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Implementation of Doppler UHR backscattering technique for investigation of the poloidal plasma velocity oscillations in the FT-2 tokamak

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The Doppler frequency shift f_D of backscattered (BS) signal at oblique microwave plasma probing originated in the cutoff vicinity is often used for diagnosing of poloidal plasma velocity V_θ and corresponding radial electric field E_r in magnetic fusion devices [1, 2]. An analysis of f_D temporal dependence and corresponding frequency spectrum [3] allows investigation of the poloidal velocity oscillations associated, in particular, with geodesic acoustic mode (GAM). According to theoretical expectations this mode, localized in narrow radial zone, is a sort of poloidal zonal flow (with m = 0 and n = 0) which is induced by the nonlinear interaction of drift wave turbulent modes and in its turn could lead to the turbulence saturation and suppression of anomalous transport.

In the present paper we report observations of f_D oscillations measured by Doppler upper hybrid resonance (UHR) BS technique. This method utilizes *X*-mode microwave plasma probing out of equatorial plane of the tokamak from the low magnetic field side. It is benefiting from the effects of electric field and both poloidal and radial wave number growth in the UHR resulting in enhancement of scattering signal, millimetre spatial resolution and f_D substantial increase (in comparison with Doppler reflectometry). It was implemented recently for poloidal plasma velocity profiles measurements [4] demonstrating fine spatial and temporal resolution and reasonable accuracy.

The measurements were carried out at FT-2 tokamak (R = 55 cm; a = 7.9 cm) in fast (20 MA/s) current ramp up (CRU from 22 kA to 32 kA) experiment (Fig. 1a) with $n_e(0) < 2.6\times10^{19}$ m^{-3}, $T_e(0) < 510$ eV, $T_i(0) < 140$ eV, $B_t < 2.2$ T. Investigation of electron and ion temperature, electron density profiles and radiation losses evolution together with ASTRA code modelling allows to compare the radial UHR positions for different probing frequencies f_i with the safety factor profiles $q(r)$ (Fig. 1b).

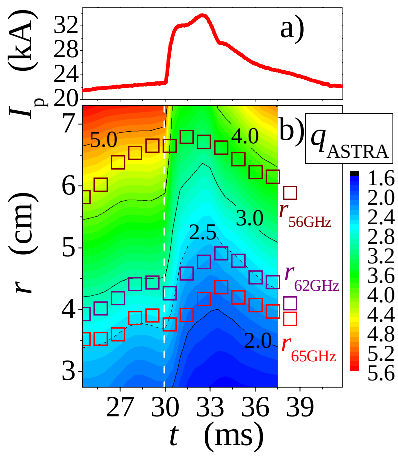

Fig. 1. Plasma current, UHR radial positions for f_i = 56, 62, 65 GHz (squares) and the safety factor profiles obtained with ASTRA code modelling.

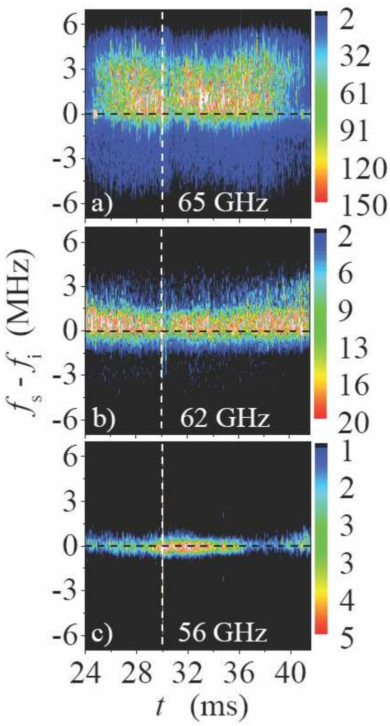

Fig. 2. ES Doppler shifted spectra for f_i = 65 (a) , 62 (b), 56 GHz (c).

The averaged ES spectra P_{ES} measured by quadrature technique [5] for different probing frequencies at vertical antennae shift +15 mm are shown on Fig. 2. The spectral width and Doppler frequency shift decrease in the direction of plasma edge. The mean f_D values estimated from momentary spectra as a first moment $f_D(t) = \int f\,|P_{ES}(f)|df \big/ \int |P_{ES}(f)|df$ with time interval between neighboring points 2.56 mks are presented on Fig. 3a. The signal registered by one of Mirnov's coils is plotted on Fig. 3b. The MHD signal's bursts to the values out of the ADC range at 31.1 ms > t > 30 ms and 34 ms > t > 32.5 ms were caused by influence of the control magnetic fields, which has made impossible adequate calculation of spectra in the given ranges.

Examples of averaged frequency spectra calculated from $f_D(t)$ and MHD signals for f_i = 65 GHz at t = 25.7 ms and 29.1 ms are shown on Fig. 4a,b. The yellow vertical line indicates the value of GAM frequency [6] $f_{GAM} \sim V_{Ti}\,(7/4+T_e/T_i)^{1/2}/(2\pi R)$ estimated from local values of electron and ion temperature and electron density at corresponding radial UHR positions. At least two intense spectral lines are clearly seen in the f_D spectrum (Fig. 4a, curve 1) at frequency f = 49 kHz and f = 66 kHz. The first one coincide with spectral line registered by Mirnov coil (curve 2), nevertheless the second clear line in f_D spectrum is not correlated to the MHD signal and it's frequency is close to the theoretical GAM frequency. Shifting the UHR resonance to plasma periphery by 3-4 mm we have found that this line (with f close to GAM frequency) disappears, whereas f_D and MHD spectra become very similar (Fig. 4c). Pronounced lines in f_D spectrum vanish at displacement of the scattering point to the plasma edge at f_i = 56 GHz (Fig. 4d).

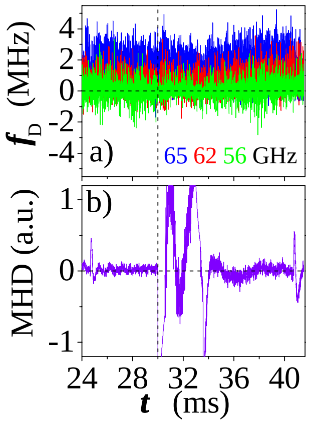

Fig. 3. (a) f_D evolution for different f_i; (b) MHD signal.

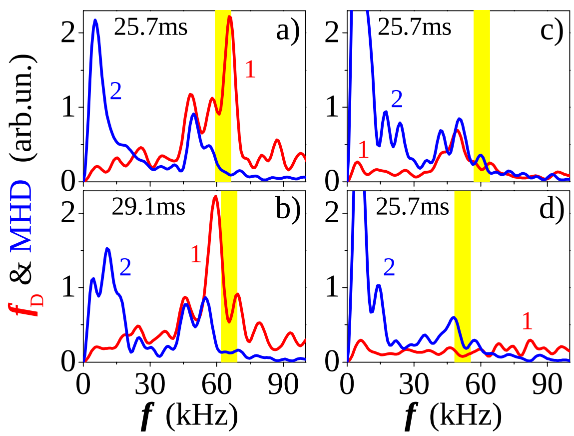

Fig. 4. f_D (1) and MHD (2) spectra for f_i = 65 GHz (a, b), 62 GHz (c), 56 GHz (d).

The discussed spectra have been calculated for

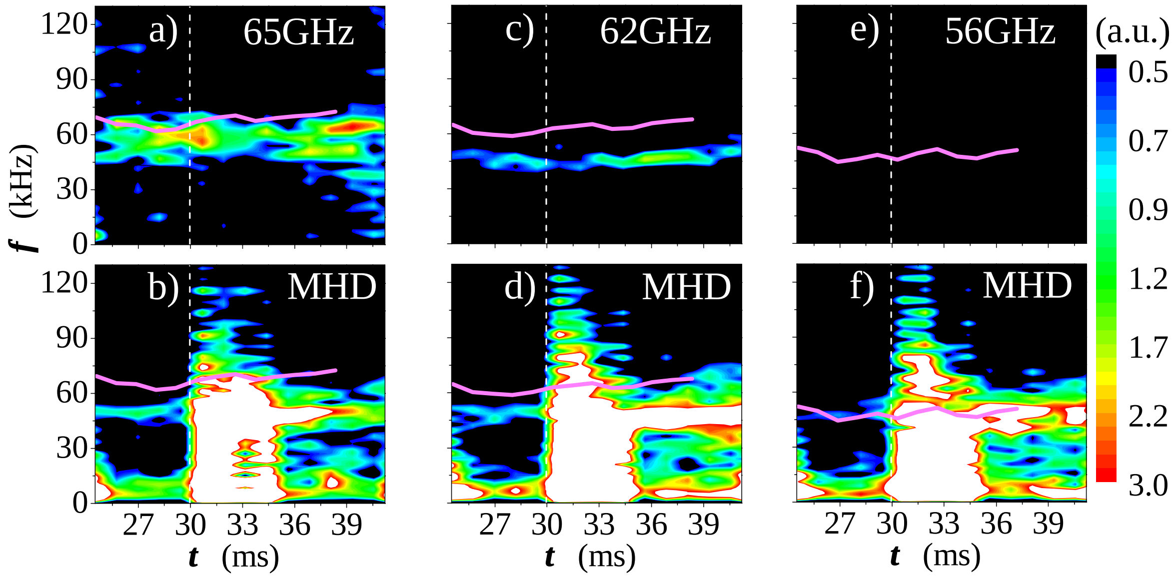

Fig. 5. f_D ***(a, c, e) and MHD (b, d, f) spectra for*** f_i ***= 65, 62, 56 GHz.***

various discharge times and radial UHR positions at different tokamak shots when the probing frequency f_i was changed from shot to shot. The f_D spectrum for $f_i = 65$ GHz and corresponding MHD spectrum are presented in Fig. 5a,b. Both spectra are plotted in logarithmic scale and magenta curve corresponds to the GAM frequency estimated theoretically. In this case the electron temperature in the point of UHR BS was high enough, that it was possible to separate a frequency line corresponding to MHD signal from a region where the GAM frequency was predicted theoretically. The clear line in f_D spectrum not correlated to the MHD signal and close to the theoretical GAM frequency could be easily observed in this case. The f_D spectrum for $f_i = 62$ GHz coincides with MHD spectrum (see Fig. 5c,d) and has a frequency less than GAM frequency. At the plasma edge for $f_i = 56$ GHz no lines were observed in the f_D spectrum (see Fig. 5e).

Special efforts have been made for spatial localisation of pronounced spectral structures observed in the f_D spectrum (Fig. 5a). We applied the correlation ES diagnostics [7]. Two signals at close probing frequencies with difference $|f_2 - f_1| = \{20, 40,..360\}$ MHz, corresponding to two slightly separated UHR layers in plasma, where the ES by fluctuations occurs, were measured simultaneously by two homodyne channels. Because of considerable Doppler frequency shift of the quadrature spectrum (Fig. 2a) this shift is also seen in the homodyne spectrum. Calculating the $f_D(t)$ in the same manner as it was done for quadrature spectrum we obtained two signals $f_{D1}(t)$ and $f_{D2}(t)$ corresponding to two UHR positions. These physical values $f_{D1/2}(t)$ obtained from homodyne spectra are not directly the Doppler frequency shifts, they also possess information about fluctuations of the spectral width. However in case of occurrence of coherent object influencing both signals it is quite natural to

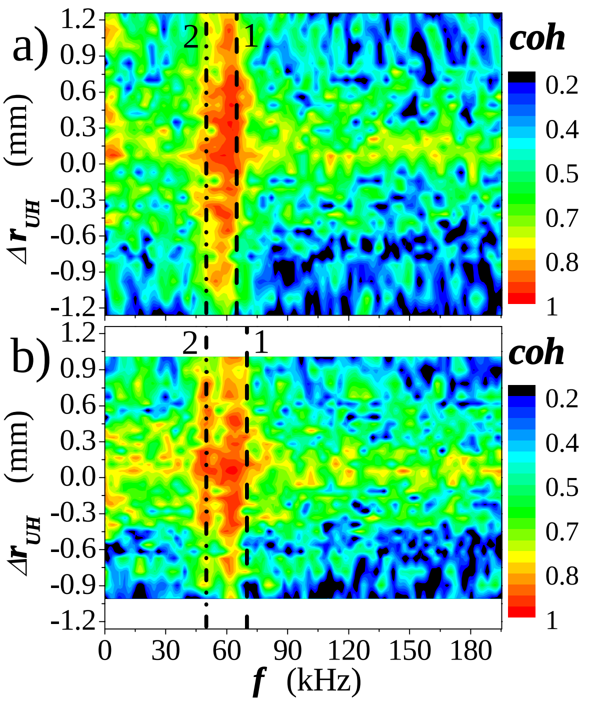

Fig. 6. Coherence spectra for f_i = 65 GHz.

expect the high level of correlation between $\boldsymbol{f}_{D1}(\boldsymbol{t})$ and $\boldsymbol{f}_{D2}(\boldsymbol{t})$ signals with corresponding frequencies. The coherence frequency spectrum of the above signals is shown in Fig. 6a for $\boldsymbol{t}$ ~ 26 ms and in Fig. 6b for $\boldsymbol{t}$ ~ 38 ms, where the level of coherence ***coh*** = 0.22 corresponds to the loss of correlation. The dashed vertical line 1 corresponds to the GAM frequency estimated for each case. The dashed double doted line 2 corresponds to the MHD frequency taken from Fig. 5b. Both signals (close to MHD and close to GAM) are clearly seen in the spectra but the radial coherence of the signal connected with MHD disappears on a shorter scale.

Conclusions.

Implementation of the new technique for study of plasma velocity oscillations have resulted in several promising findings. Several lines are clearly seen in the Doppler frequency spectrum. In spite of the fact some of the lines coincide with those registered by Mirnov's coils, nevertheless the clear line in $\boldsymbol{f}_D$ spectrum not correlated to the MHD signal and close to the theoretical GAM frequency was observed at mid radii. At the plasma edge $\boldsymbol{f}_D$ and MHD spectra were very similar, probably because of coincidence of the UHR and magnetic island. The radial correlation measurements of the Doppler frequency shift spectral components corresponding presumably to GAMs have demonstrated high level of coherence at spatial separation of couple of millimetres unlike the MHD lines in the spectrum, which have a shorter correlation.

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