Dynamic Studies of a Small Plasma Focus Device

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Abstract

Experimental study of the dynamics of the plasma in a plasma focus device is carried out in a 3 kJ plasma focus. Results obtained are analyzed and fitted with the computation results obtained by using the Lee Model plasma focus modelling package. The discharge current is measured by a Rogowski coil and the axial acceleration of the current sheath is investigated by using magnetic probe. The electrode length of the plasma focus devices is 22 cm and the operating gas is deuterium at 0.5 mbar. A good fit of the experimental and numerical current signal is obtained by incorporating current shedding factor of around 0.8. Although the system is operated at low pressure, higher percentage of mass is carried by the current sheath. The axial acceleration velocity are measured along the electrodes and has the velocity of around 9 cm/μs near the end of the electrode. This agrees reasonably well with the computed axial velocity with a mass factor in the region of 0.8 to 1 during the axial phase.

1. Introduction

A plasma focus device is a high power pulsed discharge which is able to produce a compressed dense plasma at the end of its coaxial electrodes. This device has been found to be an intense source of neutrons, x-ray, ion and electron beams [1,2]. The radiation output from the plasma focus device can be used in many applications including x-ray imaging, lithography and surface modification of materials. One of the factors that dictates the final plasma focusing action and hence the radiation output is the dynamics of the plasma; the formation and the acceleration of the current sheath before it reaches the end of the electrodes.

The dynamics of the plasma focus operation can be divided into four main phases: the initial breakdown and lift-off phase, the axial run-down phase, the radial compression phase, and the final focusing phase. These phases can be physically described as follows; the gas breakdown occurs initially due to a large voltage applied across the inner and outer electrodes through a glass insulator. The resultant JxB force causes the current sheath to lift off and accelerate axially in the axial phase, where J is the radial component of current density and B is that self-induced magnetic field in the azimuthal direction. The radial compression phase starts as the current sheath reaches the end of the electrodes, where the current sheath collapses radially inward and leads to the final focusing phase.

The initial electrical energy of the plasma focus can be calculated from the capacitance and the charging voltage. During the plasma focus discharge, the energy is converted into various forms of energy including the internal energy of the plasma, the kinetic energy of the plasma slug and radiation. In order to have an efficient operation of the plasma focus device, it is important to understand the dynamics of the plasma, starting from the axial acceleration phase. In this study, the evolution of the voltage and current are measured by a resistive high voltage probe and a Rogowski coil respectively; while the instantaneous velocities of the current sheath in the axial acceleration phase is measured by using magnetic probes.

Simulation of the plasma focus discharge is carried out using the Lee Model [3]. A fitting of the simulated current and voltage waveforms with the experimental results allows the mass shedding effect and the current shedding factor to be determined and hence leads to the calculation of other parameters. In this way the model is adjusted empirically to fit the experimental data and hence the actual amount of current and mass swept into to the plasma can be calculated. The possible radiation output at optimum condition can also be calculated based on the model.

2. Method and Results

The dynamic model used to simulate the axial phase of the plasma is the snow-plough model with coupled circuit equation [4]. The schematic diagram of the plasma focus dynamics and its equivalent circuit are shown in Figure 1 and Figure 2 respectively.

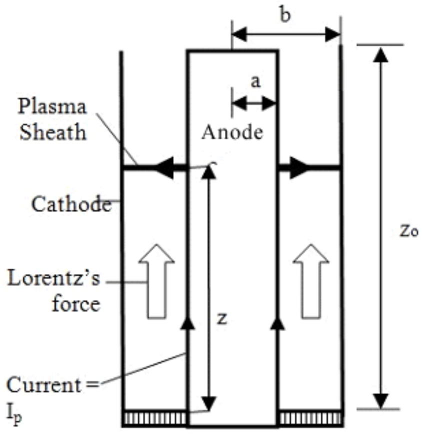

Fig. 1. Diagram of the dynamic model of the current sheath during the axial phase of a plasma focus discharge.

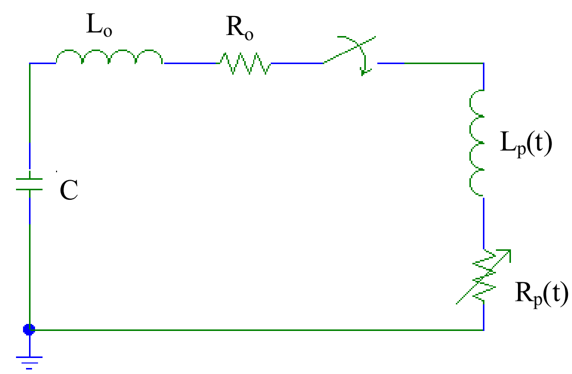

Fig. 2. The equivalent circuit diagram of a plasma focus device.

In this experiment, UNU/ICTP PFF plasma focus device with electrode length of 22 cm is used. The system is charged to a voltage of 15 kV to give a total energy of 3.3 kJ. Deuterium gas is used throughout this experiment. Deuterium filling pressure is fixed at 0.5 mbar, which is found to be optimum in terms of the reproducibility of the plasma focus high radiation output. Typical signals of current and voltage are shown in Figure 3. Two miniature magnetic pick up probes are employed. One is placed next to one of the cathode rod from the side on direction, at axial position of 17 cm. The other magnetic probe is installed from the end on direction, placed between the inner and outer electrodes. This magnetic probe is placed at the different axial positions from 1 cm to 22 cm from the back wall.

Average velocities of the current sheath during the axial acceleration phase is obtained by analyzing the arrival time from the magnetic pick up probe's signals along the axial positions. Figure 4 show a set of the signals obtained.

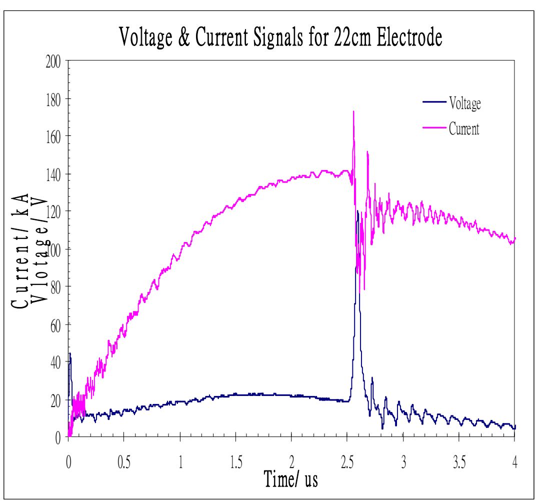

Fig. 3 Typical current and voltage signals at 0.5 mbar deuterium discharge.

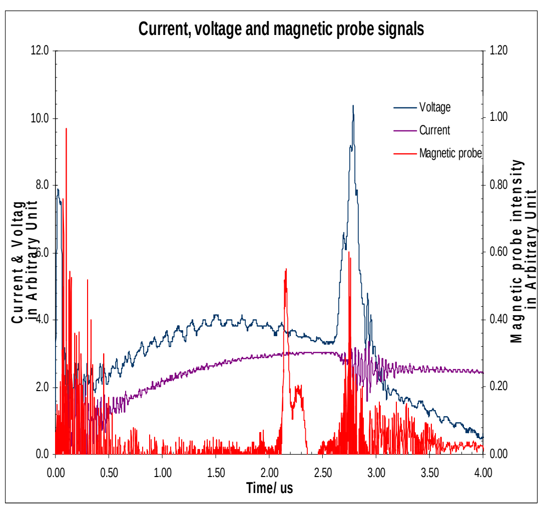

Fig. 4 Signals of the current, voltage and the magnetic probe placed at 17 cm from the back wall of the chamber.

3. Numerical Computation and Fitting Results

A short circuit discharge waveform has been obtained by discharging at high ambient pressure of 25 mbar. The lightly damped LCR discharge signal obtained is used to calculate the circuit inductance and its stray resistance. The external inductance and stray resistance of the present system determined to be about 130 nH and 24 mΩ are used for the numerical experiments using the Lee model.

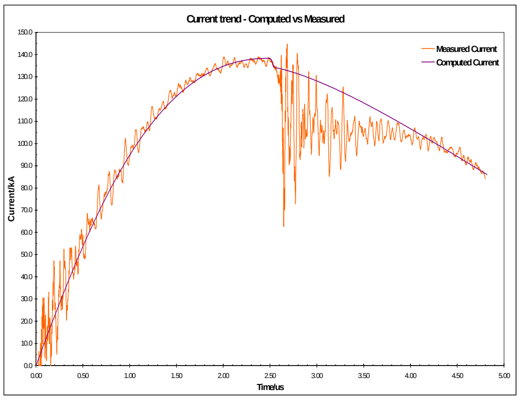

Fig. 5 Fitted computed current with measured current waveform of UNU/ICTP PFF 3kJ with electrodes length 22cm. The Model parameters f_m, f_c, f_{mr} and f_{cr} are 0.3, 0.85, 0.8 and 0.8 respectively.

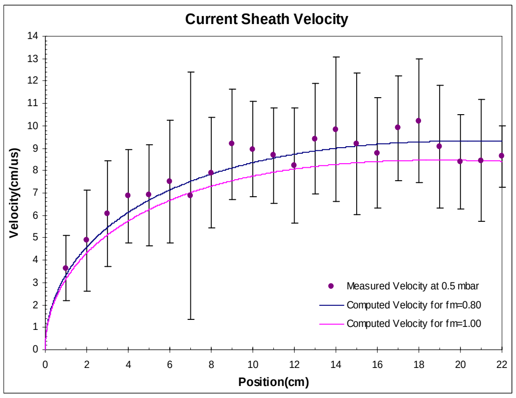

Fig. 6 Comparison of the measured current sheath velocity with the computed current sheath velocity. The model parameter of f_m is in between of 0.8 to 1 to match with the measured velocity of current sheath.

Discharge current waveforms obtained are fitted by varying the model parameters of axial mass swept-up factor f_m, axial current factor f_c, radial mass factor f_{mr} and radial current factor f_{cr}. The fitting process takes into account all these factors and attempts are make to achieve a best fit to the experimental signal. The axial mass swept-up factor f_m, axial current factor f_c, radial mass factor f_{mr} and radial current factor f_{cr} obtained are around 0.3, 0.85, 0.8 and 0.8 respectively.

Figure 5 shows a set of computed current waveform together with one current discharge waveform that we attempt to fit. The computed current trace fitted well with the measured current trace for the axial acceleration phase. This indicated that a good estimate of the current and mass shedding factors for this discharge can be obtained from the numerical results. At the end of the axial phase, the current sheath collapse radially and enters the radial phase. The first part of the current drop has also been well fitted by the model. However, in the experiment for the radial phase we notice that the measured current dip is deeper than the computed current trace. This disagreement for the radial phase may be due to phenomena such as instability during or immediately after the radial compression phase. The matching of measured and computed current trace is shown in the Figure 5.

The measured velocities of the current sheath in the axial phase are taken as an average of 6 repeated shots; the result are shown in Figure 6 with error bar indicating the standard deviation of the data. The velocity observed increases gradually and reaches a peak value of about 10 cm/µs at the distance of about 14 cm. It drops slightly towards the end due to the change in the magnetic field at the end of the electrodes. Generally the velocity lies within a value of 7 cm/µs to 10 cm/µs. The final velocity measured around the end of the electrodes is about 8.4 cm/µs. Effect is also made to fit this velocity curve by computing the axial velocities with the model. The axial mass swept-up factor f_m is varied to give series of computed velocities and compared to the experimental results. The computed results with axial mass swept-up factor f_m around 0.8 to 1 fit well with the experimental results, Hence an axial mass swept-up factor $f_m = 0.9$ is estimated, and the velocity of the current sheath reaches a peak value of about 9 cm/µs.

4. Conclusion

The axial phase of the current sheet acceleration is portrayed reasonably well by the Lee model and has been verified by many experimental data. Here, we attempt to investigate our experimental data by fitting them with this model. A new electrode length of 22 cm was used to replace the 16 cm electrode of the UNU/ICTP PFF and found to show better performance in terms of focusing action and radiation yield. Results on the radiation output from this system will be reported elsewhere. A good fit of the experimental and numerical current signals is obtained by incorporating current shielding factor of around 0.85. The axial mass swept-up factor of around 0.9 has been estimated, with the maximum axial velocity of around 9 cm/μs. This supports the observation of the good performance of the system as the result of the enhancement in the axial acceleration of the current sheath with the increased mass factor.

Acknowledgements

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