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Use of reflectometry diagnostics with tilted antenna beam for comparative studies of H-modes in TUMAN-3M tokamak

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Introduction

The reflectometry remains one of the basic methods for study the peripheral turbulence behavior during the transition to the H-mode. Such study has been previously performed in the Tuman-3 tokamak under the transition to the Ohmic H-mode triggered mainly by the traditional for this machine method of the pulsed gas puffing [1]. During the recent years several other ways of the H-mode initiation have been discovered in the Tuman-3M. Gas puffing, ICRH pulse, current ramp up or fast magnetic compression have been used to switch on the transition. As the turbulent suppression is one of the key processes in a sequence of the events leading to H-mode it will be interesting to study plasma fluctuation during these four different H-modes. In this report the turbulence behavior is compared with use of microwave reflectometry diagnostics to reveal the common and specific features of fluctuations accompanying various types of H-modes.

Reflectometry diagnostics

The Tuman-3M microwave backscattering diagnostics based on the single antenna reflectometer scheme has been described in detail elsewhere [1]. The reflectometer operates in the K-band (F=17-25 GHz) that corresponds to the cutoff layer peripheral location in a vicinity of the H-mode transport barrier. The conical antenna is used to transmit microwaves from low magnetic field side. The instrument has been specially designed to tilt the antenna at different angles ψ with respect to cutoff surfaces. However on the present stage of investigations the main results have been obtained under the normal incidence of microwave probing beam. The quadrature detection in microwave region was employed to obtain the complex output signal and the backscattering spectra for the both upper and lower side bands. The spectra have been computed in frequency band ± 2 MHz.

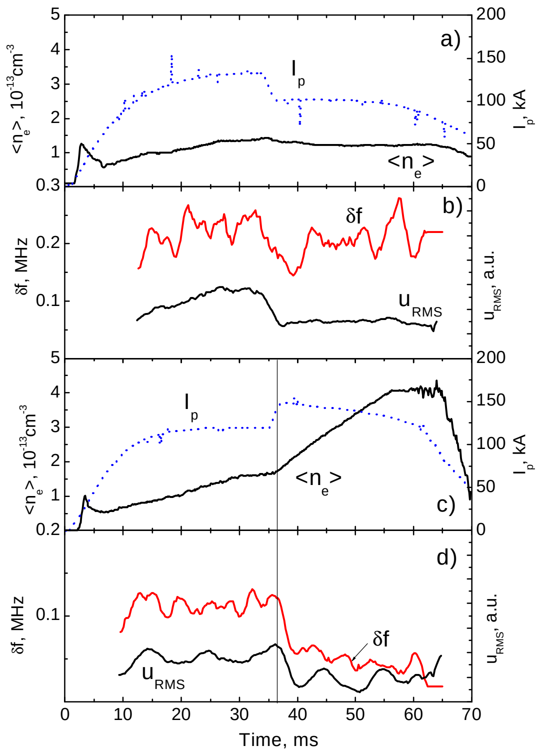

Fig.1 Comparison of waveforms for the current ramp down b) and up d) experiments. Vertical line marks the moment of the transitions. a), c) – plasma current and density for CRD and CRU respectively. O –mode, b) -F=18GHz, d) - F=22GHz

Experimental results

The microwave backscattering experiments were performed in the Tuman-3M tokamak (a_l=0.22m, R_0=0.53 m) under the following discharge conditions: B_t=0.6÷1.0 T,

I_p=120÷150 kA, $<n_e>$=(1.0÷4.0)·10^{19} m^{-3}, $T_e(0)$=0.4÷0.5 keV, $T_i(0)$=0.15÷0.2 keV.

The substantial drop in the amplitude of the high frequency (0.3÷1 MHz) reflectometry output signal was observed during the L-H transition for all types of H-mode switching on. In many reflectometry experiments such a reduction was interpreted, as plasma fluctuation suppression. However, the experiments in the Tuman-3M tokamak have shown that the amplitude of reflectometry signal does not always correctly reflect actual change of the density fluctuations level. Therefore such indication, as reduction of a signal, not always can be used as an evidence of the H-mode transition. For an example in Fig.1 the temporal dependencies of RMS output signal are compared for plasma current ramp up and down experiments. The current rump up (CRU) is followed by the H-L transition as it is evidently seen from the averaged density and D_α-emission waveforms. On the contrary the current ramp down (CRD) does not lead to the transition. This is due to the CRD method activates positive radial electric field non-favourable for the transition [1]. Nevertheless in both cases the slope down of a signal was observed in the frequency band 0.6÷1 MHz. However the nature of the reflectometry signal reduction may be quiet different. In the first case it can be connected with the cutoff layer removing from the antenna. In the second one it could reflect the actual fluctuations suppression. In Fig.1 another performance of reflectometry signal such as width of spectrum δf is presented. One can see from Fig.1 that in a case of CRD the spectrum width remains constant and drastically decreases under the current ramp up. The spectral narrowing observed under CRU triggering is according to the expected suppression of transport processes during the L-H transition. These phenomenological facts force to exploit a spectrum width, as the main representative parameter, to compare turbulence behavior at various H-mode initiations.

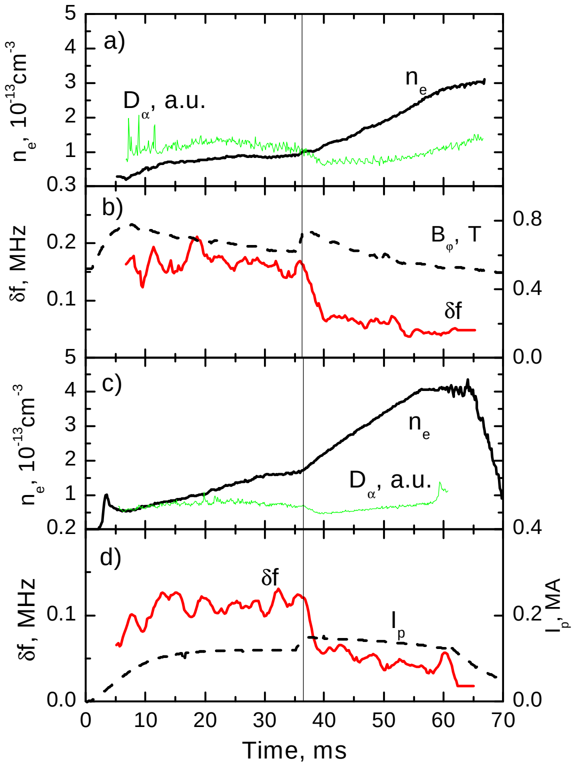

Fig.2 Comparison of spectrum width behavior for magnetic compression (a, b) and CRU triggering (c, d). O-mode, b) – F=17.5 GHz, d) – F=18GHz

In the first instance the comparison has been performed for the H-mode produced by current profile perturbation via either CRU or fast magnetic compression. The conditions of experiments are described in detail elsewhere [2], [3]. On Fig.2 the main plasma parameters characterizing the transitions are shown. The transitions take place near 36 msec. In the both cases the drastic decrease of the spectrum width is observed during the transition. The δf waveforms exhibit approximately the same features for both methods of the H-mode initiations that can testify to the similar nature of the transitions. Two other scenarios of the transition to the improved confinement are compared in Fig.3. Ohmic H-mode in these regimes was produced by some increase in gas puffing (GP) rate or by ICRH pulse. The particular transition achieved by RF pulse has been discovered in a run of attempts to heat bulk ions in core region of a deuterium discharge. The RF power up to 100 kW at hydrogen minority gyrofrequency 12 MHz and with pulse duration from 3 to 15 ms was launched from the low field side with the one loop antenna coated by Nb ceramics. Contrary to well know spontaneous ICRF heated H-mode the L-H transition in the Tuman-3M tokamak was activated just after RF pulse switching on (see Fig.3c). The GP H-mode triggering is characterized by gradual narrowing of the spectra (Fig.3b). The steepest decrease of the spectral width was observed under the transition induced by the ICRF pulse (Fig.3d). Such differences in the rate of spectral width slope down for these two scenarios well correspond to various rate of density growth and a decrease of the D_α emission. These data are the evidence of quite different origin of the transitions.

The measurements at different probe microwave frequency F were carried out for various types of H-mode to estimate in what peripheral layer existed the narrowing of spectra. On Fig.4 the temporal behavior of spectrum width are represented for two probe frequencies 17.5 and 25 GHz respectively. The estimated radial positions of cut of layer are shown as well (Fig.4a, c). In a case of the CRU transition the region of spectrum narrowing at first occurs only in a vicinity of the last close flux surface, and then gradually spreads into interior area of a discharge (See Fig4b). Quite different waveforms of δf magnitude have been obtained under the transition triggered by the ICRH pulse (see Fig.4d). During the RF power launching the spectral narrowing was indicated just for every cut of layer positions. After the RF pulse switching off the spectrum width is increased only for high probe microwave frequency.

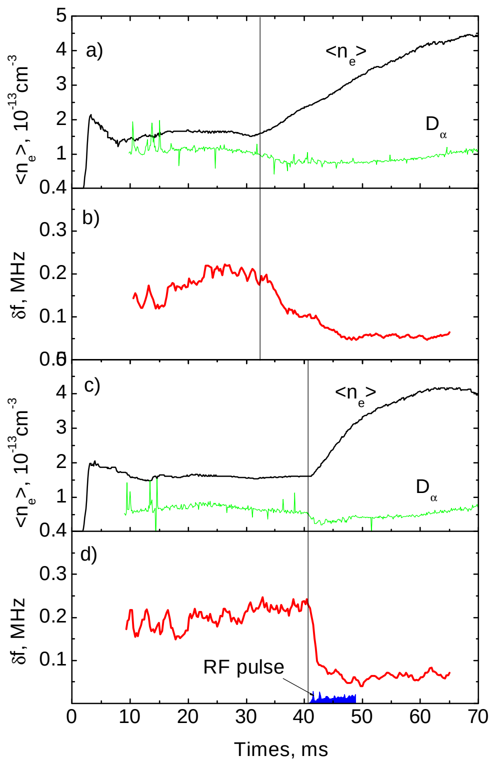

Fig.3 The same as in Fig.2 for GP (a, b) and ICRH (c-d) switching on. O – mode, b) - F = 18.5 GHz, d) – F = 19 GHz.

Additional data have been obtained under the antenna tilting with respect to cut off layer surface. Before the transition to the H-mode antenna inclination resulted in backscattering spectrum shift explained by the Doppler shift due to poloidal rotation of fluctuations. As previously [1] the asymmetry of frequency shift for the symmetrical antenna inclinations ($\pm\psi$) was happened to be observed during the transitions. The most pronounced asymmetry occurred during the ICRH induced H-L transition. The offered earlier explanation of asymmetrical spectral shift based on occurrence of vortex-like structure [1] requires the further substantiation.

Discussion

The experiments carried out for various H-modes have shown that temporal behavior of the width of backscattering spectra is always strongly consistent with time dependencies of density increase and D_α emission reduction, referring the diffusion suppression. So given the spectrum width is determined by turbulent motion of fluctuations, the observed difference in spectrum narrowing could indicate difference in the rate of anomalous transport suppression. Such guess is supported by the theory developed for the collective far forward scattering [4], which proves that the spectrum width can be directly connected with a turbulent diffusion coefficient.

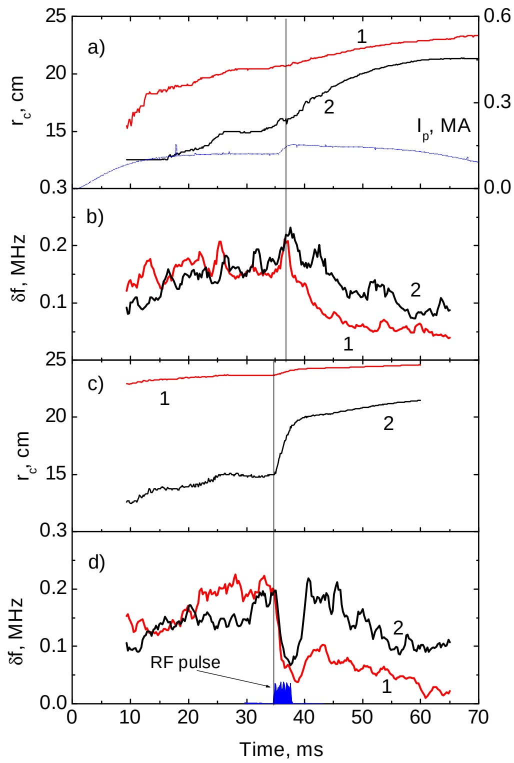

Fig.4 Comparison of spectrum width for various cut of layer position (a, c) under CRU (a, b) and ICRH (c, d) H-mode initiations. O – mode, 1 – F=17.5GHz, 2 – F=25GHz

The same features of spectral width behavior observed for CRU and magnetic compression are determined by common origin: occurrence of inhomogeneous toroidal electric field E_φ for both cases of plasma boundary perturbations [2], [3]. The Ware pinch of electrons and ions can be not equal in this field E_φ and results in appearance of the radial electric field, which reduces fluctuations. As the time of the induced field E_φ penetration is limited by a skin time (2÷3 msec), the spectral narrowing should be observed at first on edge of a discharge. It is evidenced by the results obtained with use of various probe microwave frequencies (See Fig.4b). The fast decrease of spectral width under the ICRF pulse (See Fig3d, Fig4d) allows to assume that the L-H transition is not a result of bulk ion temperature increase. This is as well supported by the fact that the act of transition did not depend on the amount of the hydrogen minority. The fast process of the transition in this case can be initiated by occurrence of radial electric field because of fast ion loss stimulated by the RF field. However, the more plausible mechanism of immediate transition is associated with direct RF power influence on plasma turbulence. An effective suppression of some types of drift instabilities was predicted in particular electromagnetic field of the lower hybrid frequency band [5]. Broad region suppression of plasma turbulence is evidently seen on Fig4d. Such suppression is followed by transport barrier emergence in a run of the RF pulse. When produced, this barrier is still retained after RF pulse switching off because of the arising of new sharp plasma parameter profiles with sheared rotation. After RF pulse switching off the barrier is localized only near the edge that is confirmed by the data obtained at different microwave frequency probing (See Fig4d).

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