

INVESTIGATION OF PLASMA WITH CORRELATION REFLECTOMETRY FROM HIGH FIELD SIDE IN T-10 TOKAMAK

D.A. Shelukhin, V.A. Vershkov, A.N. Obysov, A.O. Urazbaev

NFI RRC "Kurchatov Institute", Moscow, RF, shelukhin@nfi.kiae.ru

Correlation reflectometry (CR) is widely used now to analyze small-scale plasma density fluctuations in closed magnetic systems. Reflectometry measurements from High Magnetic Field Side (HMFS) could be very useful for the further experimental investigation of plasma turbulence. Another important topic is the development of reflectometry system at HMFS for plasma profile measurements at low cut-off of extraordinary wave as it was proposed for ITER [1]. This paper deals with measurements that were made from HMFS using new antenna array installed in T-10 tokamak recently.

HMFS antenna system consists of three antenna horns with mouth size 25×27.5 mm, placed side-by-side in poloidal direction (Fig. 1). The normal to central horn mouth lies in tokamak equatorial plane. Strong size restrictions force to make complicated horn-mirrors system so numerical simulation with 2D full wave electromagnetic code TAMIC R τ Analyzer

[2] was used to optimize the antenna radiative pattern. The results of 2D calculations then were justified using 3D full wave code. Radiative patterns were calculated for both X- and O-mode polarizations (Fig. 2). The modeling shows that antenna forms rather narrow microwave beam that is propagating perpendicular to the antenna mouth (Fig. 3). The mock-up measurements at frequency 30 GHz shows that beam widths was about 30 degrees that is in good correlation with calculations results. Side lobe magnitude is rather small and cannot interfere with measurement results.

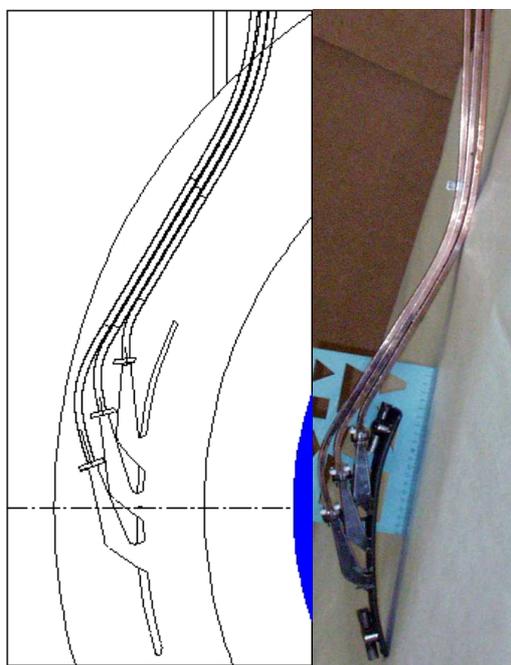


Fig. 1. Left: CAD drawing of antenna array and waveguides for HMFS measurements in T-10. Right: Antenna system with waveguides before installation.

The variations of the electric field vector of the reflected wave have been analysed in the frequency range 0–400 kHz by means of simultaneous recording of several channels using ADCs with a sampling rate of 0.8 MHz. The

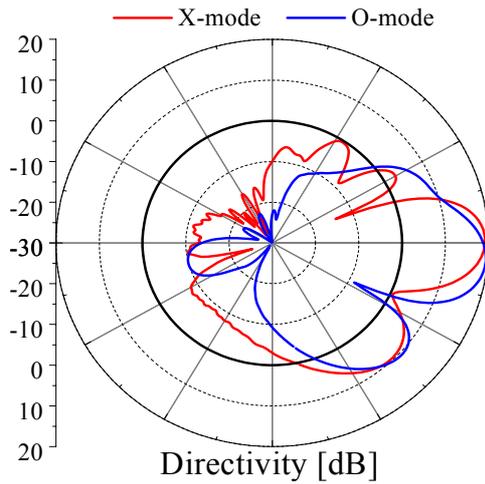


Fig.2. HMFS antenna directivity in poloidal direction based on 3D full wave simulation. Zero angle correspond to normal to antenna mouth. Probing frequency was $F=35$ GHz.

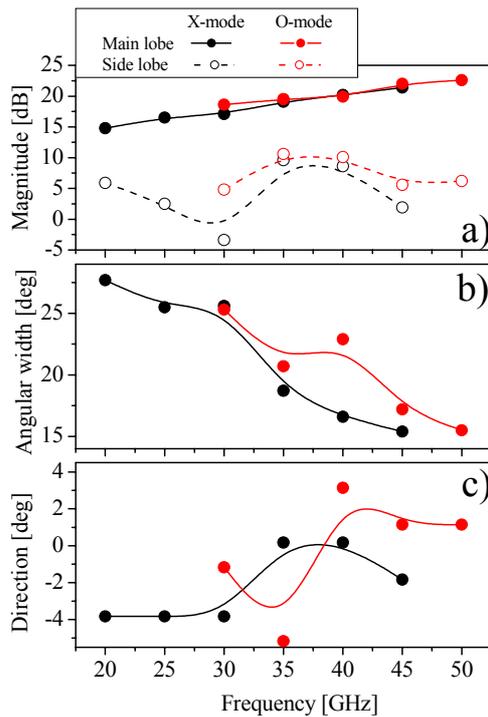


Fig.3. Dependence of antenna parameters from reflectometer frequency (3D full wave simulations). a) Magnitude of main lobe (solid circles) and side lobe (open circles); b) beam width; c) – direction of main beam.

amplitude (A) and the phase (φ) fluctuations of the reflected electric field vector were decomposed using a quadrature detector in imaginary ($U1 = A\sin(\varphi)$) and real ($U2 = A\cos(\varphi)$) parts. All signals were processed in the complex form. Routine T-10 Correlation Reflectometry system [3] was used to compare turbulence characteristics from Low Magnetic Field Side (LMFS) with those for HMFS.

First experiments show that the turbulence level at HMFS is small in plasma core region. The results of correlation analysis of reflectometer signals reflected from HMFS in Ohmic discharge shown in Fig. 4. As one can see turbulence specter contains the same components as at the LMFS. Broad Band (BB) and Low Frequency (LF) fluctuations dominate in spectra while Quasi Coherent (QC) oscillations is smaller that at the LMFS in accordance with 3D gyrokinetic simulation results [4]. The fluctuations in frequency range 15-30 kHz that is often interpreted as Geodesic Acoustic Modes was not observed in equatorial plane at HMFS yet. This fact could be considered as additional conformation of the hypothesis that this oscillation is GAM or could be explained by data base insufficiency. Poloidal coherency of fluctuations is high enough to provide the velocity measurements.

Radial profile of the relative amplitude of density fluctuations was measured in series of reproducible discharges with $I_p = 220$ kA, $B_T = 2.4$ T, $\langle n_e \rangle = 2.75 \times 10^{19} \text{ m}^{-3}$, by varying reflectometer frequency (Fig. 5). Total power of

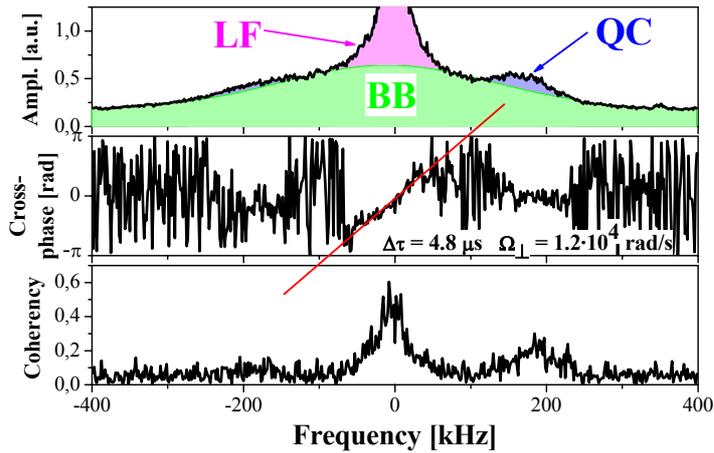


Fig. 4. Fourier spectra of CR signals from HMFS. Signal (a), poloidal cross-phase (b) and poloidal coherency (c) Fourier spectra amplitude are shown. The slope on the cross-phase specter corresponds to the turbulence rotation.

central heating at second harmonic of electron cyclotron resonance (ECRH) was about 1 MW. Algorithm proposed in [5] was used to reconstruct the amplitude of local density fluctuations from reflectometer data. One can see that density fluctuation profile at HMFS shows the same properties as at LMFS: fluctuations amplitude is constant in plasma core and significantly increase at plasma periphery. However, the amplitude of fluctuations has strong poloidal asymmetry. In Ohmic discharges density fluctuations amplitude in gradient region was 0.25 % at HMFS in comparison with 0.5 % at LMFS at the top. This asymmetry even increased during ECRH because the turbulence level increased at LMFS up to 1 % and remains the same at HMFS. Such behavior justifies the 3D gyrokinetic simulation results and theoretical opinion that main origin of instability in tokamak is unfavorable curvature of magnetic field at the external side of plasma column.

Although fluctuations amplitude not changed at HMFS, certain variations observed in signal spectra (Fig. 6). All spectra were normalized in the way, based on [5], to represent the spectra of local density fluctuations. As one can see that in Ohmic phase of discharge the specter at HMFS has a QC component at frequencies about 150 kHz. QC oscillations completely disappear during ECRH at HMFS while at LMFS one can see strong QC modes.

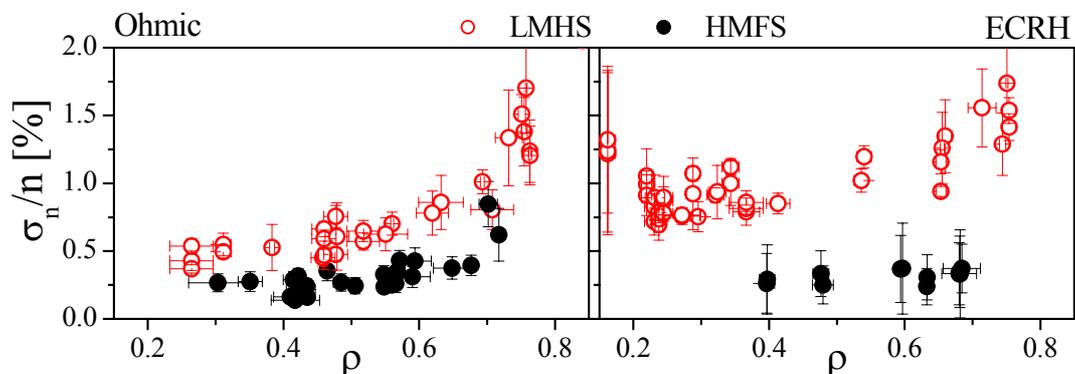


Fig. 5. Radial profiles of density fluctuations amplitude at LMFS (red) and HMFS (black). Left plot corresponds to Ohmic discharge, right one – to ECRH discharge.

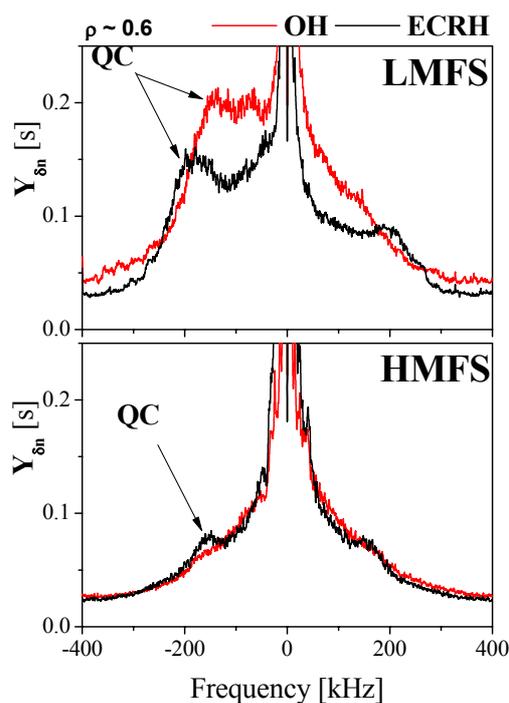


Fig. 6. Comparison of density fluctuation Fourier spectra from LMFS (top) and HMFS (bottom) in Ohmic and ECRH discharges.

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This fact could be explained in following way: density fluctuations arise due to excitation of instabilities at LMFS. Further evolution of the system leads to formation of radially elongated structures (“fingers”) that was achieved both in theory [6] and in 3D simulations [4]. Then density perturbations extend along the magnetic field line and reach HMFS. Amplitude and contrast of QC oscillations decrease during ECRH and it leads to disappearing of QC at HMFS. This hypothesis is rather rough and further investigation is required both from experiment and from theory to reveal this question.

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