Small-Chamber 4.7 kJ Plasma Focus for Applications

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Abstract. The performance of a small-chamber Plasma Focus designed to maximize the output fluence and to be used as portable radiation generator is presented. The neutron yield; the x-ray intensity; the applied voltage and the flowing current between the electrodes, were measured at different deuterium filling pressures. Voltage spikes of about 10 times the amplitude of the initial interelectrode voltage were obtained at focalisation time, thus indicating very good focusing. The mean neutron yield was 3 x 10^8 neutrons of 2.45 MeV per shot, corresponding to a 10^6 neutrons/cm^2 fluence on the external surface of the chamber. Both, the measured current sheath kinematics and neutron production are compared with numerical models, showing very good agreement. The x-ray emmision was applied to obtain radiographies of metallic objects, whereas the neutron output was used for low-Z elements detection.

INTRODUCTION

Plasma Focus (PF) devices appeared as potential nuclear fusion devices based in the pinch phenomenon occurring during the path of high electric currents through the working gas. The operation of PF has been extensively studied and several PF configurations has been developed over the years aiming to increase the neutron emission[1-4]. Currently, PF pulsors are among the cheapest available neutron generators, with unique features of extremely short output pulses (hundreds of ns) that suit them for a number of interesting applications. There are also interesting possibilities to take advantage of x-rays (1-100 keV), electron and ion beams emitted during PF shots.

The plasma-focus phenomenon occurs at the open end of coaxial electrodes when an intense electrical discharge between them is induced by external means. The coaxial electrodes are located inside a vacuum chamber filled with deuterium gas at low pressure. A charged capacitor bank is connected to the closed end of the electrodes

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through a switch. After closing the switch, a gas discharge starts in the gap between the electrodes forming a plasma layer. The azimuthal magnetic field located in the toroidal volume enclosed by the current, produces a Lorentz force that pushes the sheath toward the open end of the electrodes. The run-down of the current sheath is a sweeping supersonic shock that propagates collecting the gas particles ahead of the front. On its arrival at the open end (some μs after triggering), the magnetic field starts to contract, accelerating the plasma toward the axis. Finally, the sheath clashes on the axis in the form of a small dense plasma cylinder (focus). The lifetime of the focus is about 300 ns.

The emitted neutrons can be applied to perform radiographs[5] and substance analysis, taking advantage of the penetration and activation properties of neutral radiation[6]. Likely, the intense x-ray pulses produced by focalized electron bremstralung are excellent candidates for radiography of moving and soft objects[7-8] and for microelectronic lithography[9].

Had small portable PF devices been available, the added value of the emissions would substantially increase, for larger fluences can be provided in wider domains of applications. However, due to the strong interaction between the hot plasma and the vacuum chamber, the electrode housing is usually big leaving room for the plasma blast. The main trouble with having the electrodes too close to the container wall is the gas contamination with impurities, which conspires against performance and regularity of the emissions[10].

In this communication, a small chamber PF device, pulsing at 1 shot per minute with good performance is presented. The configuration assures that the neutron yield is not severely affected by the vacuum chamber, separated 50 mm from the pinch. The associated x-rays emissions were applied to obtain radiographs of small metallic components, and the emitted neutrons were used to detect water by neutron inelastic scattering.

DEVICE PARAMETERS

The Plasma-Focus GN1 is a compact version of a Mather-type machine. The anode is an electrolytic-copper cylinder, 38 mm diameter, 1.5 mm thick, 87 mm long. The cathode is formed by 12 bronze bars, 3 mm diameter, 100 mm long, cylindrically placed, and welded at the end to a bronze ring 72 mm diameter. The container is a stainless-steel cylinder 157 mm long, 96 mm diameter with a lateral NW25 vacuum port for pumping and gas loading. The insulator is a Pyrex glass cylinder 35 mm long and 4 mm thick.

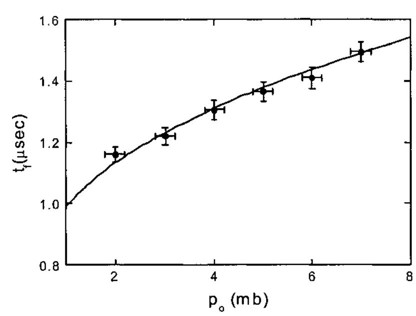
Using a mechanical pump and an oil diffuser, base pressures down to 10^{-8} mbar can be reached. The external circuit is a capacitor bank, divided in three discharging modules; each of them composed by 5 Maxwell type 31161 condensers. The total capacitance is 10.5 μF and the charging voltage is 30 kV. The three modules are fired simultaneously and peak currents of 350 kA are attained in a quarter of period (~1.1 μs).

The system operates between 1 to 8 mbar of Deuterium. After each shot, the filling pressure increases about 0.05 mbar due to the release of impurities from the chamber, electrodes and insulator walls. Consequently, the chamber is pumped down (mechanically) after each shot in order to assure constant pressure conditions. The maximum shot frequency was 1 shot per minute, limited by the charger. Under these conditions, the frontal wall temperature increases about 20 °C over the ambient temperature after 30 shots, cooled passively by air natural convection and heat conduction through the metallic structure. The working gas is renewed after 10 shots.

OUTPUT CHARACTERISTICS

A series of 1000 shots were carried out at different load pressures. The time derivative of the current flowing to the anode, dI/dt, and the voltage across the electrodes, V, were monitored for each shot by a Rogowski coil and a resistive voltage divider, respectively, and were registered using a 500 MHz, 1 Gs/s digitizing oscilloscope. Very intense voltage spikes (~120 kV) are obtained at the time where the maximum compression takes place, thus indicating good focusing. Such peaks impose severe design conditions on the insulator, which should be considerably thick in order to stand the stress (2 mm of Pirex glass is destroyed with few discharges).

It is observed that, as expected, the focus occurs later for higher pressures. Figure 1 (left) shows the average dependence of the focus timing with the deuterium pressure. The continous trace is the focussing time derived from an analytical snow-plow description coupled with an isoentropic plasma compression model [11].



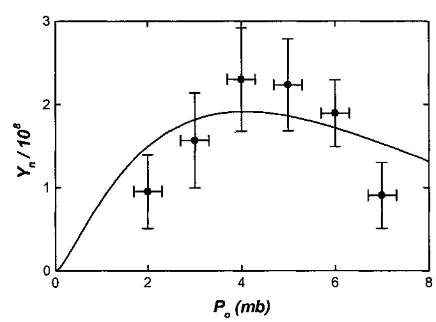


FIGURE 1. Pressure dependence of (left) the focusing time (right) neutron yield.

The time integrated neutron yield was also measured for each shot by silver activation response as a function of pressure. The neutron detector was placed at 60 cm from the focus in a line perpendicular to the axis. The sensitive area was

900 cm^2. The neutron measuring system was calibrated by comparison against TLD detectors. Figure 1 (right) shows the dependence of the average neutron yield per pulse with the filling pressure. The continuous trace corresponds to same model of Figure 1 (left). The optimum average yield, 3 x 10^8 neutrons per shot, occurs at 4 mbar. This yield corresponds to a fluence of about 10^6 n/cm^2 per shot in the external frontal wall.

Several different insulator lengths were tested in preliminary series of measurements aimed to investigate each design performance. It was found that variations of 5 mm in that length lead to noticeable degradation of the neutron yield at all the explored pressures.

The anisotropy, A, of the time integrated neutron production, defined as the ratio between the neutron yield emitted on-axis and the emission at 90° with respect to the axis, is being measured using two silver activation detectors simultaneously operated on every shot. Systematic series of measurements at 3, 4, 5 and 6 mbar gave an overall representative value of A = 1.40 +/- 0.02 with a slow tendency to decrease with the filling pressure (see Figure 2).

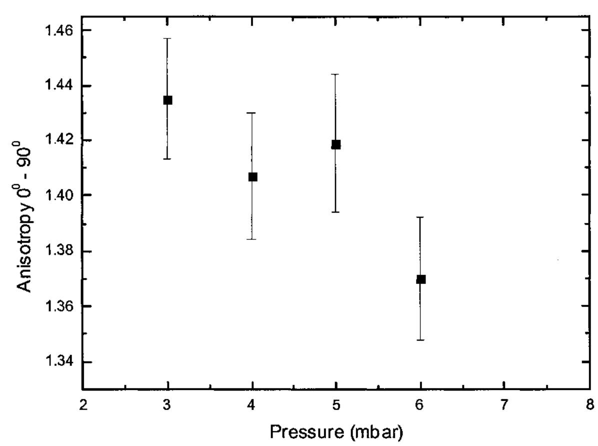


FIGURE 2. Pressure dependence of the neutron yield anisotropy defined as front-on (0°) respect to side-on (90°)

The time resolved x-ray and neutron production was also monitored on every shot using a single photo-multiplier (PMT) attached to a 5 cm long, 5 cm diameter NE102A plastic scintillator. The PMT-scintillator set was placed 3.9 m away from the GN1 chamber. Very intense x-ray peak followed, after ~150 ns, by a broad valley characteristic of neutrons are normally obtained. Studies were conducted to demonstrate a possible correlation between the neutron yield and the x-ray production using the same set up and detectors already described. Under these conditions we observed shots with both, good neutron and x-ray production, shots with good neutron yield but very poor x-ray production, and shots with low neutron yield and high x-ray production.

DISCUSSION AND CONCLUSION

A compact chamber Plasma Focus device, operating at 1 pulse per minute, connected to a 4.7 kJ capacitor bank, was constructed in order to optimize the available neutron fluence on the external wall. The system produce 3×10^8 neutrons per shot, corresponding to fluences of 10^6 n/cm^2 (2.45 MeV) per shot. It was found that a key factor for good performance is the insulator thickness, which has to be 4 mm thick to stand high voltage peaks during the pinch stage, as well as its length, which had to be determined within 5 mm margin to optimize the neutron yield. The device performance as a neutron generator can be explained by an analytical snow plough model coupled to an isoentropic description of the pinch compression.

This compact plasma-focus is primary oriented to applications of the radiation emissions, primarily introspective images of samples. The x-ray emission when operating in Deuterium was used to obtain radiographs of metallic objects. Independently, the neutron pulses were used to detect water by neutron scattering. These two applications are reported on in a separated communication to this Conference.

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