MEASUREMENTS OF TOROIDAL ROTATION VELOCITY IN TUMAN-3M TOKAMAK IN NBI AND H-MODE REGIMES

[1]L.G. ASKINAZI, G.I. ABDULINA, A.A. BELOKUROV, V.A. KORNEV, S.V. LEBEDEV, D.V. RAZUMENKO, L.K. SHUVALOVA, A.I. SMIRNOV, A.S. TUKACHINSKY, N.A. ZHUBR

[1]Ioffe Institute, St/Petersburg, Russian Federation
Email: Leonid.Askinazi@mail.ioffe.ru

ACKNOWLEDGEMENTS

Operation of standard diagnostics on TUMAN-3M tokamak are supported by Ioffe Institute State contract FFUG-0024-0028. NBI experiments are supported by Ioffe Institute State contract FFUG-0021-0001. Radial electric field studies on TUMAN-3M tokamak are supported by Russian Scientific Foundation project 22-12-00062.

The velocity of the toroidal rotation in the peripheral plasma in the TUMAN-3M tokamak was measured [1] in two scenarios: co-current NBI H-mode and in ohmic H-mode using Doppler-shifted CII impurity line. It was found that the time evolutions and steady-state velocity values of the toroidal rotation velocity at the periphery are very similar in both cases, indicating that the effect of the L-H transition prevails over the direct influence of the beam injection. The observed toroidal rotation is associated with the generation of negative radial electric field at the periphery during the L-H transition.

Neutral Beam Injection (NBI) is one of the main methods of auxiliary plasma heating in magnetic confinement fusion devises. Together with energy transfer from beam to the plasma, NBI also leads to the mechanical momentum and radial electric field generation in plasma. The radial electric field plays an important role in turbulence and anomalous transport suppression. It is known to be a trigger for the confinement mode switching toroidal devices. Such studies have been conducted at various tokamaks and stellarators for many years [2, 3], but the mechanisms for generating plasma rotation and radial electric field have not yet been fully elucidated. The mechanisms responsible for affecting plasma rotation profile are numerous (direct momentum transfer, radial currents of uncontained particles, artificially created electric fields, plasma viscosity etc.) and manifest themselves differently in different spatial regions of the plasma and with different experimental geometries, in particular, with co- and counter-injection [4]. In addition, intrinsic generation of plasma rotation was also identified [2], even in the absence of external source of mechanical momentum or electric field.

In this paper we present first results of toroidal rotation studies in the tokamak TUMAN-3M performed in co-current NBI regime with L-H transition and in pure ohmic H-mode. The main goal was to identify the main processes responsible for plasma rotation and radial electric field formation, such as direct beam-plasma momentum transfer, fast ion losses or H-mode influence.

The experiments were carried out on the TUMAN-3M tokamak (R = 0.53 m, a = 0.23 m, $T_e(0)$ = 400(L) – 700(H) eV, $\langle n_e \rangle$ = 1.5(L) – 4(H) 1019 m-3, I_p = 123-150 kA, B_t = 0.7 – 1 T, NBI energy W_b ~ 18 – 20 keV, NBI power Pb ≥ 150 kW, the symbols L and H indicate the values that are different in the L- and H-modes). In some discharges, the L-H transition was initiated before the injection pulse. Hydrogen NBI was performed in co-current direction with tangency radius of 0.42m. The toroidal rotation measurements were performed using the Doppler-shifted spectral lines of the singly ionized carbon (C+) CII doublet (657.8 nm and 658.3 nm) with an ionization potential of 11.26 eV. Temporal behaviour of the two lines was nearly identical, so only 658.3 nm line is shown below. The intensity of CII lines was found to be independent on the presence of atomic beam. It means the CII emission was not a result of charge-exchange process $C^{2+} + H \rightarrow C^{*+} + p$, but is rather produced by electron impact excitation of neutral carbon near the edge. The main goal of these experiments was to investigate the possibility of implementing the FIDA (Fast Ion D-alpha) diagnostics to study the fast ion distribution function [5], and observing the Doppler shifts in the CII lines was an additional diagnostic opportunity. Generally speaking, the impurity rotation velocity does not necessarily equal to the rotation velocity of the main ion, but this method is often used both to measure the rotation velocity and to determine the magnitude and spatial distribution of the radial electric field [6]. The experimental layout included an MDR-2 monochromator with an HS103H CCD camera [7] installed in place of the exit slit, a light guide, an objective, and a mirror installed inside the tokamak chamber to provide the required direction of the observation line. It was directed towards the beam and formed an angle of 61° with it. Figure 1 shows some plasma parameters and Doppler-shifted CII 658.3 nm line relative position as a function of time in a shot with NBI pulse in an interval t = 60 - 84 ms.

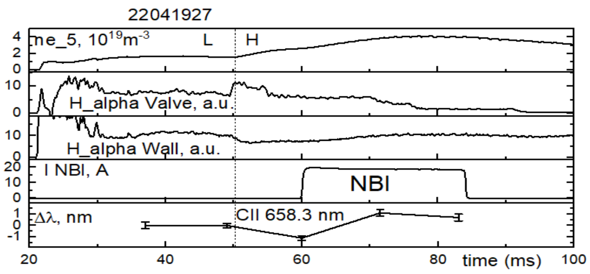

Fig1. From top to bottom: central chord-averaged density, H_α emission near the gas valve and near the wall, NBI pulse current, relative shift of CII line measured in five 11 ms time windows (points in the center of each window are connected by a line for visibility).

At time t = 49.5 ms (i.e. approximately 10 ms before the start of the neutral injection pulse), the ohmic L-H transition was initiated in the plasma by a short (5 ms duration) gas puffing pulse to increase the plasma density during atomic injection. Spectra of CII lines were time-averaged over 11.5ms frames; there were 10 frames registered during the plasma shot. Points shown in Fig.1 corresponds to frames 2 to 6. Figure 2 shows a comparison of CII line spectral shifts obtained in 3 typical scenarios of TUMAN-3M: NB plus H-mode (a), ohmic H-mode (shot 22041921) and NBI plus L-mode (shot 22052506) (b).

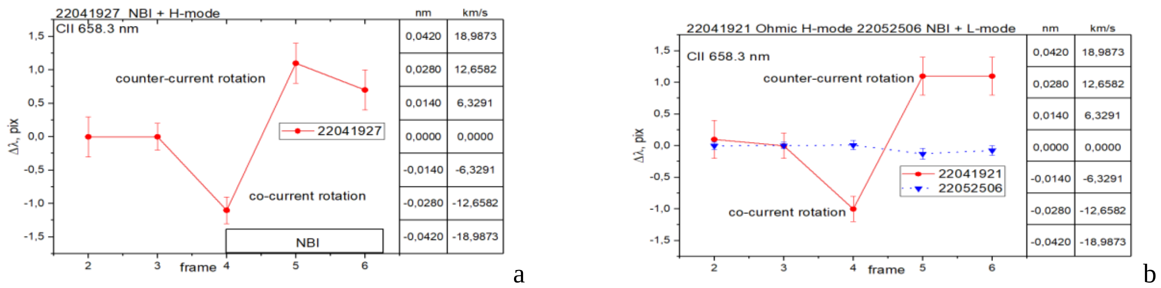

Fig.2 Temporal evolution of Doppler-shifted CII 658.3 nm line in NBI plus H-mode shot (a) and in ohmic H-mode and NBI plus L-mode shots (b). Tables to the right show spectral shift in nm and toroidal rotation velocity corresponding to the spectral shift in CCD camera pixels shown on the left vertical axis. Note that here a negative velocity means co-current direction.

Conclusions to be drawn are as follows:

- During a transient phase of L-H transition a co-current rotation velocity ~12.6km/s is observed in shots with- or without NBI
- In the developed H-mode in shots with- or without NBI a counter-current rotation is formed with velocity up to 19 km/s
- In the NBI shot in L-mode negligibly small co-current rotation is observed, if any
- All the above lead to the conclusion that in the shots under investigation the impact of the NBI to the plasma rotation was small, possibly due to luck of NBI power or high fast ion losses. All the rotation observed was solely a result of the L-H transition accompanied by a negative radial electric field formation at the edge.

Previously [8], when measuring the shift of the BIV boron line, no toroidal rotation was found in the ohmic H-mode, which may be due to the fact that this ion emits from a deeper region of the plasma because of higher ionization potential (259.4 eV). The connection between the toroidal rotation and the radial electric field can be estimated as $E_r = - V_t B_p = -$ 1.6 kV/m. This estimate is noticeably lower than the value measured earlier in the ohmic H-mode using Langmuir probes $E_r = -$ 3 kV/m [9], which can be explained both by the fact that this estimate does not take into account the contribution from the neoclassical electric field, and by the fact that the probe measurements are well localized by radius, and the above estimate for the toroidal rotation velocity is averaged over a certain spatial region near the plasma periphery.To further elucidate the mechanisms of interaction between beam injection, plasma rotation and L-H transition, the experimental results will be supplemented by numerical simulations of plasma rotation using ASTRA and NUBEAM codes.

REFERENCES

[1] ASKINAZI, L.G. et al, Observation of Plasma Toroidal Rotation during High-Energy Atomic Beam Injection and L-H Transition in TUMAN-3M Tokamak, accepted for publication in Tech. Phys. Letters (2025)

[2] J.E. RICE, Experimental observations of driven and intrinsic rotation in tokamak plasmas, Plasma Phys. Control. Fusion **58** (2016) 083001

[3] K. IDA and J.E. RICE, Rotation and momentum transport in tokamaks and helical systems, Nucl. Fusion **54** (2014) 045001

[4] S.V. LEBEDEV et al, Counter-NBI assisted LH transition in low density plasmas in the TUMAN-3M Nucl. Fusion **49**, 085020, (2009)

[5] SHUVALOVA,L.K. et al, FIDA diagnostic modelling using FIDASIM for observation of fast-ion distribution function during neutral injection in the TUMAN-3M tokamak, Tech. Phys. Letters, (2024), **50,** 11, 16-20,

[6] K.H. BURRELL, Role of sheared E × B flow in self-organized, improved confinement states in magnetized plasmas, Phys. Plasmas 27, 060501 (2020)

[7] https://www.czl.ru/catalog/spektr/digital-cameras/proscan-hs-103h.html

[8] A.A. BELOKUROV et al, The first application of the HIBP diagnostics for co–NBI plasma potential measurement in the TUMAN–3M tokamak, Tech. Phys. Letters, **48**, 12, (2022) 69-73

[9] L.G.ASKINAZI1 et al, Peripheral radial electric field evolution during the ohmic H-mode transition in the TUMAN-3M tokamak, 31st EPS Conference on Plasma Phys. London, 2004 ECA Vol.28G, P-4.153 (2004)