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

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ABSTRACT

- The velocity of the toroidal rotation in the peripheral plasma in the TUMAN-3M tokamak was measured in two scenarios: co-current NBI H-mode and in ohmic H-mode using Doppler-shifted CII impurity line.
- 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.

BACKGROUND

- In this paper the first results of toroidal rotation studies in the tokamak TUMAN-3M [1] performed in co-current NBI regime with L-H transition and in a pure ohmic H-mode as well are presented. 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
- NBI leads to the mechanical momentum and radial electric field generation in plasma. The radial electric field and plasma rotation studies have been conducted on various fusion devices [2, 3], but the mechanisms for generating plasma rotation and radial electric field have not yet been fully elucidated.
- The mechanisms 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]. Moreover, intrinsic generation of plasma rotation was also identified [2], even in the absence of external source of mechanical momentum or electric field.

EXERIMENTAL LAYOUT

TUMAN-3M tokamak

R = 0.53 m, a = 0.23 m, Te(0) = 400(L) – 700(H) eV, <ne> = 1.5(L) – 4(H) 10^{19} m^{-3}, I_p = 123-150 kA, B_t = 0.7 – 1 T, NBI (H->H) energy W_b ~ 18 – 20 keV, NBI power $P_b \geq$ 150 kW, tangency radius 0.42 m. Ohmic L-H transition was initiated before the NBI by a gas puffing pulse.

MEASUREMENTS LAYOUT

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). The experimental layout included an MDR-2 monochromator with an HS103H CCD camera [7] installed in place of the exit slit; this setup has inverse linear dispersion 1/D = 0.028 nm/pix. The observation line of sight was directed towards the beam and formed an angle of 61° with it.

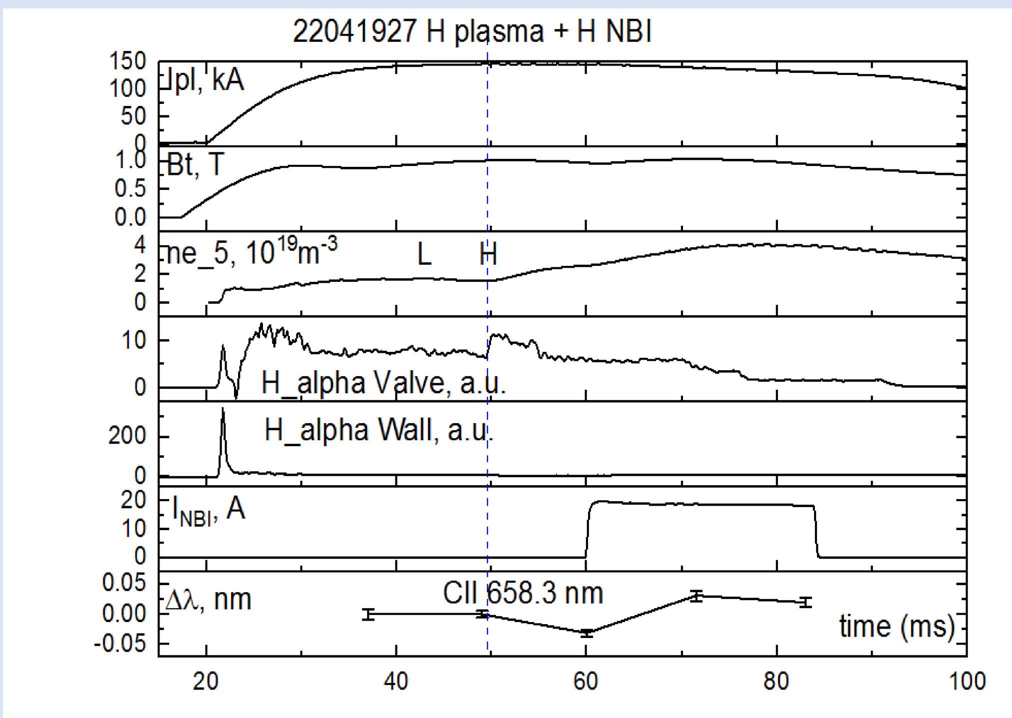

FIG.1. From top to bottom: plasma current, toroidal magnetic field, central chord-averaged density, H_α emission near the gas valve and near the wall, NBI pulse current, relative shift of CII line measured in five 11.4 ms frames (points in the center of each window are connected by a line for visibility). Points corresponding to the frames 2,3,4,5 and 6 are shown.

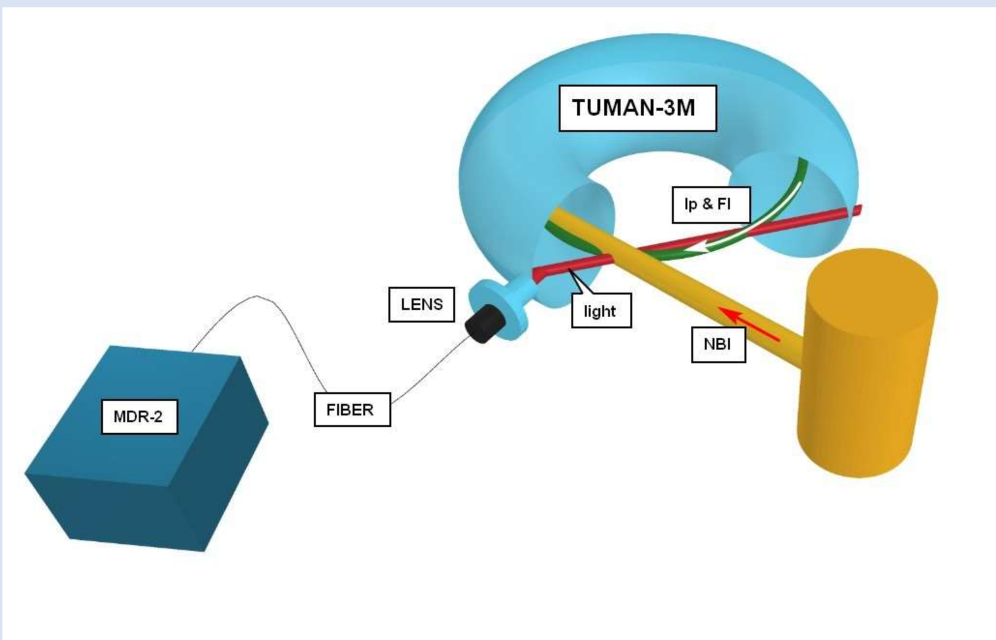

FIG.2. Experimental setup of Doppler spectroscopy on the TUMAN-3M tokamak. The direction of NBI and plasma current is indicated by red and green arrow, respectively. Dark red region shows the sample volume of plasma observed by the spectroscopy diagnostic through the lens and in-vessel mirror (not shown in the figure.

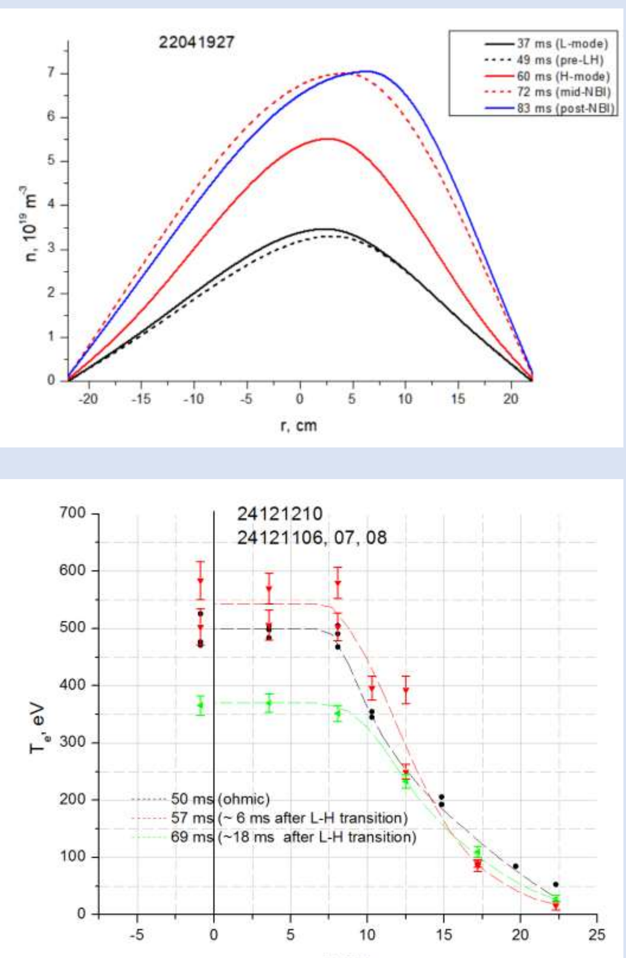

FIG.3.(a) Electron density profile evolution reconstructed from the microwave interferometry data in the shot 22041927 with ohmic L-H transition and NBI heating; (b) electron temperature profile measured by TS along vertical chord in ohmic discharges otherwise similar to 22041927

ACKNOWLEDGMENT

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OUTCOME

Comparison of the spectral shift of CII lines in the shots 22041927 with L-H transition and NBI (Fig.5.a, red line) and 22041921 with L-H transition but without NBI (Fig.5.b, red line) shows that edge toroidal rotation evolution is approximately the same in these scenarios. Toroidal rotation evolves in time from zero in ohmic L-mode to a co-current velocity of 12.8 km/s during L-H transition and then flips to the counter-current 12.8 km/s in developed H–mode. It means that the rotation here is governed by the L-H transition; the effect of injected atomic beam is negligible. A similar behavior is seen if one compares pure ohmic shot 22041921 with L-H transition (Fig.5.b, redline) and shot 22052506 without the transition but with NBI (Fig.4.b, blue line). Again, L-H transition causes strong perturbation in the toroidal rotation velocity, while the NBI does not affect the rotation.

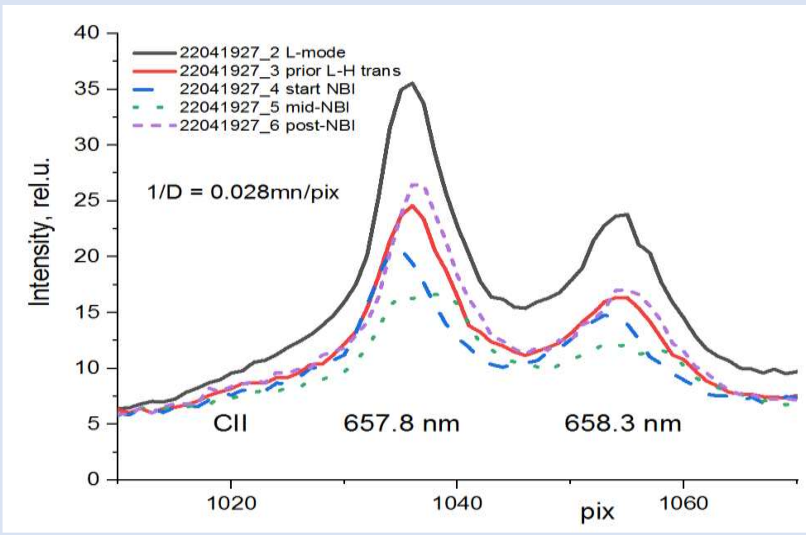


Fig.4. Spectral contours of the CII doublet (657.8nm and 658.3 nm) measured in 5 consecutive frames indicated in Fig.1. Line broadening is due to the instrumental counter (2.3 pix, 0.065 nm) and plasma Doppler broadening

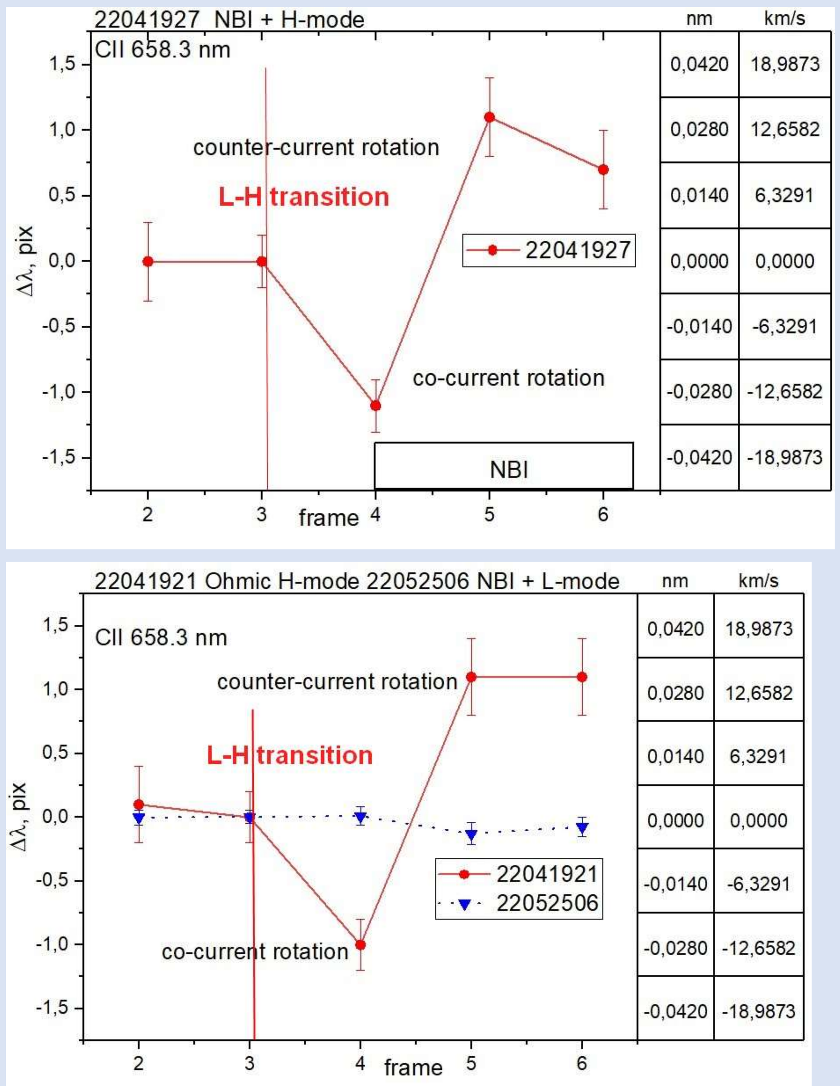
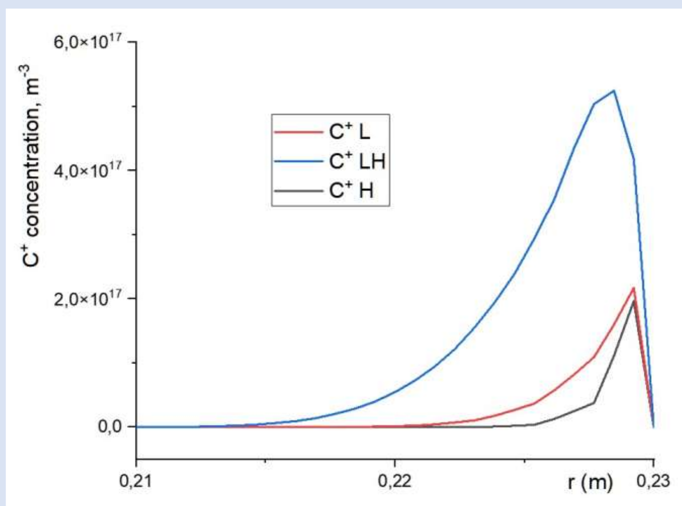


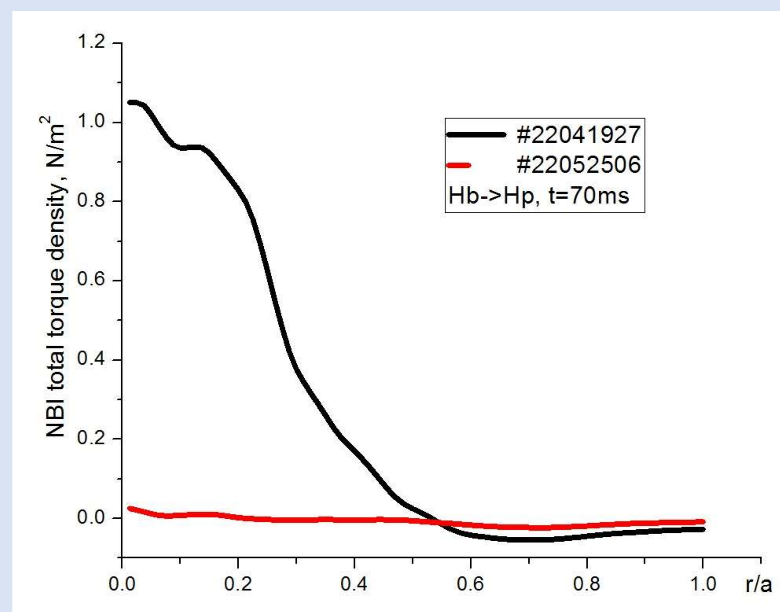
Fig.5. Temporal evolution of Doppler-shifted CII 658.3 nm line in NBI plus H-mode shot (a) and in ohmic H-mode and NBI plus L-mode shots (b). Tables to the right show spectral shift in nm and toroidal rotation velocity corresponding to the spectral shift in CCD camera pixels shown on the left vertical axis. Note that here a negative velocity means co-current direction.

- 1D modelling of the C^+ ion distribution shows localization close to the edge
- Ion source: electron impact ionization of neutral carbon deposited from the wall,
- Ion sink: ionisation from C^+ to C^{2+} and C^{3+}.
- Diffusion: 3m²/s, Convection: -10m/s, r
- Data on carbon ionization cross-sections were found in [9].
- The calculated radial profiles of C^+ ions density is presented in Fig.5.



- The radial electric field may be estimated as $E_r \sim -V_tB_p = -V_tB_ta/(Rq) = -1.56$ km/s,
- This estimation is close to the results of HIBP measurements in ohmic H-mode in the TUMAN-3M [10, 11].
- On the other hand, this estimation neglects the possible impact from the diamagnetic effect on the spectroscopic measurement of CII line shift. Indeed, as is seen, there are strong and changing gradients of C^+ ion concentration at the plasma edge.
- For accurate accounting for this effect a spatially resolved multi-point measurements are needed.

- The ASTRA+NUBEAM modeling indicates that in the shot with higher density and beam power (shot 22041927) there is some torque applied to the plasma in co-current direction and deposited in the core region.
- At the plasma periphery this torque density is small and even slightly negative due to the radial current caused by fast ion losses.
- In the shot 22052506 calculated torque is negligibly small due to the lover density and beam power.



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