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STUDY OF ELECTRON BEAM PRODUCTION BY A PLASMA FOCUS*

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A preliminary investigation of the electron beam produced by a plasma focus device using a current charged transmission line is described. Electron beam currents as high as 10 kA were measured. Interaction of the extracted beam and the filling gas was studied using open shutter photography.

While the majority of plasma focus experiments have addressed the measurement of accelerated ions,[1-6] relatively little attention has been given to extraction of the accelerated electrons and direct measurement of their parameters (e.g., current, energy).[7-9] Such electron measurements are of interest in developing a complete understanding of the high fields present in plasma focus experiments. Also, there may be application of the plasma focus device as a compact particle accelerator for electrons.

The operation of a plasma focus as a compact pulsed accelerator (CPA) for ions has been previously reported.[5] This device uses a plasma focus as an opening switch for a current charged transmission line to produce a fast, high voltage pulse. The CPA consists of: (1) a single energy storage capacitor, (2) a spark gap, (3) a coaxial transmission line, and (4) a Mather geometry coaxial plasma gun. For a capacitor charging volatage of 18 kV, a proton beam with peak energy of 250 keV was observed.

The current charged transmission line has advantages over conventional pulse forming lines in terms of: (1) increased energy storage capability and (2) less stringent constraints on voltage hold-off requirements. Both of these advantages allow the CPA to be more compact than electron accelerators using conventional pulse forming lines.

The CPA, like other plasma focus devices, accelerates ions away from the plasma gun and electrons toward the plasma gun. In the typical plasma focus experiment, the energy storage capacitor bank is connected to the plasma gun with parallel plate transmission lines or cables. Therefore, there are no obstructions which prevent extraction of accelerated electrons out of the rear of the gun if a hollow anode is used. In the CPA geometry, both the capacitor and coaxial transmission line block extraction of electrons. This paper describes CPA operation for electron beam production by use of a new coaxial plasma gun design. The beam was fired into a drift region containing the same gas environment as the plasma gun. In this region, preliminary measurements were performed on the electron beam.

Main components of the CPA are shown in Fig. 1. The energy storage capacitor (15 μF, 3 kJ) was typically charged to 18 kV. Charging of the coaxial transmission line was initiated by a high voltage trigger pulse (30 kV) which was applied to a needle electrode inserted at the midplane of the spark gap. The water filled coaxial transmission line (inner radius 2.54 cm, outer radius 7.3 cm, length 30 cm) has an impedance of 7 Ω. A diagnostics ring connected on the end of the transmission line contains a Rogowski coil and capacitive voltage probe. The Rogowski coil measures the main current (I_m) through the coaxial line, and the capacitive probe measures the voltage induced at the time of current disruption. Theory of operation for the CPA is found in Ref. 5.

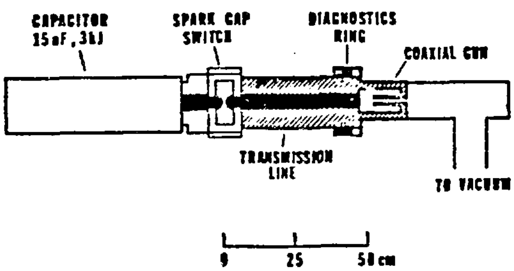

FIG. 1. The compact pulsed accelerator.

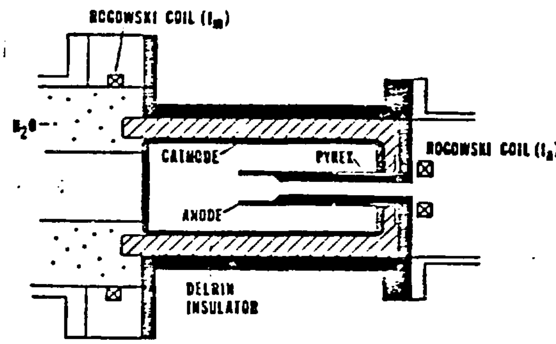

FIG. 2. Plasma focus gun.

A new plasma gun design which allows extraction of electrons from the CPA is shown in Fig. 2. The copper electrodes have the same dimensions as those used for the ion experiments (i.e., 2.54 cm diameter anode, 7.7 cm diameter cathode) and are separated by a pyrex insulator. The center conductor of the transmission line (charged negatively) is attached to the outer conductor (cathode) of the plasma gun. The outer conductor of the transmission line is folded inward to become the center conductor (anode) of the plasma gun. The plasma gun section was designed so its characteristic impedance would match the 7 Ω impedance of the water filled transmission line. Electrons are extracted out of the hollow anode through a 9 mm diameter aperture and enter a 10 cm diameter drift region filled with the same gas as the plasma gun. Filling gases of H_2, He, N_2, or Ar were used. Typical current and voltage waveforms measured with the diagnostics ring are shown in Fig. 3.

A second Rogowski coil placed at the drift tube entrance measured the apparent current (I_a). Although this diagnostic gives a good approximate representation of the actual electron beam current pulse (Fig. 4), plasma return currents may alter the pulse's height and length. The peak apparent current vs. gas pressure for He, N_2, and Ar is shown in Fig. 5. While peak currents were generally several kiloamperes, in a few shots currents of 10 kA were observed. Actual beam currents may be much greater since the beam is extracted through such a small aperture (9 mm). The most reproducible current pulses were obtained with argon gas, where the leading edge of the electron beam pulse always coincided with the interruption of the main focus current. This was not true with the lighter gases, where in some cases even multiple pulses were detected. Higher peak currents were observed in the lower pressure range for all gases.

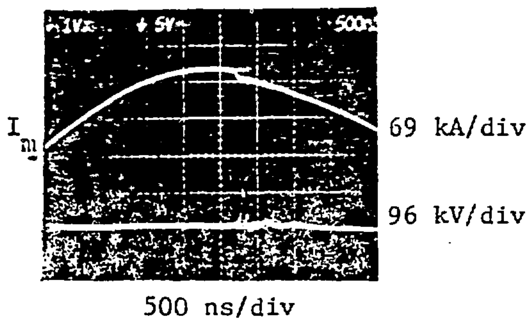

FIG. 3. Current and voltage waveforms for the compact pulsed accelerator.

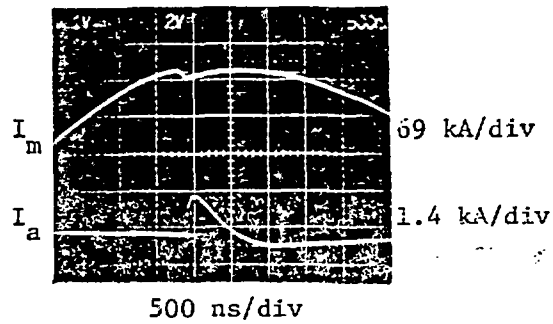

FIG. 4. Oscilloscope trace of the apparent current measured by the Rogowski coil placed in the drift tube.

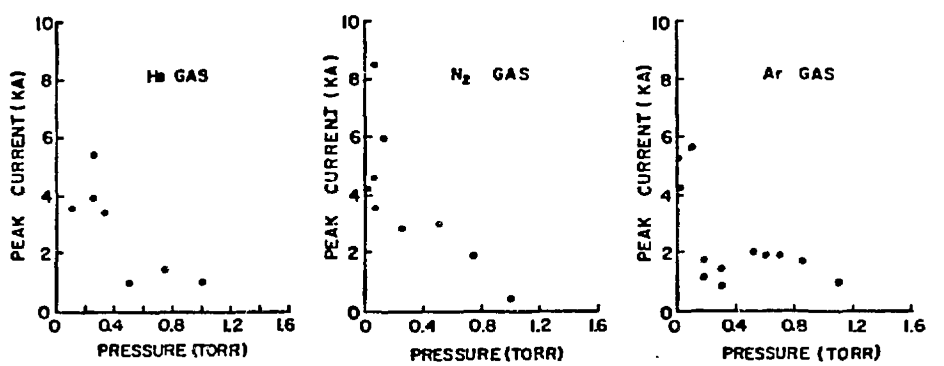

FIG. 5. Plots of peak measured current (I_a) vs. gas pressure for He, N_2, and Ar.

Open shutter photographs were made for observation of the interaction between the electron beam and filling gas. An acrylic tube with a copper mesh insert was attached between the plasma gun and vacuum pumping section for this series of shots. Observation of the beam-gas interaction over a broad pressure range (0 ~ 2 torr Ar) revealed two distinct propagation regimes as shown in Fig. 6. The structure observed in the low pressure shot of Fig. 6 was very reproducible throughout the low pressure regime. These measurements will aid in placement of beam-diagnostics and interpretation of their results in future work.

The compact pulsed accelerator has been successfully operated in the electron beam mode. The beam produced by the focus has a peak current density of 15 kA/cm^2 which is comparable to intense beams produced by much larger electron accelerators. A heavy gas (Ar) was found more efficient for providing a reproducible electron beam. Light gases supply light ions which can be more easily accelerated across the plasma opening switch, thereby decreasing the efficiency of electron acceleration. For the current pulses which were coincident with interruption of the focus current, the acceleration can be linked to the fields created by the plasma focus opening switch. Future work will include measurement of the electron energy spectrum and a comparison with expected magnitude of the plasma focus fields.

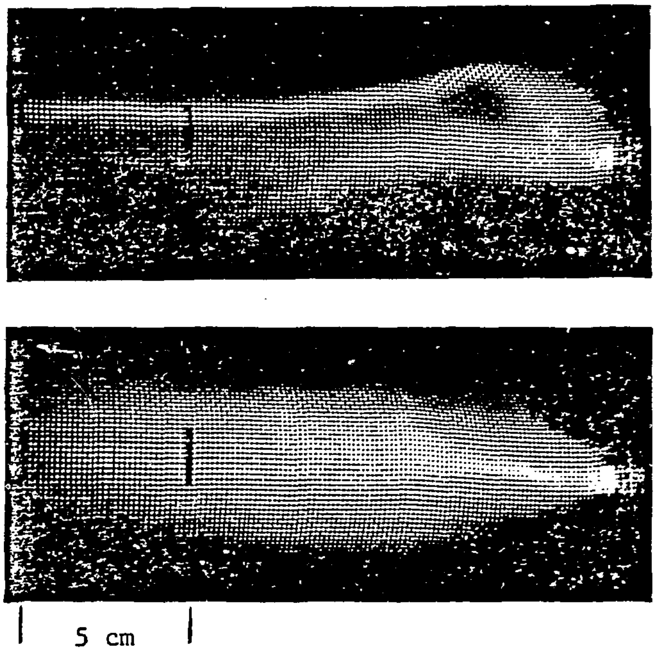

Fig. 6. Open shutter photographs of electron beam injection into a gas filled drift tube. Results of (a) 0.4 torr Argon and (b) 1.6 torr Argon are shown.

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