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Fast Particle Confinement Studies in the Globus-M Spherical Tokamak

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Abstract

The study of fast ion behaviour by Charge-eXchange (CX) diagnostics during auxiliary plasma heating was continued in the Globus-M spherical tokamak [1]. The operation principle and parameters of CX diagnostic apparatus are given. New data obtained during Ion Cyclotron Range of Frequencies (ICRF) and Neutral Beam Injection (NBI) plasma heating is presented. The results of particle trajectory simulations performed to explain the experimental data are shown. The effect of first orbit losses on fast particle confinement and ion heating efficiency is discussed.

1. CX diagnostics

The CX diagnostic complex at the Globus-M tokamak employs two Neutral Particle Analyzers (NPAs) of ACORD type [2,3]:

1) ACORD-12 NPA installed perpendicularly to the plasma column.

2) Newly developed ACORD-M NPA directed tangentially to the plasma column.

The apparatus arrangement is shown in Fig.1.

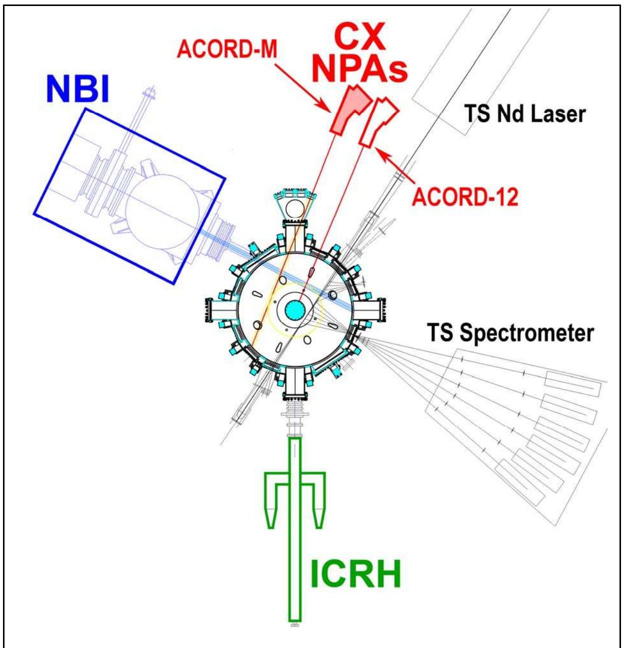

Fig.1
Apparatus arrangement at the Globus-M tokamak.

The analyzers provide the mass-resolved CX energy spectra measurements, supplying information about plasma Hydrogen/Deuterium (H/D) composition, ion temperature (T_i), and non-maxwellian ion distribution tails that appear during auxiliary plasma heating. The application of the ACORD-M analyzer allows to provide measurements in tangential direction and to obtain new information about passing ions, which was unavailable until now. ACORD-M NPA has a doubled number of energy channels, which makes possible to obtain a detailed ion energy distribution during one plasma shot.

The operating principle of both NPAs is based on the ionization of neutral particles emitted by plasma in the gas stripping cell and on the subsequent analysis of the resulting secondary ions in electric and magnetic fields. The basic NPA parameters are listed in the Table 1.

Table 1. Main NPA parameters

NPA type / **Parameter**	**ACORD-12**	**ACORD-M**
Energy range	0.2-70 keV	
Energy dynamic range	(E_{max}/E_{min}) ~ 7	
Number of detectors	6x2 (H and D)	12 (x2 in project)
Detector type	Channeltrons (Russia)	Channeltrons (Germany)
Energy step (between channels)	40-65 %	20-40 %
Mass suppression (H/D)	10^{-3}	
N_2 stripping pressure	$(1\text{-}4)\text{x}10^{-4}$ Torr	

2. ICRF heating

The main mechanism of ICRF plasma heating in the Globus-M tokamak is the Radio Frequency (RF) power absorption by H-minority ions at fundamental cyclotron harmonic [4]. This mechanism is accompanied by generation of suprathermal minority ion tails, which can be characterized by the effective tail temperature T_{tail}. The analysis of recently obtained data showed that T_{tail} is limited by the value of T_{tail} ~ 1.2 keV (T_{tail} was evaluated using the energy range of 2-5 keV). It indicates that the RF power absorbed by minority ions is also limited. We assumed that this limitation is connected with finiteness of energy of accelerated minority ions. In other words the minority ions undergo first orbit losses if they exceed some maximal energy E_{max}.

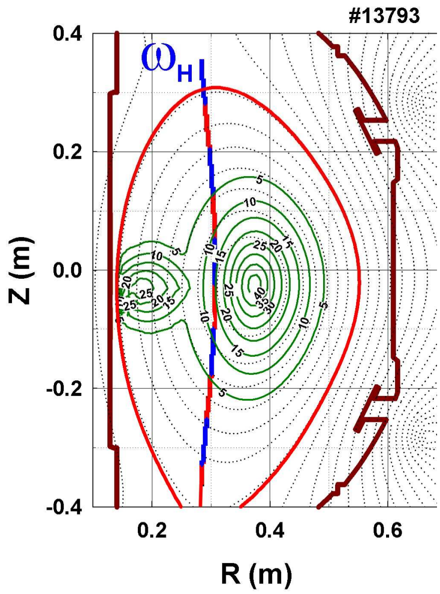

Fig.2
ICRF heating. Results of trajectory simulations of accelerated minority ions. The map of banana orbit tip positions of confined particles with different E_{max} is plotted over the Globus-M poloidal cross section.

Due to a weak signal at high energies the measurements of CX flux above 5 keV was complicated. However using the observation of 4 keV CX flux decay after RF termination, the maximal energy of accelerated H-ions was estimated as E_{max}~ 15 keV [5].

To prove the experimental estimate the trajectory simulations of minority ions in the Globus-M magnetic field, reconstructed using the EFIT code [6], were performed. The map of banana orbit tip positions for different E_{max} was obtained (Fig.2). As can be seen E_{max} is about 15 keV for ions having the banana orbit tips near the fundamental harmonic region. This correlates well with the value estimated from experiment.

3. NBI heating

The noticeable fast particle losses are expected in the Globus-M spherical tokamak during the NBI heating [5]. At present the NBI experiments at Globus-M are focused on finding the regimes with reduced direct losses (first orbit + shine through losses) in order to increase the plasma heating efficiency.

<u>NBI heating of shifted plasma.</u> The increase of NBI heating efficiency was observed after the shift of plasma volume toward the tokamak central column. The time traces of main plasma parameters for shifted and non-shifted plasma are presented in Fig.3. As it is seen the ion temperature increase during NBI (δT_i) is about 2.5 times higher in the case of shifted plasma. About 75 % of $\Delta T_i = \delta T_i^{shift} - \delta T_i^{norm}$ difference can be explained by difference in plasma volume V_{pl} and plasma density $n_e(0)$. The performed ion trajectory simulations partly explain the remaining 25 % of difference due to better beam particle confinement in the case of shifted plasma.

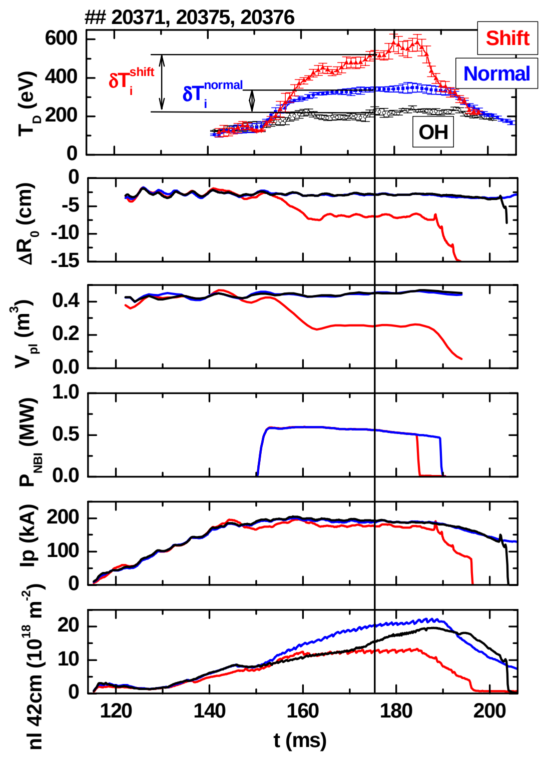

Fig.3
<u>NBI heating.</u> Time traces of main plasma parameters in the case of shifted plasma (shift) and in the case of non-shifted plasma configuration (normal).
OH – reference ohmic plasma shot.

<u>Comparison of H-NBI and D-NBI.</u> The comparison of fast ion behavior during H-NBI and D-NBI was performed by new ACORD-M NPA. The H and D slowing down energy spectra measured at 10 ms after beginning of NBI are presented in Fig.4. The energy structure of beams is clearly seen on the spectra as the step at beam's half energy $E_b/2 \sim 9$ keV. Integrally the shapes of both spectra well correspond to the theoretical prediction of slowing down due to coulomb collisions [7]. However, the measured step at $E_b/2$ is bigger than the one expected from beam composition of both H-NBI and D-NBI. At the same time the magnitude of the step at $E_b/2$ is less pronounced in the case of H-NBI. All these facts are in a good agreement with the results of beam particle trajectory simulations, which predict the direct loss level of 20 % for H-beam and 40 % for D-beam.

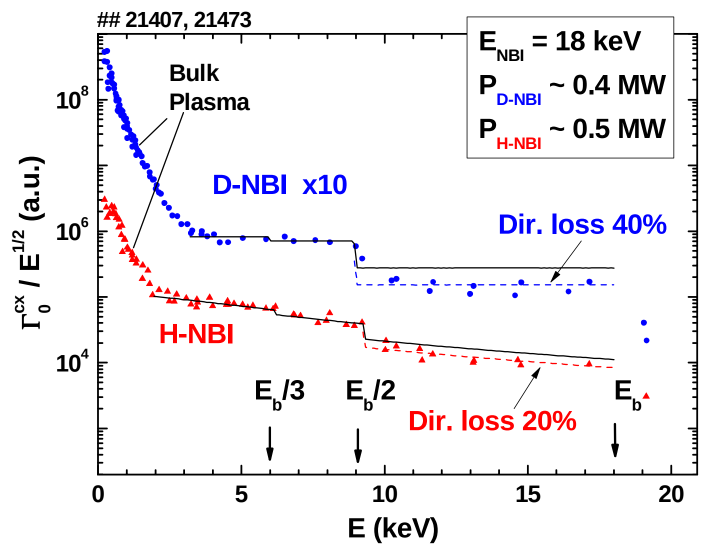

Fig.4

<u>NBI heating.</u> Slowing down energy spectra measured during H-NBI and D-NBI.

Solid line – theoretical prediction $\sim (E^{3/2}+E_{cr}^{3/2})^{-1}$ [7]

Dashed line – theoretical prediction with direct losses.

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