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Spatial Profiles of the DD Product Yield in the GDT Experiments

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Introduction

Experiments with plasma heating by 3.8 MW deuterium beams are continued in the gas dynamic trap (GDT) to simulate the axial profile of the fusion reaction intensity in the projecting GDT-based neutron source [1]. The GDT plasma consists of two components. The first component is a collisional target plasma with the electron temperature about 100 eV and density of up to 6×10^{19} m^{-3} . This thermal plasma is confined in a collisional regime that is characterized by the condition that a mirror-to-mirror distance considerably exceeds the effective ion mean free path of scattering into the loss cone. The second component is produced by oblique neutral beam injection at the midplane of the device. This component is strongly anisotropic fast ions with mean energy of $\approx$10 keV and density up to 10^{19}m^{-3}. These fast ions are confined in collisionless regime. The main objective of the experiments with deuterium neutral beam injection in GDT was to simulate the spatial profile of the neutron flux in a 14 MeV neutron source based on GDT that is dedicated to fusion materials testing.

According to the predictions of the Coulomb-collisions theory, the fast ion relaxation in the target plasma of this neutron source is to be dominated by electron drag and therefore, their pitch-angle distribution remains quite narrow. As a result, the fast ion density has strong maximum near the turning points where longitudinal velocities of fast ions are close to zero. In case of injection of deuterium and tritium neutral beams this effect increases neutron yield within those regions, which house the test zones in the prospective GDT-based neutron source.

It is expected that in the two-component GDT-based neutron source possible microinstabilities of the anisotropic fast ions will not de-

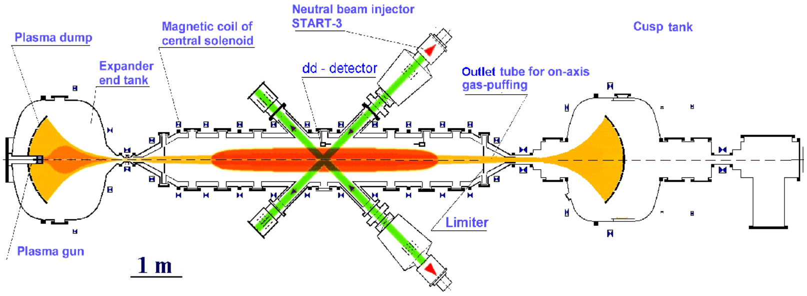

Fig. 1. The GDT layout.

velop due to filling up of the loss-cone by the warm target plasma ions. This microstability of fast ions is crucial issue for this neutron source since the neutron flux peaks may strongly broaden by anomalous fast ion scattering caused by instability drive. Here we present the results of recent experiments with increased magnetic field and improved detection system. The axial and radial profiles of 3.02 MeV proton flux measurements have been carried out.

Experimental setup

The GDT device (Fig. 1) comprises the central cell and two end cells. The mirror-to-mirror distance is 7 m, magnetic field at midplane is set to 0.25 T (for most experiments), typical mirror ratio is about 40. The hydrogen target plasma was produced by the plasma gun located in one of the end cells. Six neutral beams (NB) (total injected power ~3.8 MW, pulse duration 1.1 ms, injection energy about 17 keV) were used for plasma heating and fast ions build-up.

The single-particle counting regime was chosen for measurements of DD reaction product fluxes. The main reasons were: no need for the detector calibration. A 3.02 MeV proton flux has been measured by using an organic scintillator with 5 mm thickness. Detail description of the detector is presented in [2]. A new mount unit and a collimator providing enhanced angular resolution of ~2 cm were installed to allow scanning in the transverse direction.

Recent upgrade of the GDT magnetic field system, an increase of heating beam power, and optimization of the experiment scenario resulted in a noticeable growth of fast ion energy content and DD reaction intensity. The measured DD reaction intensity increased more than 7 times comparing with the previous experiments [3]. The number of fusion protons emitted by 1 m length of the plasma column 1.75×10^{10} s^{-1} m^{-1} in the region of fast ion turning point was achieved.

Results of experiment and simulations

The basic idea of this work was to compare the measured axial profile of DD reaction intensity with the calculated one taking into account cross section of DD reaction and distribution function of fast deuterons over energy and pitch angle. It is important to note that projecting neutron source based on a Gas Dynamic Trap does not allowed essential enhancement of angular scattering rate of fast ions in comparison with coulomb scattering rate. Thus the distribution function of fast deuterons must be close to the solution of the Fokker-Planck kinetic equation for the case of two-body Coulomb collisions. To compare experimental results with the predictions of the theory based on two-body Coulomb collisions, the following two calculation methods for the fast ion distribution were used:

- a synthesis method which constructs the fast deuteron distribution from analytic steady-state solutions of space-independent Fokker-Planck equations. It allows to describe approximately the fast ion distribution function in velocity and pitch-angle space [4];

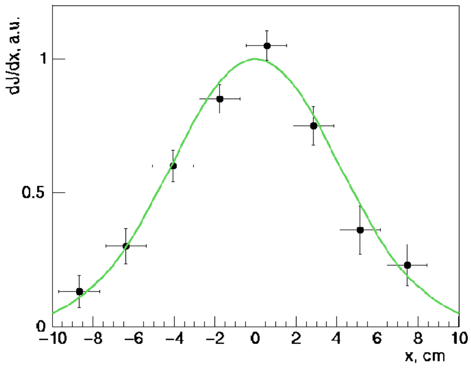

Fig.2 Transverse profile of 3.02 MeV proton flux

- a Monte Carlo simulation of particle histories on the basis of the time, space and energy-dependent Fokker-Planck equation for the field of fast ions [5].

Using measured plasma parameters, characteristic time of energy relaxation for deuterons with energies 6÷17 keV was obtained as about 0.7 ms, which is essentially smaller than the duration of neutral beams. On this basis one can conclude, that fast deuteron distribution function is close to a steady-state one providing the evidence of applicability of the synthesis method.

Since a fast deuteron gyroradius is comparable with characteristic radius of target plasma under conditions of the GDT experiment, characteristic radius of guiding center density profile of fast ions is the basic parameter for calculation spatial distribution of DD reaction intensity. Perpendicular profile of DD proton flux was measured to estimate this basic parameter. Fig. 2 shows the result of measurement. The algorithm of approximate calculations using the synthesis method was as follows.

- Radial profile of guiding center density was approximated by rectangle function with variable radius (see Fig. 3).
- Calculations of spatial profile of DD reaction intensity were carried out for different radii of guiding center distribution.
- Optimal radius (12 cm) corresponds to the best coincidence between the measured

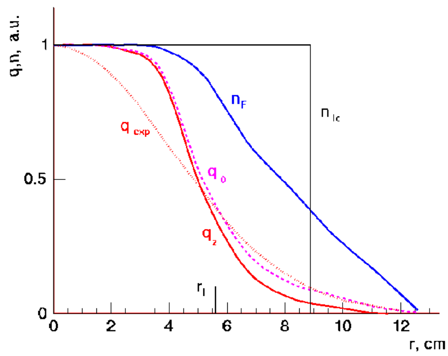

Fig.3 Model profiles at the turning point Z=175 cm:
n_{lc} – density of the guiding centers;
n_F – fast ion density;
q_z , q_0 – radial profiles of DD proton flux density (index 0 means projection from midplane);
q_{exp} – experimental profile proton flux density .

and calculated radial profiles of DD proton flux (see Fig. 3). Note that calculated radial profiles show essential influence of finite Larmor radius effects.

- Next step was the calculation of the axial profile using obtained value of the optimal radius as input parameter. Fig. 4 shows the results of measurement and approximate calculation. Fig. 4 shows also results of simulations using MCFIT code. The latter were carried out for limited radial dimension of fast ion density profile taking into account results of recent experiments.

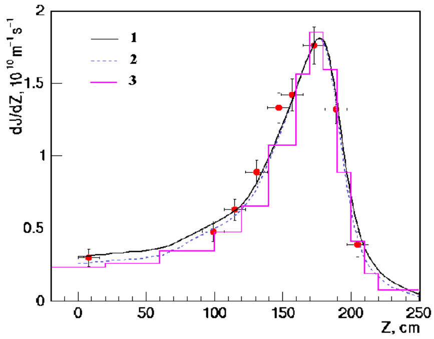

Fig.4 Axial profile of fusion yield measured (point with error bar) and calculated (lines):
1 –synthesis method taking into account finite Larmor radius effects (FLR),
2 – synthesis method without FLR,
3 – MCFIT.

Conclusions

- The experiments with oblique injection of deuterium neutral beam at the GDT facility for the first time demonstrated the principle of fusion neutron production in a neutron source based on the gas-dynamic trap.
- Finite Larmor radius effects and ion drift essentially affects on fusion product yield.
- Reasonable agreement between the experimentally measured spatial profiles of fusion product yield and results of simulations allowed to conclude that, within the measurement accuracy, two body Coulomb collisions determine the kinetic of angular scattering and slowing down of fast ions.

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