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Using of Two Frequency Doppler Reflectometer for Study of Internal Transport Barrier in TUMAN-3M Tokamak

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Introduction

One of the main goals of experimental investigation of internal transport barrier (ITB) in tokamak remains the elucidation of the role of plasma rotation shear in the ITB formation [1]. The shear of plasma fluctuation rotation has been recently observed with use of Doppler reflectometry in the regime with improved electron energy core confinement in the initial stage of the Ohmic discharge in the TUMAN-3M tokamak [2]. The Doppler reflectometry is based on backscattering with oblique incidence of microwave beam (see for example [3]). In previous experiments [2] the diagnostics was employed at a fixed microwave frequency chosen to put the cut off in a vicinity of the ITB in the TUMAN-3M. The cut off position could vary only from a shot to shot that forced us to select identical tokamak discharges for evaluating poloidal velocity profile. To overcome this disadvantage the two frequency reflectometer was designed. Two microwave frequency operation was achieved by stepped tuning of microwave oscillator frequency. The stepped frequency sweep is already used on the Tore Supra [4] and ASDEX-Upgrade [5] tokamaks. The distinctive feature of the TUMAN-3M experiments is relatively fast formation and degradation of the transient ITB. Therefore, very short temporary steps of probing on each frequency were necessary for using. For the same reason only two frequencies were used for probing in each discharge.

Microwave hardware and diagnostics layout

The Doppler reflectometer in the TUMAN-3M ($a = 0.23$ m, $R = 0.53$ m, $B_T = 0.6$-0.9 T, $I_p = 110$-140 kA, $\langle n_e \rangle = (1.2\text{-}2.0)*10^{19}$ m^{-3}) is shown schematically in Fig. 1. Microwave units are represented by thick black lines, while electronic components are shown as lighter green lines. The diagnostics technique is based on a single-antenna scheme which is used the both to probe plasma and to receive back scattered signal and is described elsewhere [3]. The probing radiation of O-mode was launched from the low magnetic field side by the conical antenna with aperture of 4 cm and a length of 8 cm. The Q-band (37-53 GHz) BWO oscillator was used as a microwave source. For frequency band from 47 to 53 GHz the cut-off is just located in a vicinity of the ITB (r = 5 - 8 cm). The antenna could be tilted in the range $\alpha = 0^0$-10^0 with respect to LCFS. The dual homodyne detection was employed to get real ($A\cos\Phi$) and imaginary ($A\sin\Phi$) parts of the backscattering signal, that makes it possible to determine the Doppler frequency shift of the scattering spectra [3]. The detection requires $\pi/2$ phase shift between reference signals of mixers. Therefore, to satisfy the phase condition without manual readjustment the two frequency scheme design required to choose a set of frequency pairs for probing.

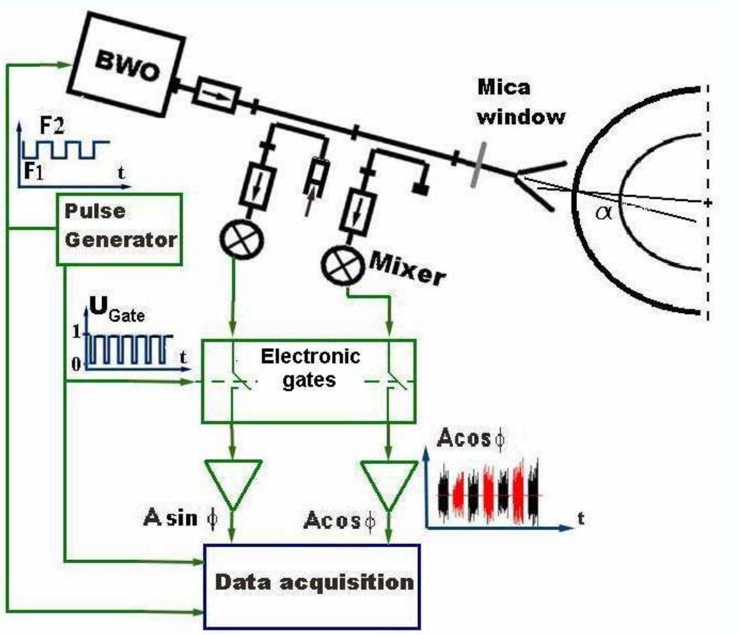

Fig. 1. Doppler reflectometer scheme

Frequency scan scheme

The frequency switching scheme is based on electronic frequency control of the BWO oscillator. The frequency of the BWO was modulated by meander like signal $U_c(t)$ to operate sequentially at two microwave frequencies. The typical frequency difference is about 1 - 2 GHz. The relevant pulse signal is shown in Fig. 2. The aim was to make the period of the meander as short as possible to be less than a time of the ITB formation and degradation. On the other hand, there were two factors restricting the period from below. The switching of the probing frequency requires a minimum settling time (≈0.3 ms) for the BWO source to re-lock. Then there is a minimum temporal step length needed to achieve a reasonable frequency resolution and to recover a reliable averaged Doppler frequency shift. This time was experimentally chosen to be more than 0.7 ms. As a result minimum period of the sweep repetition was about 2 ms. The sine and cosine signals of the mixers were transmitted into electronic gates which were used to cut parasitic oscillations appeared during the settling time. Typical pulse signal used for the gate control $U_{Gate}(t)$ is given in Fig. 2. An example of the AcosΦ signal transmitted into data acquisition system is shown here as well. The data acquisition rate was 2 MHz. Numerical data-processing allowed to select the signals for different launch frequencies and to evaluate the Doppler frequency shift.

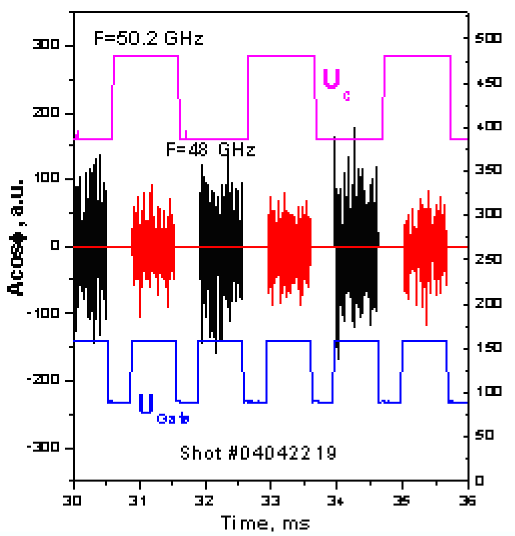

Fig. 3. An example of reflectometer signal AcosΦ, pulse signals of BWO (U_c) and electronic gate control (U_{Gate})

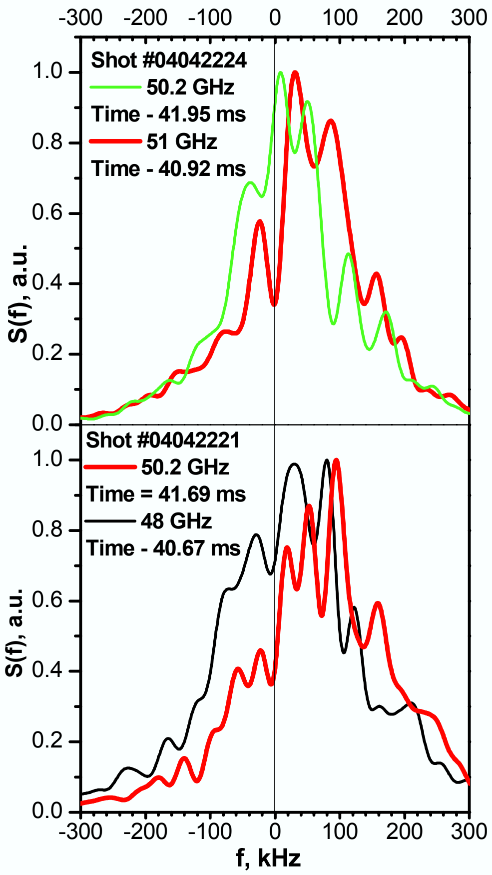

Fig. 3. Scattering spectra during the ITB phase

Experimental results

Typical pairs of the scattering spectra obtained during the ITB phase of a discharge are shown in linear scale in Fig. 3. Width of the spectra was more than 100 kHz, while the maximal frequency shift was no more than 80 KHz. Using such kind of spectra, the Doppler shift Δf was defined as "centre of gravity" of the spectrum - $\Delta f = \int f S(f)df / \int S(f)df$. The other method to evaluate the frequency shift as a derivative of the output complex signal phase: $\Delta f = (1/2\pi) d\Phi/dt$ was also used. The estimations obtained by these methods gave similar results (see. Fig.4 a, c). The frequency shifts were normalized on value $k_\theta / 2\pi = (k_0/\quad)(r_a/r_c)\sin\alpha$ to determine poloidal velocity V_θ. This k_θ-magnitude corresponds to k_θ -value on point of the refraction of the tilted microwave beam assuming axially symmetrical distribution of background electron density. Here: r_a is radial position of the antenna, r_c is a radius of refraction point, and k_0 is free space wave number of the incident beam. The evolution of the poloidal velocities is represented in Fig. 4 a,c for $\alpha = 6.8^0$. Soft X-ray emission intensity (SXR) along the central chord is shown in the figure as well (Fig. 4 b, d). The SXR signal was found to correlate with the T_e evolution in the core region [2]. The SXR increase between 34 ms and 42 ms was associated with the ITB phase of the discharge. The displacement of the radius $r_c(t)$ is also shown in the figure. The evolution of the poloidal velocities evaluated for different probing frequencies is qualitatively in line with data obtained previously [2]. (Noticeable is a 8-fold overestimation of V_θ appeared due to mistake in calculations in paper [2]) An essential increase of V_θ corresponding to 50.2 GHz in comparison with V_θ estimated at other frequencies was found during the ITB existence. The result might be interpreted as an occurrence of a layer near the ITB, where scattering fluctuations rotate faster than in neighboring plasma. The computed V_θ values approach neoclassical plasma rotation velocity. However, the neoclassical theory can not explain the observed strongly non-monotonic radial distribution of V_θ in assumption of monotone plasma density profile. The observed V_θ evolution may be an evidence of existence of the poloidal velocity shear during the ITB phase in the TUMAN-3M.

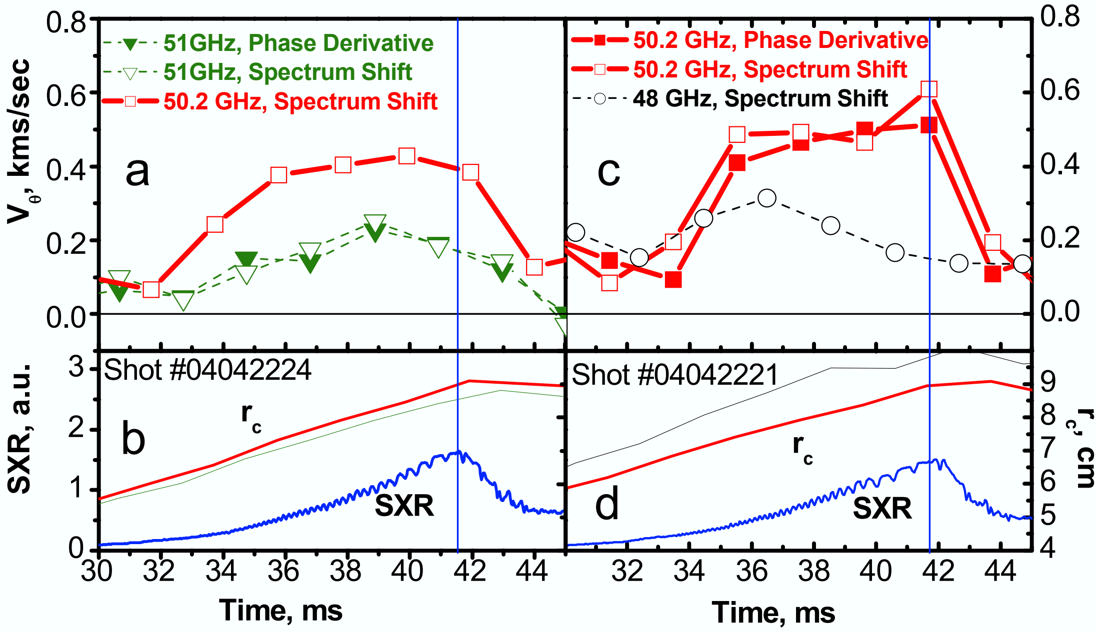

Fig. 4. Evolution of V_θ, obtained in two tokamak shots (a, c). Discrete points correspond a middle of temporal steps. SXR intensity signals and radius (r_c) of incident beam refraction (b, d)

Summary

The experiment in the TUMAN-3M demonstrates that the two frequency Doppler reflectometer is applicable for investigation of relatively fast processes in plasma. The method was successfully used for measurements of poloidal velocity in the ITB phase with typical time of about 5 - 10 ms. The scheme could be easy upgraded for multi frequency operation.

Acknowledgements

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