IMPLEMENTATION OF CORRELATIVE ENHANCED SCATTERING DIAGNOSTICS OF SMALL SCALE PLASMA TURBULENCE AT THE FT-2 TOKAMAK

V.N. Budnikov, A.D. Gurchenko, E.Z. Gusakov, L.A. Esipov, M.Yu. Kantor, D.V. Kouprienko, S.I. Lashkul, K.M. Novik, V.L. Selenin, A.Yu. Stepanov, E.O. Vekshina*

Ioffe Institute, Politekhnicheskaya 26, 194021 St.Petersburg, Russia
****SPSTU, Politekhnicheskaya 29, 195251 St.Petersburg, Russia***

PACS: 52.70.-m; 52.55.Fa

I. INTRODUCTION

Enhanced Scattering (ES) diagnostics of small-scale plasma fluctuations is based on the effect of scattering cross section enhancement in the Upper Hybrid Resonance (UHR). High sensitivity and localization of measurements are among its merits [1]. The correlative modification of this technique was proposed to improve the diagnostics wave number resolution [2]. This approach to ES diagnostics is based on the dependence of ES signal on the fluctuation phase in the UHR. The probing is performed there by two waves. The frequency of the first is constant, where as the frequency of the second is varied, providing the spatial scan of the UHR point. The correlative analysis of two ES signals could be used for reconstruction of the density turbulence frequency and wave number spectra as it was proved in several experiments at linear devices [3]. The CES measurement scheme was first tested at FT-1 tokamak for investigation of tokamak turbulence [4].

In this paper the first results of implementation of CES diagnostics at the FT-2 tokamak possessing much more developed set of standard tokamak diagnostics are presented.

II. EXPERIMENTAL SITUATION

The CES scheme is assembled at the FT-2 tokamak possessing major radius R = 55 cm, minor radius a = 8 cm. The experiment was performed in ohmic discharges at magnetic field B_t =2.2 T, plasma current I_p=20 kA, central plasma density $n_e(0)$ =3 10^{13} cm^{-3} and central electron temperature $T_e(0)$=400 eV.

The micro-scale turbulence probing is performed by extraordinary waves in the 60 GHz frequency range at power of 10 – 20 mW, launched from high magnetic field side of the torus. The backscattered signal was received by a nearby standing horn antenna. The antennae diagram is down tilted by ~8°, whereas its angular width is $\delta\theta = \pm 10°$. The measurements are taken in the ohmic phase of the discharge. The UHR position is scanned from the bulk plasma region to the edge 4cm<r_{UH}<7.5cm by variation of the probing frequency in the range 70 GHz >f_i >54GHz. The scheme of ES correlation measurements utilising calibration at intermediate frequency was described in [3,4] The evolution of CES frequency spectra in these regions is studied for different spatial scales of turbulence, contributing to the scattering signal.

III. EXPERIMENTAL RESULTS

The ES spectra measurements carried out both by superheterodine and quadrature scheme techniques have shown their high sensitivity to vertical shift of discharge

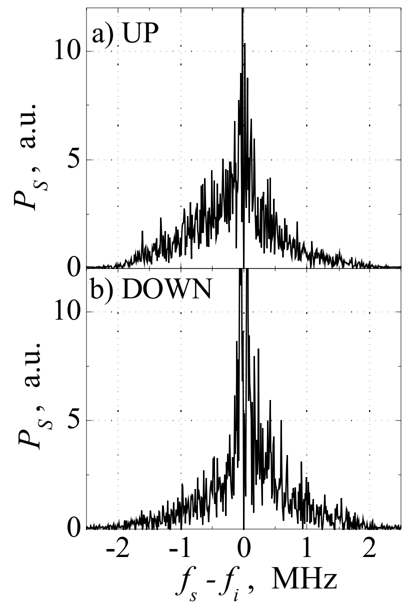

Fig.1. ES spectra at 60.6 GHz.

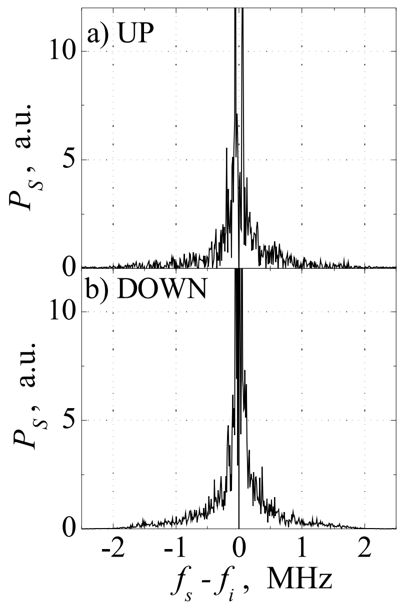

Fig. 2. ES spectra at 70 GHz.

equilibrium as well as to the probing frequency and correspondingly the back scattering point radius. The ES spectra at frequency 60.6 GHz, corresponding to 5.5 cm are shown in Fig. 1 for plasma correspondingly up (a) and downshifted (b) by 0.8 cm. As it is seen the spectra are asymmetric, especially for the case of up-shift, where it is up-shifted in frequency. In the case of downshifted discharge the spectrum is downshifted in frequency. The scattering spectra width in both cases is estimated as ±500 kHz. For higher probing frequency 70 GHz as well as for lower one 55 GHz the spectral width and its shift decreases drastically (see Fig.2 a,b). The frequency shift of the ES signal manifests itself in the phase runaway effect, which is measured with the quadrature scheme and shown in Fig.3 for both signs of discharge shift and UHR positions r_{UH}=6 cm and r_{UH}=4 cm. The time derivative of the signal phase corresponding to the mean frequency shift of ES signal is shown in Fig.4 as a function of UHR radii for both up-shifted (black sign) and down-shifted (white sign) plasma position. As it is seen in Fig.4 dependencies of frequency shift on UHR position are similar, however for down-shift of discharge the absolute value of frequency shift is smaller and the sign is opposite.

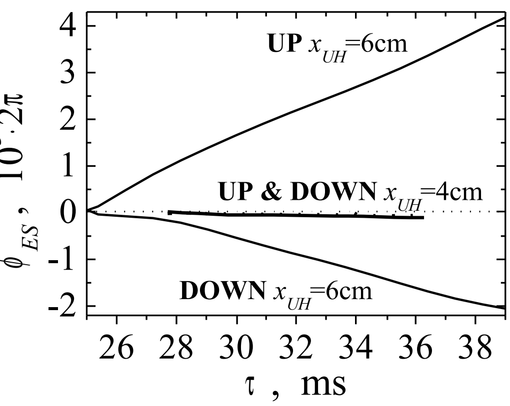

Fig. 3. ES phase runaway effect.

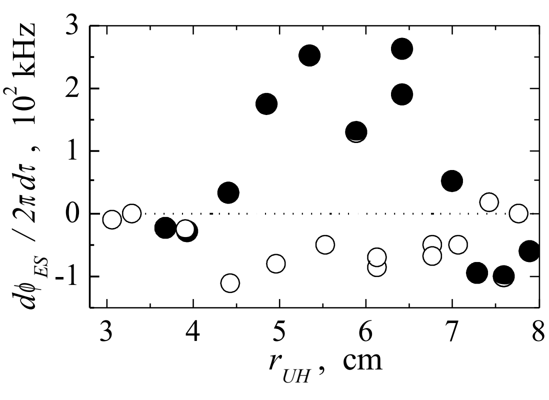

Fig. 4. The phase time derivative.

The correlative ES measurements were performed for the reference frequency 61.6 GHz, corresponding to the UHR radius 5.3 cm. The real and imaginary part of the cross correlation function of two ES signals are shown versus the frequency difference of two probing frequencies for scattering frequency $f_s=f_i$+0.2 MHz and $f_s=f_i$+1.75 MHz in Fig.5 a,b by correspondingly red and black curves. As it is seen well pronounced oscillations are observable for all these curves. The period of these oscillations is related to the wavelength of fluctuations dominating in the ES spectrum by simple formula [3] $\Delta x=\Delta f\partial x/\partial f$. For the lower frequency the real component is higher than the imaginary one, whereas for f_s-f_i=1.75 MHz their amplitudes are comparable and the phase of oscillations is shifted by 90°. The Fourier transform of experimental dependencies shown in Fig.5 according to [3] results in spectrum of density fluctuations causing ES multiplied by the ES efficiency [1]. The relevant data is represented in Fig.6 a,b. Red curves there give the real part of the spectra, whereas black curves give the imaginary part, which determines the method accuracy. The wave number spectra shown in Fig.6 possess maximum at q=180 cm^{-1} independently of the fluctuation frequency. This value is surprisingly close to the position of ES cross-section maximum calculated for the discharge parameters.

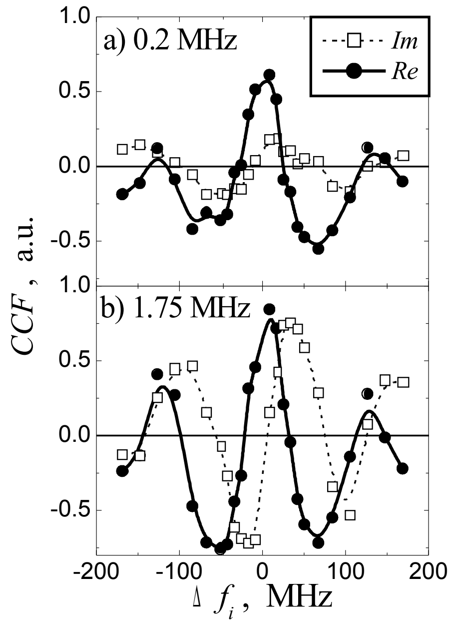

Fig. 5. Cross correlation function.

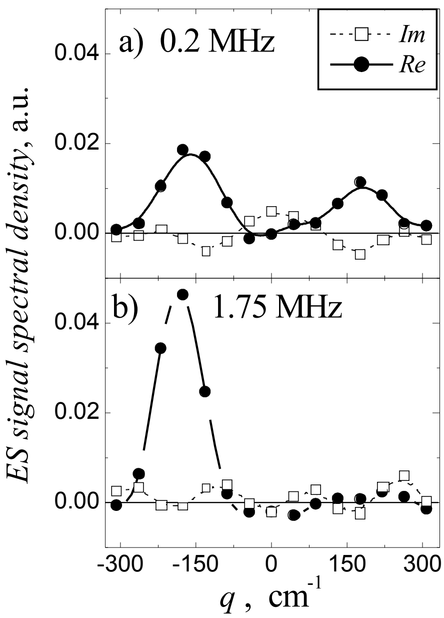

Fig. 6. Fourier transform of CCF.

IV. DISCUSSION

The high sensitivity of the scattering spectra, its width, mean frequency and sign of the phase runaway effect to the vertical shift of plasma give a clear indication of its relation to poloidal rotation of fluctuations. A simple model describing the ES spectrum formation due to this effect represents the frequency shift of ES signal in terms of Doppler shift produced by different components of the antenna diagram, when scatter off the rotating fluctuations [5]. In this model the frequency shift and width of the ES spectrum is proportional to the mean poloidal wave number of the diagram and its width in the UHR. However these characteristics of the probing beam in the UHR are different from those at the antenna. According to [5] they are mainly determined by projection of large wave number of incident wave, perpendicular to the UHR surface, onto the poloidal direction. This projection is finite, because in tokamak the UHR surface does not coincide with the magnetic surface. A model under discussion explains also a smaller value of frequency shift at down shift of plasma just by tilting of antenna diagram. Estimation of the fluctuation rotation velocity from values of phase runaway frequency and from ES spectra width, performed in accordance with procedure of [5] results in value 1.5 10^5 cm/s at r_{UH}=5.5 cm. The direction of rotation there is opposite to electron diamagnetic drift velocity. It is worth to say that according to our measurements the rotation direction change sign at the plasma periphery and in the maximal gradient region.

V. CONCLUSIONS

The correlation ES technique was successfully implemented at the FT-2 tokamak. The main input to the ES signal is shown to be produced by fluctuation scales at the ES cross-section maximum. The dominant influence of the fluctuation poloidal rotation onto the ES spectra formation is shown. The rotation velocity spatial distribution is measured and its value is estimated. The ES technique provides a promising tool for estimation of plasma rotation, however further experimental comparison of its data to the independent results of plasma rotation measurements is desirable.

Supports of RFBR grants 02-02-06525, 01-02-17926; 00-15-96762, RFBR-NWO grant 047.009.009, INTAS grants 01-2056, 2002-104 is acknowledged.

REFERENCES:

1. Novik K.M. and Piliya A.D., Plasma Phys. Control. Fusion **35**, 357 (1994).
2. Arkhipenko V.I., Budnikov V.N., Gusakov E.Z. et al., Tech. Phys. Lett. **19**, 20 (1993).
3. Gusakov E.Z., Kaganskaya N.M. et al. Plasma Phys. Contr. Fusion **42,** 1033 (2000).
4. Gurchenko A.D., Larionov M.M. et al., 27 EPS Conf on CFPP **24B**, 416 (2000).
5. D.G. Bulyiginskiy, A.D. Gurchenko, E.Z. Gusakov et al., Phys. Plasmas **8**, 2224 (2001)