Fluctuation measurements in Tuman-3M by microwave reflectometry with tilted antenna beams

V.V.Bulanin[1], S.V.Lebedev[2], L.S.Levin[2], V.S.Roitershtein[1]

[1]St.Petersburg Technical University, Polytechnicheskaya 29, 195251, St.Petersburg, Russia
[2]A.F.Ioffe Institute, Polytechnicheskaya 26, 194021, , St.Petersburg, Russia

Introduction

In the course of the reflectometry measurements the phase ramping inconsistent with the cutoff layer actual position (the so called “phase runaway” – PRA) sometimes appears in tokamak plasmas under the strong fluctuations conditions [1]. The PRA phenomena could be easily explained by the Doppler frequency shift due to poloidal propagation of fluctuations provided the incident microwave beam is tilted to the cutoff layer surface. The beam tilting may appeared due to antenna misalignment and usually exists with the use of two-antenna reflectometry schemes. To study the antenna tilting effects the direct experiments have been performed with a variable probe beam inclination. The spectra of the reflected signals have been investigated in the Tuman-3M tokamak during the transition to the Ohmic H-mode. It is was then that the anomalous PRA has been previously observed in the reflectometry measurements [1].

Microwave backscattering diagnostics

The Tuman-3M microwave backscattering diagnostics is based on the single antenna reflectometer scheme with X and O mode propagations. The conical antenna of 4 cm in diameter is used to transmit microwaves from low magnetic field side. The instrument has been specially designed to tilt the antenna at different angles with respect to cutoff surfaces. To do this the microwave unit was rotated as a whole in a plane of minor cross-section of a torus. The tilt angle was adjusted from shot to shot to proceed with the measurements at the same discharge conditions. The following set of angles was used: $\varphi = 0^0, \pm5^0, \pm10^0, \pm20^0, \pm30^0$. 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 [1]. The spectra have been computed in frequency bands ±0.5 and ±2 MHz. The reflectometry specific data like the complex signal phase and amplitude have been computed as well for the discharge length of time. 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.

Experimental results

The backscattering experiments has been carried out in the Tuman-3M tokamak (a=0.22m, R=0.53 m, $B_t \le 1.2$ T, $I_p \le 175$ kA, $n_e \le 6.2\cdot10^{13} cm^{-3}$) after the vessel boronization. The Ohmic H-mode was initiated by pulsed gas puffing and/or RF pulse at ICR frequency. The peripheral transport barrier was evidenced by both the averaged electron density rise up and the D_α-emission reduction [2].

As expected, the microwave antenna inclination results in the shifting of the backscattering spectra. The spectra have been shifted as a whole with loss of coherent reflection signal. So

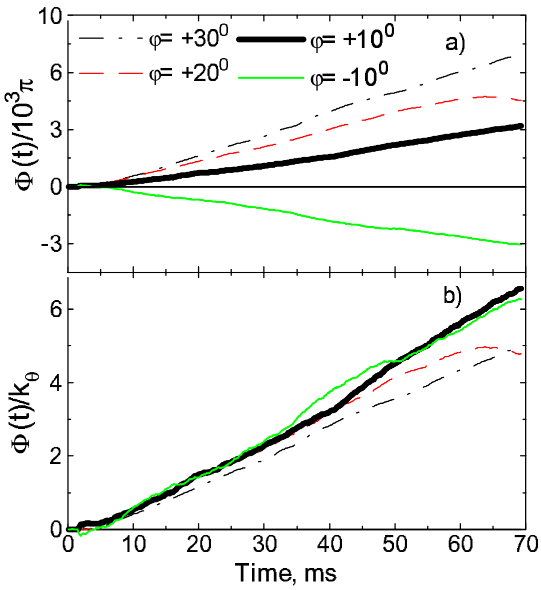

Fig. 1 Phase runaway for different antenna inclinations at F=17GHz (X-mode), b- normalized phase for the same conditions.

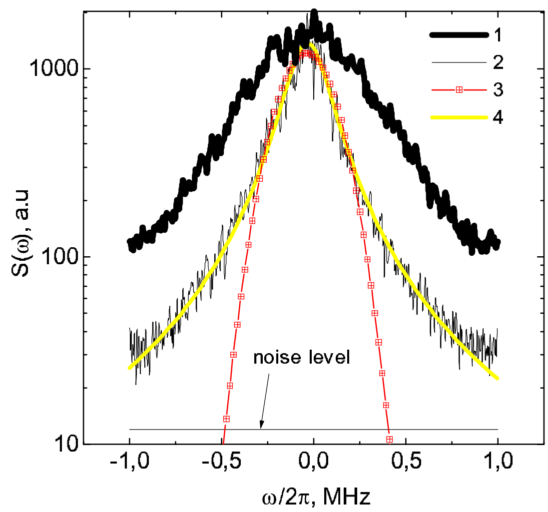

Fig. 2 Backscettering spectra obtained before (1) and after (2) the transition to H-mode. φ=30⁰, F=17.1 GHz. Best fit Gaussian (3) and Lorentzian (4) profiles.

the spectrum evolutions are quite different from ones observed recently in the W7AS machine [3]. The frequency shift was increased at larger tilt angles. This shift was small compared to the spectrum width at every antenna inclination angle. Prior to the H-mode the frequency shifts for the tilt angles (±φ) symmetrical respective to a midplane were of a same absolute value but of different signs. The averaged frequency shift presented by $<\omega>=\int \omega S(\omega)d\omega / \int S(\omega)d\omega$ has been derived as function of time. This one integrated over the time, which is otherwise a phase, has been compared with the phase $\Phi(t)$ computed at once from the complex signal. These both exhibit the same PRA effect resulted from antenna tilt and attributed to poloidal rotation of plasma fluctuations - $k_\theta v_\theta$ (k_θ, v_θ - poloidal component of scattering fluctuation wavevector and poloidal velocity respectively). The sign of the PRA depended on the cutoff layer position was consistent with either electron or ion diamagnetic directions. Fig. 1b shows the normalized phase curves that is Φ / k_θ where k_θ for the peripheral cutoff layer position is given approximately by $k \sin\varphi$ (where k is free space wavenumber). The curve slope turns out the same irrespective the tilt angle φ and defines the poloidal velocity of nearly $8 \cdot 10^4$ cm/sec.

The prominent feature is that the observed spectra are of Lorentzian shape (see Fig. 2). On the same picture the two spectra taken prior and after transition to the H-mode are plotted to demonstrate the drastic difference of spectrum width. The spectrum width computed overall the discharge duration is shown in Fig. 3 for two different φ values. The width drastic drop just after the transition to the H-mode is evident under the near normal incidence of the microwave beam. The frequency F has been specially tuned to achieve the same cutoff layer positions. However the spectrum width narrowing is not so much pronounced with the antenna inclination.

The mean square magnitude of the complex signal $<u^2>$ depended on tilt angle is plotted in Fig. 4 as a function of k_θ-value. The given k-spectrum is found slightly broader compared to the estimated k_θ-spectrum of the incident beam.

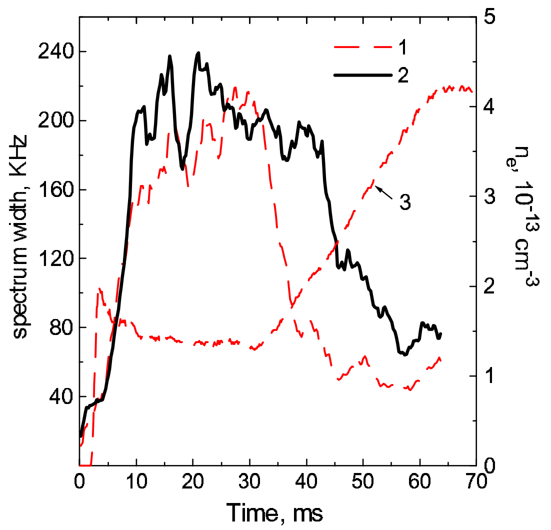

Fig. 3 Temporal behavior of spectrum width computed for two different antenna tilts. 1 - φ=5^0, F=17.5 GHz, 2 - φ=20^0, F=18.9 GHz. 3 -<n_e>. O-mode

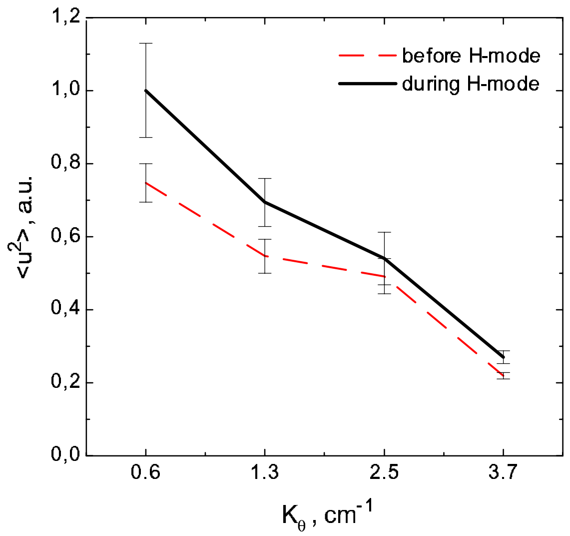

Fig. 4 Mean square of complex signal estimated in whole frequency band versus k_θ -value. F=17.5 GHz, O-mode.

The mentioned above similarity of the PRA for the symmetrical antenna tilts (±φ) sometimes fails during the transition to the H-mode (See Fig. 5). At the moments later than 30 ms, related to the H-mode transition the PRA mismatch becomes evident. This mismatch is accompanied by the anomalous PRA phenomenon under the normal probe beam incidence as well.

Discussion.

The carried out experiments prove that the antenna inclination results in the backscattering spectrum shifting known as PRA effect. In the absence of the H-mode the reasonable value of the poloidal velocity has been derived from experimental data in time of OH stage. The spectrum shift has observed to be less than spectrum broadening. The latter could not be explained by the Doppler shift spread on account of shear of plasma rotation only. Otherwise the extremely strong shear of plasma rotation has to be assumed – about $5\cdot10^6$ cm/sec per few cm. Moreover along the lines of known theories the shear of rotation is to be increased during H-mode. Therefore the spectrum broadening is expected to be increased which is not the case of our experiment (see Fig. 2). On the other hand the known random screen model [4] explaining the spectrum broadening under the strong fluctuations predicts the Gaussian spectrum profile rather than the observed Lorentzian one. The Lorentzian profiles are expected for the developed turbulence provided the scattering fluctuation scale

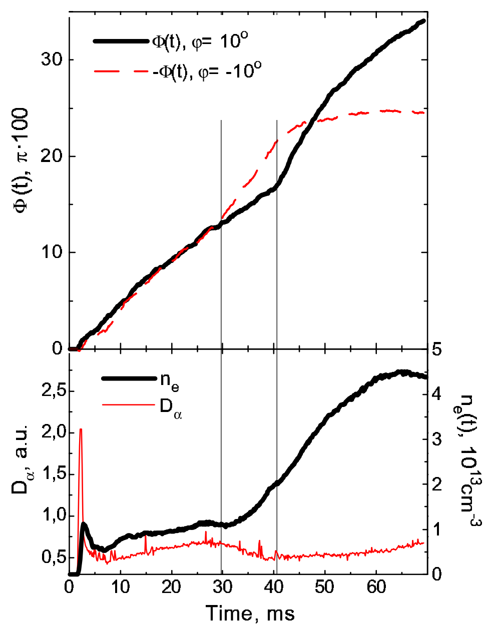

Fig.5 Top: asymmetric phase runaway for two symmetric angles (±10^o) F=22.08 GHz, X-mode. Bottom: <n_e> and D_α emission curves. Vertical lines mark the moments of different phase ramping.

is larger than the turbulent motion correlation length [5] and expressed by:

$$S(\omega) = \frac{(k^2 D_\perp)^2}{(\omega - \mathbf{ku})^2 + (k^2 D_\perp)^2} \qquad (1)$$

where $D_\perp$ is the turbulent diffusion coefficient and $\mathbf{u}$ is the mean averaged plasma velocity. According to Eq.(1) the frequency spectrum width is directly connected with the cross-diffusion coefficient $D_\perp$. Unfortunately in our case the accurate estimation of $D_\perp$ is problematic because of the pronounced uncertainty of k-value. Furthermore, according to our experiments the spectrum broadening is not essentially influenced by the k_θ variations with a change of antenna tilt. This might be accounted for the 2D isotropic turbulence excitation within a narrow k-module interval. As for example, according to 2D simulation data the k-module interval of 3-4 cm^{-1} is not opposed to experimental k_θ-spectrum on Fig. 4. The taken k-module magnitudes fit the cross-diffusion coefficients of 8 m^2/sec and 2 m^2/sec for the OH and H-mode respectively which are typical for the peripheral zone of the Tuman-3M tokamak [2]. Nevertheless the spectrum broadening due to multiple scattering should not be ruled out at all [6]. The spectrum extra broadening under the incident beam inclination during the H-mode (see Fig. 3) could be explained with mechanism discussed in [7].

The discovered nonidentical PRA behavior for the symmetrical tilt angles (see Fig. 6) could be associated with unisotropic plasma fluctuations predicted by the H-mode theory [8]. Under the strong fluctuation condition the detected signal is determined by the scattering of the incident wave rather than the reflected from cutoff layer. It is in this case off non-linear scattering the twisted ellipse-like eddies may result in nonidenctical PRA observed under the symmetrical incidences of microwave beam. So the PRA effect in a reflectometry could appear due to high level unisotropic turbulence.

Acknowledgements

The authors wish to thank Professor E. Gusakov for fruitful discussion. This work was supported in part by the RFBR Contract No 97-02-18119 and the INTAS Contract No 97-11018.

References

1. V.V. Bulanin, D.O. Korneev, Plasma Physics Reports, **20**, 14 (1994).
2. S.V.Lebedev et al., Plasma Phys. Control. Fusion, **38**, 1103 (1996).
3. C. Christou et al., Proc. of 25th EPS Conf. on Contr. Fusion and Plasma Physics. **22C**, 1466 (1998).
4. R. Nazikian, E. Mazzucato, Rev. Sci. Instrum**. 66,** 392 (1995).
5. F. Gervais et al., Proc. of 21st EPS Conf. on Contr. Fusion and Plasma Physics. **18B** part II, 118 (1994).
6. E.Z. Gusakov, private communication.
7. V.V. Bulanin et al., Proc. of 22nd EPS Conf. on Contr. Fusion and Plasma Physics. **19C**, 89 (1995)
8. K.H. Burrell, Phys. Plasmas **4**, 1499 (1997)