Experimental study in a plasma focus with modified electrodes

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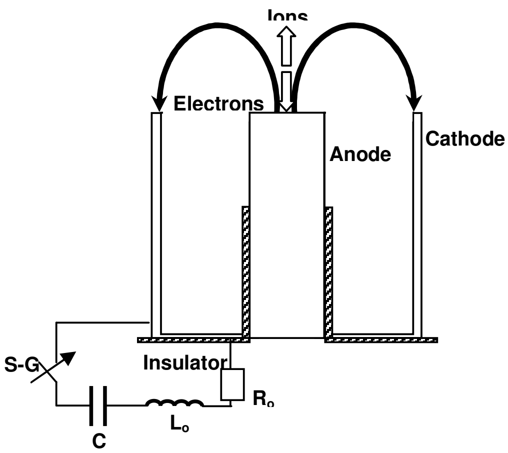
Abstract. Experiments in a small and fast plasma focus device with temporal polarity inversion of the electrodes have been carried out. In this way the beam target mechanism for neutron production has been suppressed, and the operational conditions in which the neutron emission is due only to thermonuclear mechanism have been found.

Introduction. The mechanisms of nuclear fusion and the subsequent neutron production in plasma focus (PF) discharges are still an open and controversial field. It is widely accepted the participation of two main processes in the total neutron yield, Y, produced by a pinch discharge: thermonuclear fusion and ion beam-target fusion. Thus, the total neutron yield is $Y=Y_{th} + Y_{b\text{-}t}$, where Y_{th} is the thermonuclear component and $Y_{b\text{-}t}$ is the beam target component. If the fusion mechanism is thermonuclear an isotropic emission is expected. Experimentally, anisotropic emission of neutrons is observed and it is accepted that less than 15% of the neutrons are produced within the pinch column by thermonuclear mechanism, and more than 85% of the neutrons arise from the deuterium ion-beam bombardment of the deuterium gas in a region that is over the plasma pinch region [1, 2].

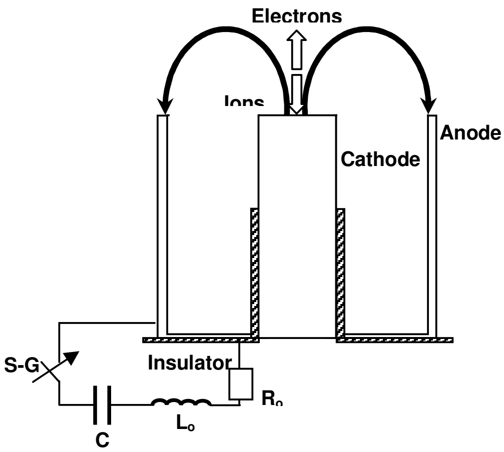
A feature of plasma focus discharges is that they present a self scale behavior in a wide range of devices working with stored energies from less than one joule to MJ, differing only in their stability properties [3]. This self scale characteristic implies that plasma focus devices operated at different energies produce plasma pinches with practically the same temperature, bigger devices do not produce plasmas with significantly higher temperatures than small devices with several orders of magnitude less of stored energy. With the ideas of: a) increase the pinch temperature, b) decrease the neutron emission from beam target mechanism; an experimental study on plasma focus with modified electrodes is being developed. The modification of the electrodes include: a) temporal polarity inversion of the electrodes, b) anti-anodes to decrease the pinch plasma volume and beam target source. The experiments in small plasma focus devices operated in deuterium at hundred of joules [4] and tens of joules [5, 6] have been designed. Programmed diagnostics include: electrical signals, plasma images, neutron time of flight measurements using scintillators with photomultipliers, and neutron yield measurements with 3He proportional counter and silver activation counter. In this work results with temporal polarity inversion of the electrodes are presented.

The plasma focus is usually operated with the inner electrode as anode. Interchange of the polarity causes an important decrease in neutron yield (several orders of magnitude) [7]. The reasons for this behavior are mainly two: a) the pinch characteristics are strongly dependent of the breakdown phase and sheath formation on the insulator; the interchange of the polarity increase the time of breakdown and sheath formation as well as produce a different sheath structure [7], b) as the beam target components come from the interaction of deuteron ions and the deuterium gas over the anode (see figure 1a), the inversion of the polarity produces that the deuterons do not interact with the deuterium gas (see figure 1b) [7]. In this work a way to produce a pinch plasma focus with the inner electrode with negative voltage at pinch time and positive voltage at the breakdown phase is presented.

Experimental set-up. The experiments were carried out in the PF-50J device, a small and fast plasma focus operating at tens of joules with characteristic parameters given by: 160*nF* equivalent capacitance, ~ 40*nH* total inductance in short circuit, 150*ns* first quarter of period, 25 - 35*kV* charge voltage, energy E ~ 50 - 100*J*, 50-70*kA* peak current in short circuit [5, 6]. The electrode configuration consists of a central stainless steel electrode of 3 *mm* radii. The insulator effective length is 24.5 *mm*. The external electrode is made from six 5 *mm* diameter stainless steel rods, 34 *mm* effective length, located in a circle of 8.75 *mm* radius. Neutron diagnostics consist of two detection systems based on moderated ^{3}He proportional counters tubes for neutron yield measurements, details in references [6, 8, 9].



(a)



(b)

Figure 1. a) Normal operation of a plasma focus with the inner electrode positive. b) Operation of a plasma focus with inverse polarity, inner electrode negative.

Results. From a set of experiments in deuterium at different operational conditions [6] the behavior shown in figure 2 is especially interesting. On the one hand, because it corresponds to the maximum observed neutron yield, and on the other hand because it has two zones of pressure with relative maximum emission. A more accurate insight of the collected data shows that the maximum in the neutron yield at 5.3 mbar of deuterium corresponds to a pinch close to the first maximum of positive current (figure 3 a) (PF in normal operation, when the inner electrodes is positive, as is shown in figure 1a), and the maximum neutron yield at 10 mbar corresponds to a pinch close to the maximum of the first negative current (figure 3b, i.e. when the inner electrodes is negative, like in figure 1b).

In figure 4 the anisotropy factor measured with two detectors located, one in the axial direction over the inner electrode, and a second located in the radial direction, is reported. These data show that the neutron emission is isotropic in the range 8 to 10 mbar, i.e. when the pinch occurs, the inner electrode is negative.

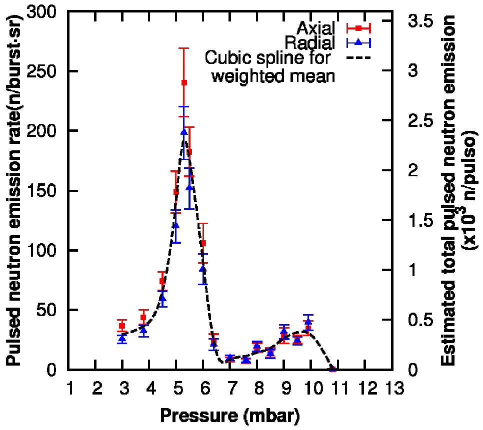


Figure 2. Neutron yield versus deuterium filling pressure for the PF-50J with an effective inner electrode length of 6.3mm operating at 28.7kV

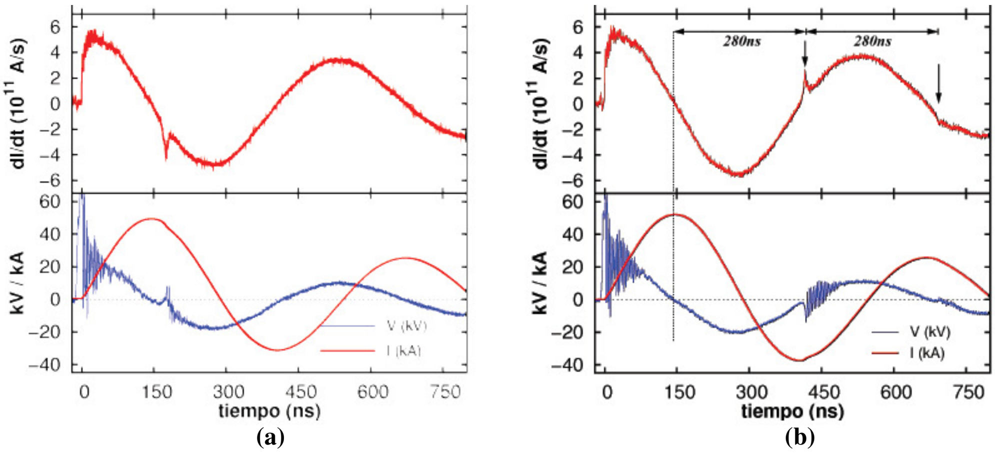


Figure 3. a) 5.3 mbar, pinch occurring when the inner electrode is positive (PF normal operation). b) 10mbar, pinch occurring when the inner electrode is negative.

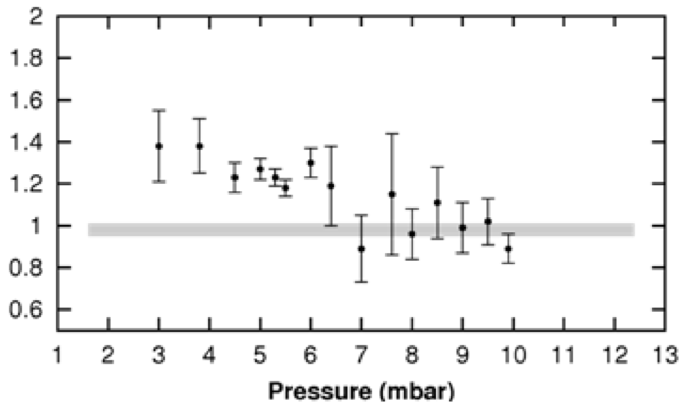


Figure 4. Anisotropy factor: (neutron axial emission / neutron radial emission) vs. deuterium filling pressure.

Conclusions. The conditions in which the breakdown phase of a plasma focus is produced with a positive inner electrode, and a pinch is produced when the inner electrode is negative, have been found. In this way, the problems due to an inverse polarity (inner electrode negative) at the breakdown phase have been suppressed. In addition, as the pinch occurs when the inner electrode is negative, the neutrons due to beam-target mechanisms have also been suppressed. The neutron emission observed at these conditions appears isotropic, indicating that the neutrons are produced from a thermonuclear mechanism. This emission, Y_{th} according with this analysis, is 1/6 of the total emission, $Y=Y_{th} + Y_{b\text{-}t}$, observed in the conditions in which the inner electrode is positive (PF normal operation).

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