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STUDY OF FUSION NEUTRON YIELD FROM PF-360 FACILITY EQUIPPED WITH SOLID-STATE OR GAS-PUFFED TARGETS

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The paper reports on results of Plasma-Focus (PF) investigation carried out within the PF-360 device, which was equipped with exchangeable targets made of heavy-ice (D_2O) layers or D_2-gas puffs. The main aim of these studies was to increase a neutron yield from PF discharges by using fast deuteron beams, which are usually emitted from a pinch column and which can interact with additional targets.

1. Introduction

Studies of neutrons and other products of fusion reactions, as well as studies of high-energy ions, fast electrons, and X-rays, have been carried out in plasma laboratories all over world. Numerous Plasma-Focus experiments, which were performed at different laboratories, showed a promising scaling of the neutron yield (Y_n) from D-D fusion reactions. Some investigation extended this scaling to a multi-MJ and multi-MA level [1], but this hypothesis has not been so far verified experimentally. On contrary, it was found that the neutron emission saturates or even decreases when the initial energy input and discharge current are increased above certain threshold values [2-3]. Hence, the record neutron yields from the largest PF machines operated at $W_0 < 800$ kJ, reached only about 10^{12} neutrons/shot.

The first PF-20 device was constructed in Swierk in the 60s, and the PF-360 machine was built during the turn of the 70s and 80s [4]. Measurements of charged particles emitted from the PF-360 device were carried out in the 90s [5-8]. For that purpose various time-integrated and time-resolved diagnostic techniques were applied.

2. Experimental set-up

The PF-360 facility was equipped with Mather-type, coaxial electrodes made of pure copper. The inner electrode was 120 mm in diameter, and the outer one was 170 mm in diameter. Both electrodes were about 300 mm in length, and the basis of the inner electrode (anode) was embraced with a ceramic insulator tube of 80 mm in length.

The main experimental chamber of the PF-360 machine was filled up with pure deuterium under the initial pressure varied from 5.15 mbar to 12.0 mbar. The PF-discharges were powered from a capacitor bank of 288 μF (or sometimes 252 μF). The initial charging voltage was limited to 30 kV for safety reasons, and the most PF-360 experiments were performed within the energy range from 122 kJ to 130 kJ. The general view of the modernized PF-360 facility has been shown in Fig. 1.

In order to increase the neutron yield it was proposed to make use of fast deuterons, which escape from the PF-region. In the first case a planar target, which was equipped with a thick metal plate connected with a Dewar type tube for a cooling liquid-nitrogen flow, was design. The construction enabled the target plate to be positioned on the z-axis, at a variable distance from the PF electrode outlet. In order to make possible the

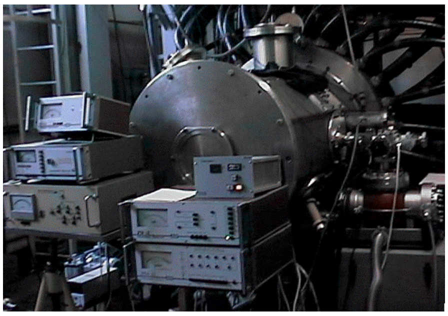

Fig. 1. General view of the PF-360 device

formation of a heavy-ice (D_2O) layer upon the target plate there was installed an additional vacuum valve, which supplied a small amount of heavy water. The thickness of the D_2O-ice layer was varied by a change in amount of the injected heavy water and cooling medium flow.

In order to make use of accelerated deuterons moving in the radial direction (mainly during the current-sheath callapse and the PF-pinch phase), there was proposed another version of the cryogenic target. It was designed as a thin-wall copper tube of about 5 mm in diameter, and 150 mm in length. That needle-like cryogenic target was cooled down by an inside flow of a liquid nitrogen stream, and it was also covered with a thin heavy-ice layer.

Another experimental method, as proposed in order to increase the neutron yield, was based on the application of an additional deuterium-gas target produced within the PF region. A special fast-acting gas valve was installed inside the inner electrode. That valve was powered before the current-sheath collapse, with the time shift τ of about 400 – 500 μs.

Several diagnostic techniques in the PF-360 experiment 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 the distances: d_1 = 266 cm and d_2 = 383 cm from the pinch region. Time-integrated measurements of the X-ray were carried out with an X-ray pinhole camera and two VAJ-type radiometers. Time-resolved measurements of

X-ray pulses were performed with a scintillation set of the XET type.

3. Experimental results

3.1. D_2O-ice planar target

Several series of PF shots were performed with the planar target placed on z-axis of device at different

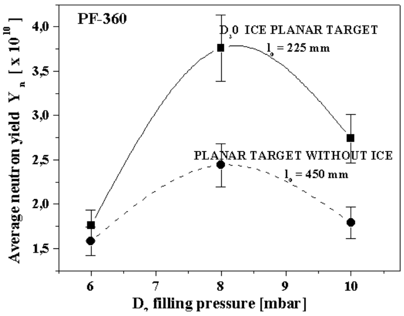

Fig.2. Average neutron yields versus the initial D_2-filling pressure, as measured for PF-360 discharges performed with the D_2O-ice planar target at different axial position. The initial conditions were U_0 = 30 kV and W_0 = 130 kJ

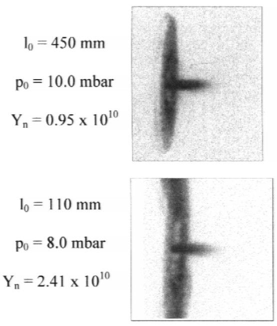

Fig.3. Soft X-ray pinhole pictures, which were taken with a pinhole camera, for discharges performed in the PF-360 facility. It was equipped with the planar cryogenic target placed in different axial positions. The shots were performed at U_0 = 30 kV, and W_0 = 122 kJ. The upper picture shows the pinch region, when the planar target without cooling down was applied. The lower one was taken with the target covered with the D_2O-ice layer

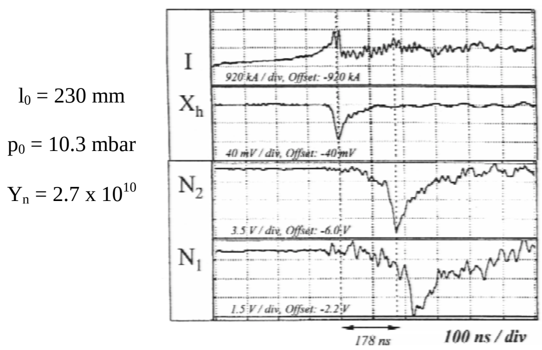

Fig.4. Time-resolved traces from the scintillator-photomultiplier neutron probes, which were obtained for PF-shots with the D_2O-ice planar target, at U_0 = 30 kV, and W_0=130 kJ. Also shown are the discharge current (I) and hard X-rays (X_n) signals

distances from the electrode outlet. Preliminary optimization measurements have demonstrated a considerable increase in the average neutron yield (from 2.4 x 10^{10} to 3.8 x 10^{10}) at determined experimental conditions (p_0 = 8.0 mbar D_2, U_o = 30 kV, W_o = 130 kJ). The optimal position of the target was at a distance l_0 = 225 mm from the electrodes ends, as shown Fig. 2.

The X-ray pinhole pictures, which were taken side-on the electrode outlet, showed that the X-ray emission from the PF pinch column did not change considerably when the planar cryogenic target was placed in different axial positions. Some examples of the X-ray pinhole pictures have been presented in Fig. 3.

A comparison of the voltage and current-waveforms showed that the position of the planar cryogenic target did not influence PF discharges considerably, provided that it was placed not too close to the electrode outlet (i.e., at a distance l_o > 80 mm). Example of time-resolved neutron signals has been presented in Fig. 4.

3.2. D_2O-ice needle type target

It was proved, by the modeling computations of ion trajectories within the collapsing current-sheath and the region of the PF pinch column (which were performed with taking into account the appearance of current filaments [9]), that a considerable portion of accelerated deuterons can move in the radial direction. Therefore, it was reasonable to try to apply a “needle- like” cryogenic target (described in the previous section).

There were carried out several series of the PF-360 experiments with the needle-like target. The neutron yield measurements showed that the placement of such a target near the PF-360 electrode outlet (at l_o = 20 mm) did not influence the average neutron emission very much. However, it should be mentioned, that in general a small decrease of Y_n was observed (especially for the target position at l_o = 65 mm position). In that case one could also achieve an increase in the neutron yield, particularly at higher initial pressures in the experimental chamber D_2-filling, and at l_o = 100 mm. It that experiment the highest neutron yield Y_n = 2.3 x 10^{10} neutrons/shot, as measured for series of several successive shots, was obtained at the initial deuterium pressure p_o = 10 mbar D_2. In general the needle-like target disturbed the pinch column too much (see another paper in this conference [10]).

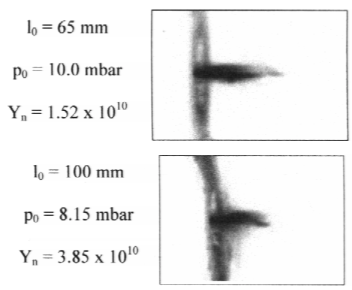

Fig.5. Examples of soft X-ray pinhole pictures, as taken with a pinhole camera, for PF-360 machine operated at U_0 = 30 kV and W_0 = 122 kJ, with the needle-like cryogenic target. That target was placed along the z-axis, within the PF pinch region

The detailed X-ray measurements, which were performed with the X-ray pinhole camera placed side-on the main experimental chamber, showed that the application of the needle cryogenic target did not influence the X-ray emitted region considerably. Such results were obtained when the top of the needle-like target was placed not too close to the electrode outlet (i.e., at $l_0 > 20$ mm). Some examples of the soft X-ray pinhole pictures, as obtained in condition described above, have been shown in Fig. 5.

3.3. D_2 gas – puffed target

Several series of the PF experiments with deuterium-gas puffed targets were performed. The fast acting gas valve, as described in the previous Section 2, was operated mainly at p_v = 21 bar D_2, U_v = 3.2 - 3.5 kV. The gas valve was activated 400 μs or 500 μs before the triggering of the main PF discharge. Several series of PF shots were performed at various initial pressures in the main chamber. With the application of such a gas target the PF-360 facility was able to operate at slightly lower initial pressures.

During the experiments described the pressures varied from about 5.15 mbar D_2 to about 8.2 mbar D_2. The neutron measurement from PF-360 shots, which were performed with described above target, showed that an average neutron yield depends also strongly on the gas conditions. The neutron emission dependence as a function of valve parameters has been shown in Fig. 6.

For the deuterium-puffed PF discharges the highest

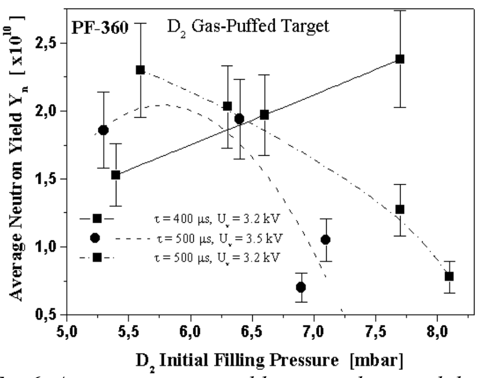

Fig.6. Average neutron yields versus the initial deuterium pressure as measured for PF-360 experiments, performed with additional gas-puffed target at V_0 = 30 kV and W_0 = 122 kJ. The different values of valve time shift (τ) and valve voltage (U_v) were applied

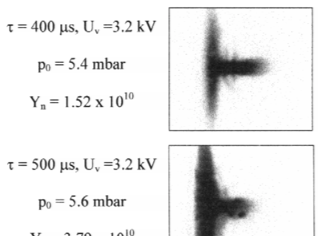

Fig.7. Soft X-ray pinhole pictures, which were taken with a pinhole camera for discharge performed in the PF-360 facility equipped with the gas-puffing equipment at U_0 = 30 kV and W_0= 122 kJ. The different values of valve time shift (τ) were applied

neutron yield (equal to $Y_n = 2.3 \times 10^{10}$ neutrons/shot), was obtained at the initial pressure p_o = 5.6 mbar D_2, and at a lower density of the deuterium target. Such conditions were achieved when the gas-valve was operated at lower voltage (U_v = 3.2 kV), and the main discharge was triggered later (τ = 400 μs). The X-ray measurements, which were carried out with the X-ray pinhole camera, showed noticeable differences in the X-ray emission. That emission depended on the initial gas conditions and the gas-puffed target formation. Some examples of the X-ray pinhole pictures have been shown in Fig. 7.

It was observed that the gas-puffed target could change dynamics of the PF-compression phase, but under appropriate gas conditions an average neutrons yield could also be increased considerably.

4. Summary and conclusions

The most important results of the neutron yield studies described above can be summarized as follows:

- Preliminary optimization measurements with planar cryogenic target have demonstrated a considerable increase in average neutron yield (from 2.4×10^{10} to 3.8×10^{10}) at determined experimental conditions.
- The experiments with the needle-like cryogenic target have shown insignificant increase in the average neutron yield (up to 2.3×10^{10}) at the investigated experimental conditions.
- The use of the gas-puffed target showed a change in dynamics of the PF-compression phase, but the neutron yield was changed slightly. More detailed neutron optimization studies are needed.
- The described measurements of neutron yields, with the use of different additional targets, should be performed also in other PF facilities in order to determine the neutron scaling.

Acknowledgements

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