Observation of filaments in the Globus-M tokamak via Doppler reflectometry

V.V. Bulanin[1], V.K. Gusev[2], N.A. Khromov[2], S.V. Krikunov[2], G.S. Kurskiev[2], M.M. Larionov[2], V.B. Minaev[2], M.I. Patrov[2], A.V. Petrov[1], Yu.V. Petrov[2], N.V. Sakharov[2], S.Yu. Tolstyakov[2], V.I. Varfolomeev[2], A.Yu.Yashin[1]

[1]*St.Petersburg State Polytechnical University, St.Petersburg, Russia*

[2]*Ioffe Physico-Technical Institute, RAS, St.-Petersburg, Russia,*

Introduction

Plasma edge turbulence in a tokamak often manifests itself by the developing of filament structures observed during edge localized mode (ELM) and inter-ELM periods [1]. The filament like density perturbations are assumed to play an important role in peripheral transport. So the filaments are intensively investigated with the using of different methods such as fast camera images, reciprocating Langmuir probes, multi-pulse edge Thomson scattering. In this report the data concerning the filaments in the Globus-M tokamak are presented as a result of first application of Doppler reflectometry (DR) in a spherical tokamak.

Doppler reflectometer in the Globus-M tokamak

The Doppler reflectometry is based on microwave backscattering under the oblique incidence of microwave probing beam [2]. The diagnostics allows us to derive perpendicular rotational velocity from the Doppler frequency shift of the scattered radiation induced by moving density fluctuation. The perpendicular velocity has a direction of diamagnetic drift velocity of charged particles. In the Globus-M tokamak the probing O-mode radiation was launched from the low-field side with the help of a movable horn antenna which can be tilted in the both poloidal and toroidal directions. The range of the incident frequencies was varied from 19 up to 26 GHz to localize the scattering region near the last closed flux surface (LCFS). The backscattered radiation was detected by IQ detection technique described elsewhere [3]. Computation of the spectrum of complex IQ detector signal $I(t) = I_{\cos}(t) + iI_{\sin}(t)$ allows us to estimate the Doppler frequency shift and relevant perpendicular velocity.

Revealing of filaments

The Doppler reflectometry measurements were performed in the Globus-M spherical tokamak (R = 0.36 m, a = 0.24 m) during H-mode triggered by NBI heating with plasma parameters as follows: I_p = 170-200 kA, B_{tor} = 0.4 T, $n_e = (1\text{-}3)\cdot 10^{19}$ m^{-3}, $P_{NBI} \approx 1$ MW. The

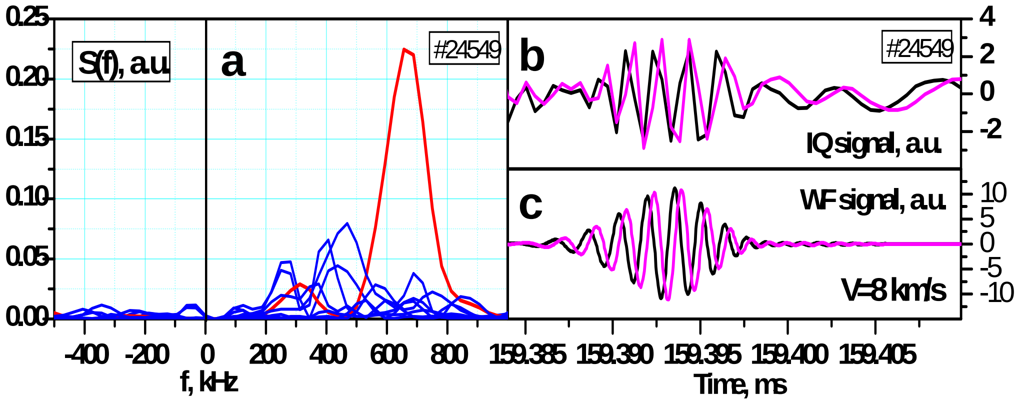

Fig. 1. a-backscattering spectra estimated in 16 μs sample, b-sine and cosine IQ detector signals and c-simulated IQ detector signals.

H-mode was accompanied by D_α emission spikes treated as a manifestation of type-I ELMs [4]. The narrow backscattering spectra with significant intensity and frequency shifts occurred in the course of Doppler reflectometry measurements. Such kind of spectrum is shown as a red curve in Fig. 1a among a set of broadband low amplitude spectra (blue curves). The direct examination of the signals of the Doppler reflectometer detector shows that the narrow spectra correspond to the bursts of high amplitude oscillations. An example of the sine and cosine burst signals is shown in figure 1b. The bursts appeared during H-mode with an interval 5-50 µs. So they were not rare event. The most plausible reason of the burst exitations is the backscattering from filament like structure. To appreciate this process the following integtal for the IQ signals obtained in Born approximation can be usefull [5].

$$I(t) = \int [W_{\cos}(R,Z) + iW_{\sin}(R,Z)]\delta n(R,Z,t)dRdZ \ .$$

Here: $W_{\cos}(R,Z), W_{\sin}(R,Z)$ are 2D weighting functions, and $\delta n(R,Z,t)$ is plasma density fluctuation. The weighting function computed for geometry close to the Globus-M one is shown in Fig. 2. If a filament with perpedicular size less than spatial period of the weighting function intersects the scattering volume then the IQ detector signals begin to oscillate and burst is formed. A frequency of the recorded oscillations is propotional to the perpendicular velocity of the filament. The simulated signals are compared with experimental data in figure 1 for filament movement along Z-direction with fitted velocity 8 km/s.

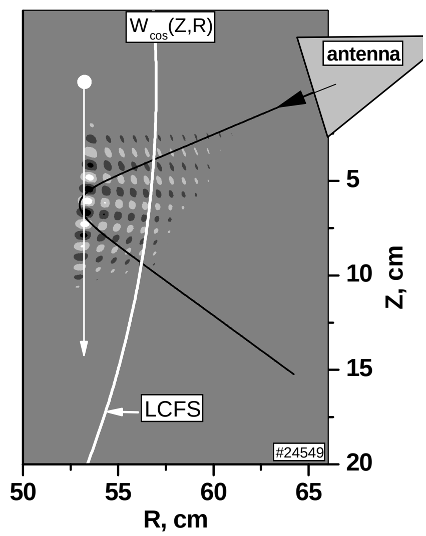

Fig. 2. 2D plot of weighting function with schematic trajectory of a filament. Gray background means zero level.

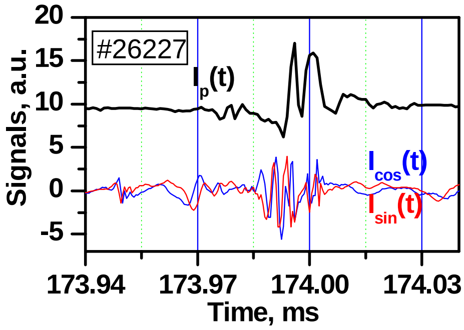

Fig. 3. Ion saturation current signal and IQ detector signals

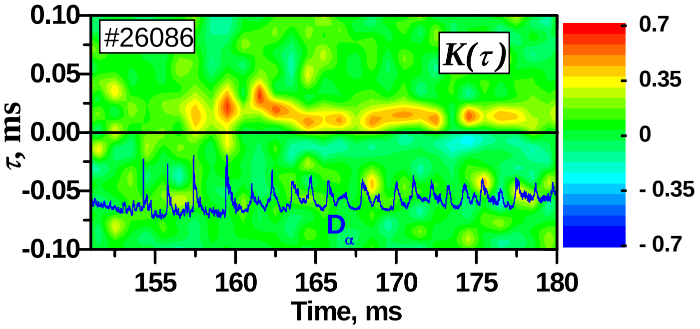

Fig. 4. 2D plot of cross-correlation function and D_α emission signal

To provide support of the model the IQ signals were compared with ion saturation current of a Langmuir probe. The mid-plane probe has been mounted in the port of vessel nearby the Doppler reflectometry antenna. The radial position of the probe with respect to the LCFS ΔR_{LCFS} can be varied from shot to shot. The ion saturation current in temporal intervals between the type-I ELMs are presented as a series of spikes with a width 5-20 μs, which are separated by 20-100 μs. Fig. 3. shows an example of the temporal evolutions of both the IQ detector signals and the probe current. The probe position ΔR_{LCFS} was 4 cm, and the cut-off layer was near the LCFS. One can see that the sharp peak of the probe current corresponds to the burst of the IQ signal oscillation. This coincidence is in line with the proposed model according to which the IQ signal oscillations are not plasma oscillation but a result of the microwave backscattering from a filament structure. The probe current peaks are not observed for every IQ detector burst. It is because not each filament rotating near the LCFS detaches and extends to the probe [1]. Some filaments can also be missed by the probe because of various velocity of rotation near the LCFS. The correspondence between the IQ signal bursts and probe current peaks is illustrated by cross-correlation function $K(\tau)$ between probe signal and the IQ signal envelope computed for different points of time during the H-mode. The relevant 2D plot of the cross-correlation function is depicted in Fig.4.

Kinetics of filaments in the Globus-M tokamak

The intensive bursts of oscillations as manifestations of rotating filaments were clearly recognized only during the H-mode provided the scattering volume was inboard the LCFS. During L-mode it was impossible to reveal any filament against the background turbulence. After the L-H transition the filaments were registered in periods between the type-I ELMs. So the observed filaments may be treated as inter-ELM filaments similar to filaments observed on the MAST [1]. The Doppler reflectometry technique makes it possible to estimate perpendicular velocities of the inter-ELM filament near the LCFS. A significant spread in the range of the velocities and the time interval between the filaments has been discovered. This spread is evidently seen in the spectrogram shown in Fig. 5, where the spectra of bursts in velocity scale are presented as red small sections of lines. The derived velocities achieve the values expected for poloidal velocities inboard the LCFS during H-mode formation. On the other hand the filament velocities exceed the velocity of background fluctuations (blue curve in Fig. 5) estimated in periods separating bursts.

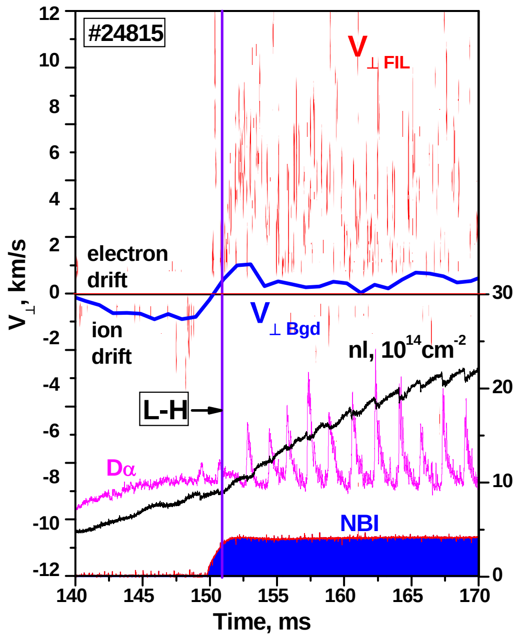

Fig. 5. Spectrogram of bursts of oscillations, blue curve - background fluctuation velocity and monitoring date envelopes. L-H is a moment of transition to H-mode.

Summary

A possibility of the Doppler reflectometry to detect and investigate filaments has been demonstrated. The registration of filaments is possible provided the filament perpendicular size is about the spatial period of the weighting function of the diagnostics. For the condition of the Globus-M experiment the characteristic perpendicular dimension of filaments has to be less than 1-2 cm. The correlations between the bursts and spikes of the ion saturation current of the Langmuir probe placed in SOL region near LCFS were observed. The filament perpendicular velocities exceed the velocity of background fluctuations and achieve 10-12 km/s during H-mode. The collective motions of the filaments are not regular as the distances between filaments are constantly changing due to different perpendicular velocities. A significant spread in the filament velocities and their spacing is a characteristic feature of inter-ELM filaments observed previously in the MAST tokamak.

Acknowledgements

This work was jointly supported by grants RFBR 09-02-00984-a and RFBR 10-02-01421-a.

Reference

[1] N Ben Ayed, A Kirk, B Dudson et al Plasma Phys. Control. Fusion **51** (2009) 1-25

[2] G.D. Conway, J Schirmer, S Klenge et al Plasma Phys. Control. Fusion **46** (2004) 951-970

[3] Bulanin V V, Lebedev S V, Levin L S et al Plasma Phys. Rep. **26** (2000) 867

[4] V.K. Gusev et al. 34th EPS Conf. on Plasma Phys. Warsaw, ECA **31I**, (2007), P.1-078

[5] V. V. Bulanin and M. V. Efanov Plasma Phys. Rep. **32** (2006) 47–55