Spatial distribution of DD-fusion neutron emission from a plasma focus measured with thermoluminescent dosimeters

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Abstract – The spatial distribution of DD-fusion neutrons emitted by the Plasma Focus Device PF - 1000 at the Institute of Plasma Physics and Laser Microfusion, Warsaw was studied experimentally. The measurements of neutrons with thermoluminescent (TL) dosimeters and fast-neutron moderators show a distinct emission anisotropy owing to the neutron scattering on the discharge chamber. The measured anisotropy is compared with the computational prediction of the emission anisotropy induced by the discharge-chamber structure.

Introduction

The principle of a Dense Plasma Focus Device operation lies in the conversion of energy collected in a capacitor bank into electromagnetic acceleration and compression of short-lived plasma which becomes a source of X-rays, charged particles and nuclear fusion netrons, when operated in deuerium. The measurement of the neutron emission is affected by the neutron interaction with the discharge chamber, surrounding equipments and laboratory walls etc. [1]. The goal of our contribution is the observation of the anisotropy of the neutron emission by the Plasma Focus - 1000 facility operated at optimal conditions of deuterium pressure and electrode configuration.

Experimental arrangement

The plasma was generated in the PF-1000 device discharging energy of 450-500 kJ in the deuterium with pressure of 3.5 Torr. The recorded maximum neutron yield is $\approx 3.5\times10^{11}$

neutrons/shot [2]. The emitted DD-neutrons were scattered and moderated in paraffin Bonner spheres (BS) having a diameter of 10 inch to be detectable by TL dosimeters ^{6}LiF:Mg,Cu,P (TLD-600H) and ^{7}LiF:Mg,Cu,P (TLD-700H) [3,4]. The paraffin sphere serving as a reference detector (BS1) was placed 1 m below the electrode outlet. The other Bonner spheres were positioned around the PF-1000 device to measure the emission in more directions, as Fig. 1a schematically shows. The TLD signals were recalculated to the solid angle corresponding to the reference BS1. The dimensions of the dosimeters were 3.2 mm × 3.2 mm × 0.9 mm. The lower sensitivity limit of the LiF:Mg,Cu,P dosimeters is 1 μGy. TL responses were read-out at a heating ramp 10 °C/s from 160 °C to 300 °C in an N_2 atmosphere using a PC-aided Harshaw Model 3500 reader. The parameter *k* equalising TLD-600H and TLD-700H responses $R^{n}_{TLD600} = R^{n+\gamma}_{TLD600} - k\, R^{n+\gamma}_{TLD700}$ to X-rays was measured for ^{137}Cs radiation [3,4]. The number of emitted neutrons per shot was also measured with 4 silver activation detectors located at different angles in *x-z* plane, see 4 boxes in the top of Fig. 1 in [2,3]. The measurements of neutron emission with TLDs were provided in the intersection planes x-z and y-z, as Fig. 1a shows.

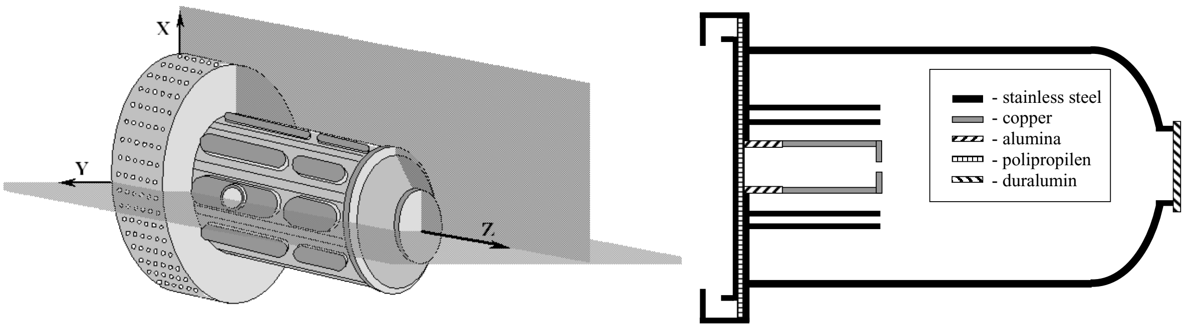

Fig. 1 Schema of the discharge chamber: (a) positions of planes at which neutrons were measured, (b) simplified geometry of the chamber for computing the neutron scattering.

The ability of neutrons to penetrate through thick layers of metals makes the measurement of neutron fluence outside the discharge chamber possible. Moreover, the placement of TLDs outside the discharge chamber provides the partial shielding of TLDs from X-rays and, thus, decreases the undesirable response of TLDs to X-rays. To provide the essential calculation of the effect of the discharge chamber on the neutron scattering with the use of a MCNP 4C code a simplified schema of the discharge chamber was considered (see Fig. 1b).

Experimental results

The earlier experiments indicated anisotropy of DD-neutron emission from the PF-1000 device [4]. Owing to the limited numbers of Bonner spheres available in the laboratory a high number of single discharges under the same conditions were needed. Fig. 2 shows the comparison of the TLD responses related to the reference BS1 signal with the computed number of direct and scattered/moderated neutrons hitting virtual sensors. The anisotropy shows distinct minima and maxima. The computed maximum at $\vartheta \approx 180°$ arises due to the set of massive electrodes

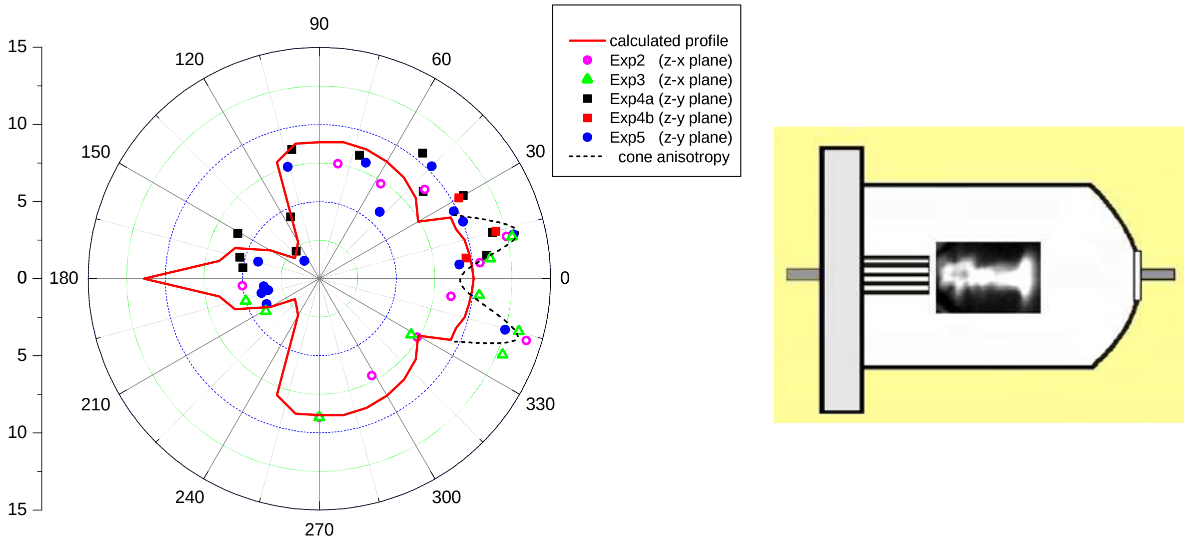

Fig. 2. Anisotropy of the neutron emission from the PF-1000 device: solid line – the computed distribution with the use of the MCNP 4C code, symbols – emission of DD neutrons in x-z and y-z planes (see Fig. 1a) measured with pairs of TLD 700H and TLD 600H. The TL signals of the TLDs were related to TL response of the dosimeters positioned into Bonner sphere 1m below the electrode outlet, dotted line – cone shape anisotropy of emission along the axis symmetry. The PF 1000 facility was operated at the energy of 450-500 kJ. The D_2 pressure was 3.5 Torr.

operating as an effective moderator as well as a collimator of direct neutrons due to its structure. The deep minima at $\vartheta \approx 110°$ to 150° and 210° to 250° arise because of the massive backside collector plate, which holds all the cables (not considered in the computation). The minima at $\vartheta \approx 30°$ and 330° correspond to the increased effective thickness of the device's tube, which is hit by neutrons under the increasing impact angle. The maximum at $\vartheta \approx 15°$ (345°) was already ascribed to plasma properties because the computing does not shows it [3] but its origin is not explicit. Although the complete structure of the discharge chamber was not taken into account and, thus, the computed anisotropy can differs from the correct numbers, the computation renders the basic information on the neutron moderation by the discharge chamber.

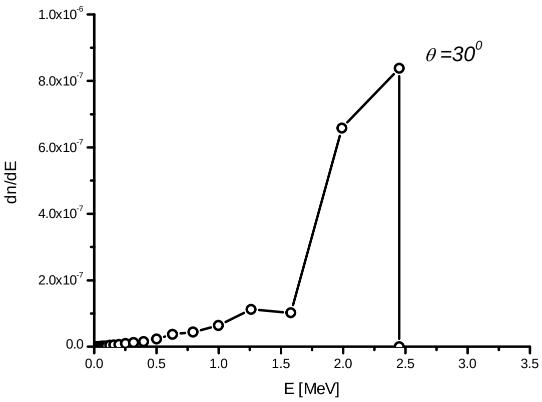

Fig 3. Computed energy distribution of DD-neutrons passed trough the discharge chamber walls for $\vartheta \approx 30°$, see Fig. 2.

The scattering of neutrons by the discharge chamber results in the moderation of neutrons and, thus, the energy spectrum shows a considerable broadening in the range of low energies, as Fig. 3 shows. It is evident that this moderation of DD-neutrons is very effective process, which significantly modulate time-of-flight spectra of DD-neutrons produced by the PF-1000 device

Conclusions

The presented experiments demonstrated the crucial effect of the discharge chamber structure on the anisotropy of the neutron emission and the important influence of this anisotropy on time-resolved signals of active neutron detectors for the evaluation of the correct values needed for the description of the plasma-focus dynamics.

Acknowledgment

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