

The two-frequency Doppler reflectometer application for plasma sheared rotation study in the TUMAN-3M tokamak

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Introduction

It is widely believed that sheared poloidal plasma rotations account for the reduction of tokamak turbulence and the peripheral transport barrier formation. To measure plasma rotation, microwave Doppler reflectometry is actively employed [1]. This diagnostics is usually applied using single frequency probing or, alternatively, utilizing a stepped tuning of microwave frequency. Unfortunately the both approaches do not allow following fast variations of the rotation shear during the L-H transition. To study sheared plasma rotation in the TUMAN-3M tokamak the Doppler reflectometer has been specially developed to operate simultaneously on two different microwave frequencies. It makes it possible to derive Doppler frequency shifts for two different cut-off radial positions and therefore to estimate poloidal velocity shear. In this paper the capabilities of the developed reflectometer are demonstrated with some results obtained for various operational conditions, with more attention focused on temporal behavior of the velocity difference during the ohmic H-mode transition.

Microwave hardware

The reflectometer operated in the K-band (18-26 GHz, O-mode propagation) to put the cut-off predominantly in a vicinity of the last closed flux surface (LCFS) in the TUMAN-3M tokamak. Figure 1 shows a schematic of the microwave and electrical circuit for the reflectometer. Two focusing antennae were employed for the both emitting of probing microwave beam and receiving the other frequency radiation backscattered by plasma fluctuations. Microwave scheme of the reflectometer consisted of two similar heterodyne receivers with IQ (incident and quadrature) detection. The two microwave sources are Gunn oscillators locked together with 1.82 GHz frequency difference. Each microwave source acts as the local oscillator (LO) for the other channel's receiver. So the frequency difference 1.82 GHz was an intermediate frequency for the both heterodyne receivers. The two oscillator signals are also mixed together to generate the 1.82 GHz reference signal for the IQ detectors.

The output signals of the IQ detectors ($I_{\cos}(t)$ and $I_{\sin}(t)$) have been digitized with 2 MHz data

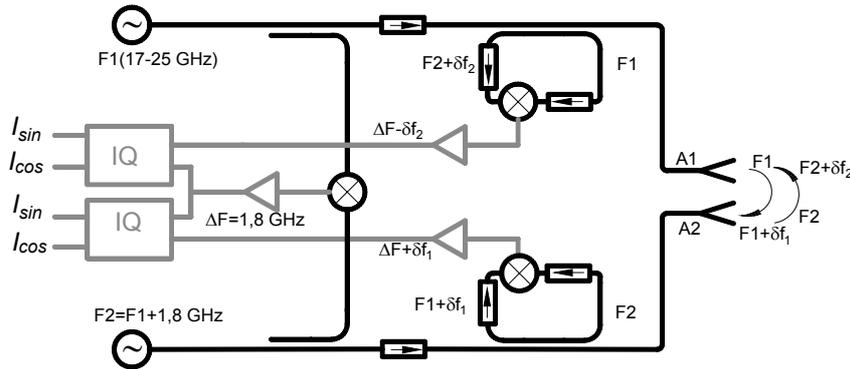


Fig. 1. Doppler reflectometer. Black lines represent waveguide, grey lines represent electronic circuitry acquisition rate and used to derive the Doppler frequency shifts.

Antenna design and experimental layout

The probing microwave signals were launched from the low magnetic field side by means of pair of antennae. They are all metal focusing hog-horn antennae. The antenna slice is schematically shown in Fig.2. The antenna aperture was 1.5 cm in toroidal direction and 8 cm in poloidal direction. To achieve better radial and wave number resolutions of the reflectometer the antennas were designed so that the wave front in antenna mouth was concave with curvature radius equal 26 cm. As shown in [2] the resolution can be substantially improved by using converging probing beams. The estimations show that the radial resolution of the method is about 1 cm that is close to the radial interval between the cut-off for the difference of the probing frequencies equals 1.8 GHz. The Doppler reflectometry layout is schematically represented in Fig.2. Minor radius of the TUMAN-3M vessel is 25 cm. A single poloidal limiter with 4cm depth was located at the low field side of the torus. A point of tilted beam refraction lays inside or outside of the LCFS depending on local plasma density and microwave frequency. The microwave scheme together with the antenna assembly was mounted at the movable structure which allowed tilting of the antennae at different angles α with respect to equatorial plane of the torus. The tilt angle was varied from 10^0 to 20^0 .

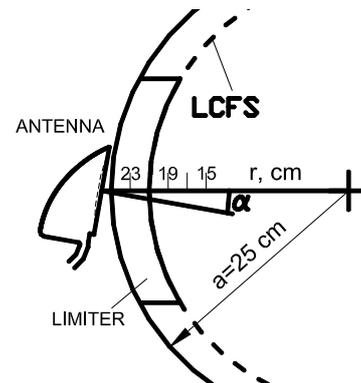


Fig.2. Minor cross-section and diagnostics layout

Preliminary experimental results

The experiments described in this paper were performed in typical TUMAN-3M ohmic H-mode shots with plasma parameters as follows: $I_p=140\text{kA}$, $B_{\text{tor}}=0.7\text{ T}$, $n_e=0.8\dots 3 \cdot 10^{19}\text{ m}^{-3}$.

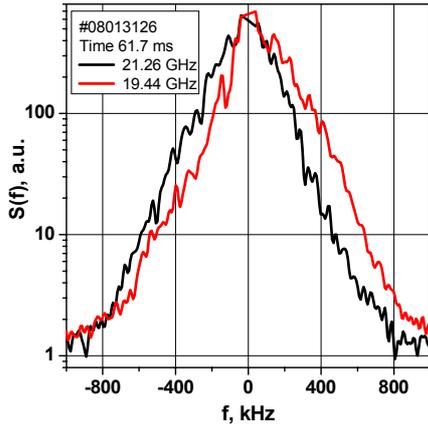


Fig.3. Scattering spectra averaged over 20 samples

The H-mode transition was characterized by increase in plasma density accompanied by D_α emission decrease.

Typical pair of scattering spectra obtained after L-H transition is shown in logarithmic scale in Fig. 3. Different shifts of the spectra are clearly seen. Using such kind of spectra, the Doppler shift Δf was defined as “centre of gravity” of the spectrum. The frequency shifts were normalized on k -value of the scattering fluctuation to obtain the poloidal velocity V_θ . Then taking the difference ΔV_θ between the two

simultaneously measured velocities divided by the cut-off separation Δr_c gives a shear of the velocity ($\Delta V_\theta / \Delta r_c$). As well known [1], the velocity V_θ is the sum of the $\mathbf{E} \times \mathbf{B}$ velocity and the phase velocity of the fluctuations. So, strictly speaking, our estimation gives the shear of this total velocity. The main uncertainty of such estimation is very low accuracy of the cut-off position evaluated from plasma density profile. The error of the n_e -profile derived from 2-mm interferometer increases substantially towards plasma periphery. So the velocity shear observed during the experiment was estimated within a factor 2. Nevertheless a moment of the shear occurrence and a rate of the shear increase were obtained reliably. Figures 4 and 5 show time dependencies of plasma parameters for two typical kinds of experiment. The first one has been carried out with relatively high microwave frequency (see Figure 4), and at relatively high target plasma density, $\sim 1.4\text{-}1.5 \cdot 10^{19} \text{ m}^{-3}$. This combination resulted in the stable cut-off location in a region when rotation in the electron diamagnetic drift direction was observed in both the L- and H-modes. It is noticeable that there is no considerable velocity shear in the both confinement modes. Contrary, in the second case of lower probing frequency (and lower target plasma density, see Figure 5) a noticeable cut-off shift towards the SOL was observed after the transition, obviously due to the

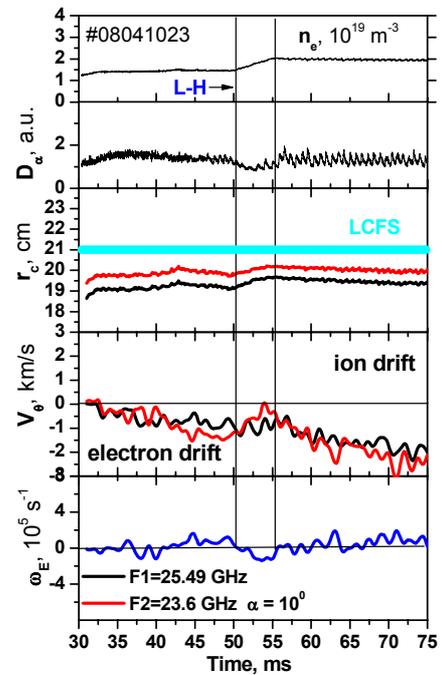


Fig. 4. Evolution of line averaged density, D_α emission, cut-off radius, poloidal velocities and shear.

steepening of density profile. It was accompanied by drastic increase of the velocity shear. Moreover, the poloidal velocity reversal from electron to ion diamagnetic drift direction was observed.

Summary

The results of first experiments could be summarized as follows.

1. Reflectometry scheme for simultaneous two frequency probing of plasma periphery was successfully utilized in the experiments with L-H transitions on the TUMAN-3M.
2. For allocated cut-off positions no detectable shear in the poloidal flow in ohmic phase of the discharge was registered.
3. Neither velocity nor velocity shear were observed to change noticeably after the H-mode transition in case of “high” probing frequency, when cut-off was located in a region when plasma flow is in the electron diamagnetic drift direction. This observation is in contradiction with known theoretical predictions [3].
4. In case of “low” frequency probing, drastic increase in the velocity shear just inside the LCFS occurred, accompanied by the plasma rotation reversal from the electron to ion diamagnetic drift direction. Possibly, this is a result of cut-off movement closer to the plasma edge, where radial electric field remains positive even after the H-mode transition, as it was found in electrostatic probe measurements performed in the TUMAN-3M earlier [4].
5. A possibility to investigate the temporal behavior of velocity shear has been demonstrated. It was found that the L-H transition was not preceded by the increase in the poloidal velocity shear.

Acknowledgements

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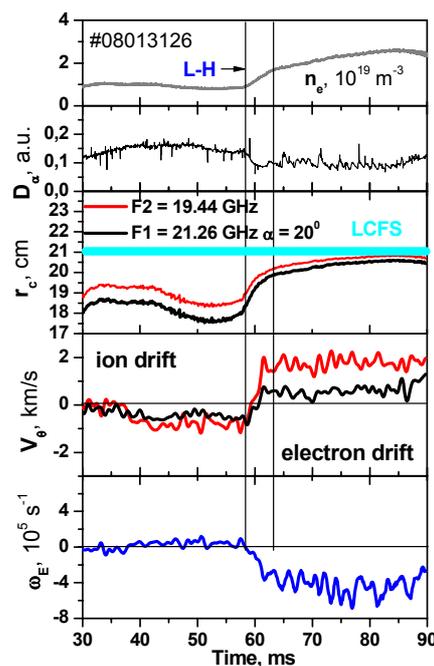


Fig. 5. The same as in Figure 4 for lower incident frequencies F1 and F2