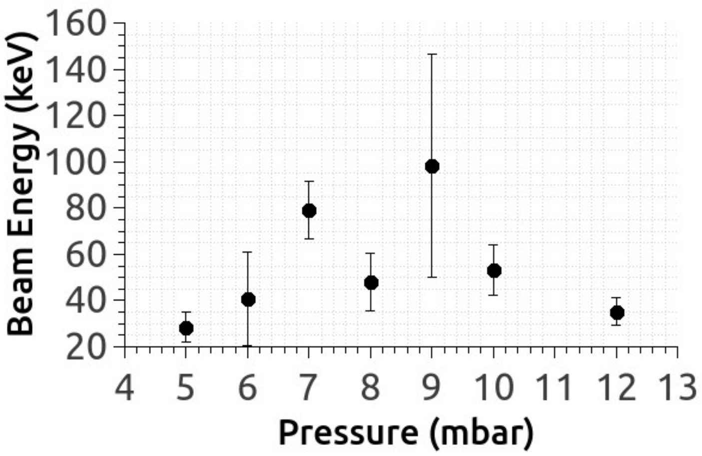

Figure 5 Variation of proton beam kinetic energy with pressure.

4. Conclusion

Proton beam measurements have been performed using an array of two Rogowski coils at the top of the anode in plasma focus device PF-400J, considering time of flight analysis. The experiments were performed at 20, 15, 12, 10 , 9, 8, 7, 6 and 5 mbar of filled hydrogen gas. The beam energy was estimated for the pressures 12, 10, 9, 8, 7, 6 and 5 mbar and at 15 mbar there was no or very weak signal was found in RC1 and at 20 mbar there were no signals found in both the coils. The energies of proton beams were found to have values ~30 ± 6 – 100 ± 50 keV for a pressure range from 5 to 12 mbar of hydrogen gas. The maximum kinetic energy was found at 9 mbar pressure.

Acknowledgement

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