

Studies of Plasma-Focus discharges within the PF-360 facility equipped with needle D₂O-ice target

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Abstract The paper describes a new technique which has been investigated in order to overcome the neutron saturation effect and to increase the neutron yield from the plasma-focus (PF) discharges [1]. The PF-360 experimental facility was constructed at the Andrzej Soltan Institute for Nuclear Studies (IPJ) in Swierk, Poland in the late 70s [4, 5]. Recently in order to improve the neutron yield from the PF-360 machine, it was proposed to use a cryogenic deuterium target, which might be placed within the plasma-focus region. For this purpose, we have been made a needle-like cryogenic target covered with a thin „heavy-ice“ layer. A considerable increase in the average neutron yield (from 1.7×10^{10} to about 2.2×10^{10} neutrons/shot) has been achieved for 122 kJ PF discharges when the needle target top was placed at a distance of about 100 mm from the electrode ends.

Key words cryogenic target • current-sheath • neutrons yield • plasma focus • X-ray

Introduction

Numerous PF experiments, which were performed in many laboratories all over the world showed a promising scaling of the neutron yield (Y_n) from D-D fusion reactions. Some investigations extended this scaling to a multi-MJ and multi-MA level [2] but such experiments have not been performed so far. In the previous PF studies, it was found that the neutron emission saturates (or even decreases) when the initial energy input and discharge currents are increased above certain threshold values [3]. In order to make use of the accelerated deuterons moving in the radial direction, mainly during the current-sheet collapse and the PF-pinch phase, it was proposed to apply a needle-like cryogenic target placed in the pinch region. The main aim of the studies reported in this paper was to determine experimental conditions when a reasonable increase in the total neutron yield is achieved.

Experimental set-up

Recent studies within the PF-360 facility have been carried out by using larger coaxial electrodes of 120 mm and 170 mm in diameter, respectively. Both electrodes were 300 mm in length, and the main ceramic insulator, embracing the basis of the inner electrode, was 80 mm in length. The main experimental chamber of the PF-360 facility was filled with pure deuterium under the initial pressure, which was varied from 5.1 mbar to 12.0 mbar. PF discharges were powered from a capacitor bank of 288 μ F. The initial charging voltage was limited to 30 kV, and the PF-360 experiments were performed mainly within an energy

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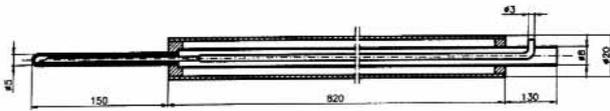


Fig. 1. Schematic of the needle-type cryogenic target designed to be placed on the z-axis of the PF-360 experimental chamber. The “cold-nose”, to be covered with a thin heavy-ice (D_2O) layer, may be located near the electrode outlet. In that case, one can study influence of fast deuterons moving within the collapsing PF current-sheath layer.

range of 122–130 kJ. Several diagnostic techniques in the experiments described were applied simultaneously. Neutron yields were measured with two silver-activation counters, placed in the plane of the electrode ends, but at different radial and angular positions. Time-resolved neutron signals and very hard X-ray signals were measured with two scintillator-photomultiplier probes placed side-on, at distances $l_1 = 266$ cm and $l_2 = 383$ cm from the pinch region. Time-integrated measurements of the X-ray emission were carried out with an X-ray pinhole camera and two VAJ-type radiometers. Time-resolved measurements of X-ray pulses were performed with scintillation probes of the XET type.

Design and manufacturing of a needle-type cryogenic target

Initially, to make use of fast deuteron beams, which are emitted mainly in the axial direction, a planar cryogenic target was designed [6]. In order to use the accelerated deuterons moving in the radial direction [7], it was necessary to design another version of the cryogenic target, which might be placed on the z-axis. For this purpose it was decided to construct a needle-like target, as shown in Fig. 1.

The needle-type cryogenic target consisted of a thin-wall copper tube of about 5 mm in diameter, and 150 mm in length. Taking into account the typical dimensions of a pinch column, as produced during the radial collapse of the

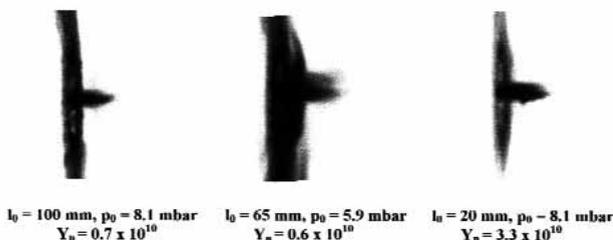


Fig. 3. Examples of soft X-ray pinhole pictures, as taken with a pinhole camera, for several discharges performed with the PF-360 machine equipped with the needle cryogenic target. It can be seen that the target was slightly off the pinch axis, but its application did not change the X-ray emitting region considerably.

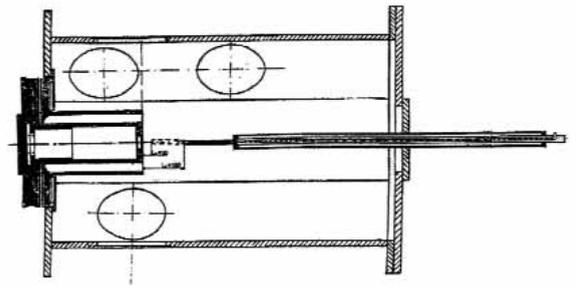


Fig. 2. Positioning of the needle-like cryogenic target inside the main vacuum chamber of the PF-360 machine, as realized during the neutron yield optimization experiments.

PF current sheath, it was chosen to make that target long enough to catch radially moving deuterons in front of the collapsing current sheath. The described target was designed to fit the same adapter flange, which was used for tests of the planar cryogenic target. After the manufacturing and assembling the needle-type cryotarget, it was tested within an auxiliary vacuum stand. During those operational tests, it was found that in order to eliminate blocking of the cooling channel (by frozen water vapor) it is necessary to cool down the cold-nose in small steps.

Experimental results

Modeling computations of ion trajectories within the collapsing current-sheath and the PF pinch column, which were performed by taking into account the appearance of current filaments, showed that a considerable portion of the accelerated deuterons (during their gyro-motion) move in the radial direction [6, 7]. Therefore, in order to increase a number of D-D fusion reactions it was reasonable to use the needle-type cryogenic target, as described in the previous section. For that purpose, needle-type target was placed on the z-axis, at different distances from the electrode outlet, as shown in Fig. 2.

Several series of the PF experiments were carried out with simultaneous measurements of X-ray and neutron emissions. The X-ray measurements, as performed with the X-ray pinhole camera placed side-on the main experimental

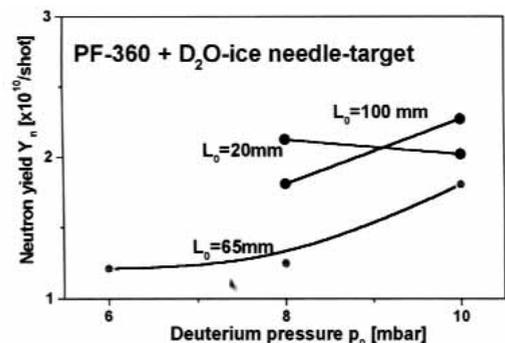


Fig. 4. Average neutron yields as a function of the initial deuterium pressure, as measured for PF experiments with the needle-like cryogenic target. Several series of PF shots were performed at $U_0 = 30$ kV, $W_0 = 130$ kJ, for different positions of the target. The highest neutron yield was achieved at higher initial pressures ($p_0 = 10$ mbar D_2), when the target top was placed at a relatively large distance ($L_0 = 100$ mm) from the electrode outlet.

chamber, showed that the application of the needle cryogenic target did not considerably influence the X-ray emitted region, when the target was placed not too close to the electrode outlet (at $L_0 > 20$ mm). Some examples of the soft X-ray pinhole pictures, as taken from the shots with the needle cryogenic target, have been shown in Fig. 3.

The neutron yield measurements showed that the placement of the needle cryogenic target near the PF-360 electrode outlet (at $L_0 = 20$ mm) did not influence an average neutron emission. It was, however, observed that with the positioning of that target at larger distances (at $L_0 = 65$ – 100 mm) one could achieve an increase in the neutron yield, particularly at higher operational pressures. The neutron emission yields, as achieved from the described PF experiments, have been presented in Fig. 4.

It was found experimentally that the highest neutron yield ($Y_n = 2.3 \times 10^{10}$ neutrons/shot) from PF discharges performed with the needle-type cryogenic target, which was covered with the heavy-ice layer, was obtained at the initial deuterium pressure $p_0 = 10$ mbar D₂.

Summary and conclusions

The neutron measurements, which were carried out with the use of the needle cryogenic target, showed that the average neutron yield can noticeably be increased. Under the determined operating conditions ($U_2 = 30$ kV, $W_0 = 122$ kJ, $p_0 = 10$ mbar D₂), when a distance between the front electrode plate and the needle target was $L_0 = 100$ mm, the average neutron yield Y_n rose from 1.7×10^{10} to about 2.2×10^{10} neutrons/shot.

The technique involving cryogenic targets could still be optimized by the application of targets containing more deuterium (e.g. pure frozen deuterium), although it would require more sophisticated and expensive cryogenic equipment.

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