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Investigation of Plasma Focus discharges in the PF-360 facility with additional D_2 gas-puffed targets

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Abstract The paper describes experimental studies of Plasma-Focus (PF) discharges carried out within the modernized PF-360 facility, which was operated with an additional D_2-gas puffing into the region of the collapsing current sheath and PF pinch formation, i.e. into space in front of the electrode outlet. 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 D_2-gas target.

Key words current sheath • deuteron beams • gas puffing • neutron yield • plasma focus

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Introduction

Studies of neutrons, high-energy ions and other products of fusion reactions have been carried out at plasma laboratories all over world. Numerous PF experiments, which were performed at different laboratories, showed a promising scaling of the neutron yield (Y_n) from D-D fusion reactions. Unfortunately, experiments performed on the largest PF devices showed that the neutron emission saturates or even decreases when the initial energy input and discharge current are increased above certain threshold values [1]. In order to overcome the neutron saturation effect and to increase the maximum neutron yield, it was proposed to use fast deuterons, which usually escape from the PF region. For this purpose the use was made of an additional deuterium-gas target, which was produced within the PF region. Such a target, bombarded by fast deuterons, should produce additional fusion-originated neutrons. One of a few gas-puff target experiments was performed with the POSEIDON PF-facility within German-Polish collaboration [3, 4]. It was found that the gas-target considerably changes the dynamics and structure of the pinching plasma as well as emission characteristics of neutrons and X-rays. It was demonstrated that using this technique the neutron yield could be increased under determined experimental conditions. Basing on our experience gained during the joint German-Polish experiments, a similar version of fast-acting gas valve has been designed for the optimization studies on the PF-360 machine.

Experimental setup

The PF-360 facility was operated at a 122 kJ, 30 kV level with the maximum discharge current reaching 1.8 MA. The device has been equipped with a 170 mm diameter outer electrode and a 120 mm diameter inner electrode, which contained a gas valve. Both electrodes were about 300 mm long. The gas valve (Fig. 1) has a cylindrical construction equipped with a movable piston, opening a gas plenum of capacity equal to 5 cm^3, which may be filled with the working gas under pressure up to 3 MPa. Electromagnetic forces induced by a current pulse, which is applied to a tubular low-inductance coil, can drive the piston. When the piston is shifted, the ring-shaped gas plenum, which is normally sealed up with two O-rings, becomes open. A pressurized gas stream flows out and after its reflection from a special conical insert, it flows through dozen narrow nozzles into the current-sheath collapse region. Return motion and closing of the gas plenum can be caused by a pneumatic pusher, which is placed behind the valve. The valve coil is supplied with an auxiliary 120 μF condenser bank charged up to maximum 3.5 kV, 710 J. It is coupled to the coil through an isolating pulse transformer. Depending on the initial pressure (p_v) of the working gas, supplied voltage (U_v) and a time delay (τ) of the PF discharge (in relation to the acting of the valve), the injected gas can form a tubular gaseous curtain or a quasi-spherical gas cloud in front of the inner electrode.

In the PF-360 gas-puffed experiments several diagnostic techniques have been applied simultaneously. Neutron yields have been measured with two silver-activation counters, placed in different radial and angular positions. Time-resolved neutron signals and very hard X-ray signals have been measured with two scintillator-photomultiplier probes, placed in different distances from the pinch region. Time-integrated measurements of the X-ray have been performed with an X-ray pinhole camera and two VAJ-type radiometers. Time-resolved measurements of X-ray pulses have been carried out with a scintillation set of the XET type [2].

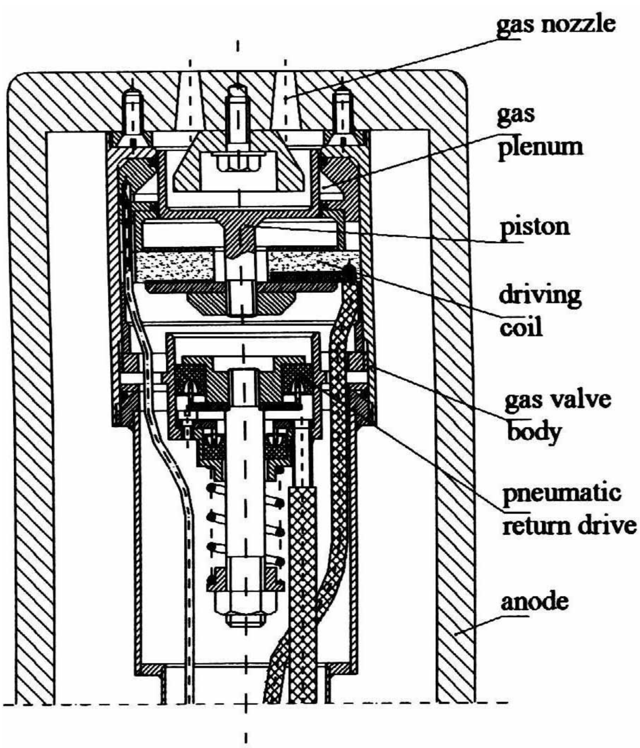

Fig. 1. Assembly of a fast high-pressure gas valve, as designed for gas puffing experiments with the PF-360 facility.

Experimental results

Several series of the PF experiments with deuterium-gas puffed targets have been performed recently. The fast acting gas valve, as described above, has been operated mainly at p_v = 21 bar D_2, U_v = 3.2–3.5 kV. The gas valve has been activated 400 or 500 μs before the triggering of the main PF discharge. Several series of PF shots have been performed at various initial pressures in the main chamber. With the application of such gas target the PF-360 facility could operate at slightly lower initial pressures. During the experiments described the pressures were varied from about 5.15 mbar D_2 to about 8.2 mbar D_2. The neutron measurements from PF-360 shots, which were performed with the described above target, have showed that an average neutron yield also strongly depends on gas conditions. The neutron emission dependence as a function of valve parameters has been shown in Fig. 2.

For the deuterium-puffed PF discharges, the highest neutron yield (equal to $Y_n = 2.3\times10^{10}$ neutrons/shot), has been obtained at the initial pressure p_0 = 5.6 mbar D_2, and at a lower density of the deuterium target. Such conditions have been achieved when the gas-valve was operated at a lower voltage (U_v = 3.2 kV), and the main discharge was triggered later (with τ = 500 μs). The X-ray measurements, which were carried out with the X-ray pinhole camera, showed noticeable differences in the X-ray emission. The emission depended on the initial gas conditions and the gas-puffed target formation. Some examples of the X-ray pinhole pictures was shown in Fig. 3. These pictures have also demonstrated the development of the instabilities of the pinch column in the case when a relatively dense D_2-target was introduced.

Conclusions

The results of the preliminary deuterium-puffed experiments reported above have demonstrated that the PF-360 facility can also be operated in a well controlled way with

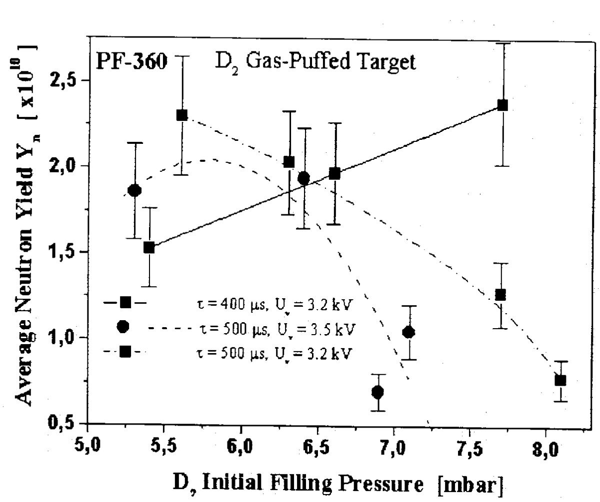

Fig. 2. Average neutron yields versus the initial deuterium pressure, as measured for PF-360 experiments performed with additional gas-puffed targets at U_0 = 30 kV and W_0 = 122 kJ. The different values of valve time shift (τ) and valve voltage (U_v) were applied.

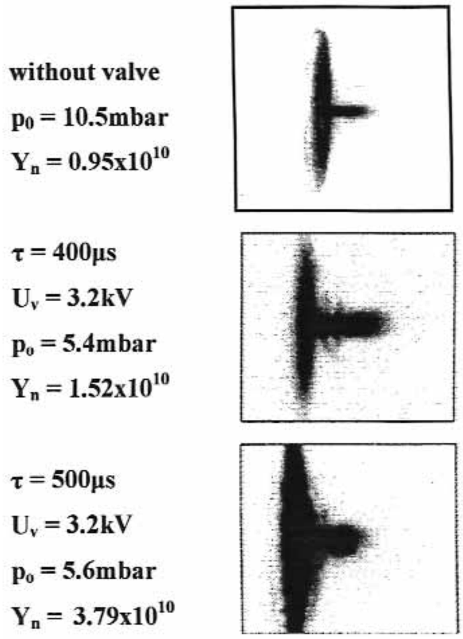

Fig. 3. Soft X-ray pinhole pictures, which were taken with a pinhole camera from discharges performed in the PF-360 facility with the gas puffing, at U_0 = 30 kV and W_0 = 122 kJ. The figure makes possible to perform a comparison of pictures taken for shots without and with D_2 puffing at different values of a time delay (τ).

the injection of an additional D_2-target, but this can change the dynamics of the compression phase and emission characteristics of PF discharges. The average neutrons yield can be increased considerably under appropriate gas conditions. In order to determine the neutron scaling more detailed optimization studies are needed, also in other PF facilities.

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