Filament structures in the Globus-M tokamak

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Introduction

At present, there is an active interest in turbulent intermittent events at the tokamak plasma edge like filament structures [1]. The filaments appeared as a result of non-linear peeling-ballooning or/and kinetic-ballooning instability developing are assumed to control the H-mode pedestal parameters and to play an important role to the thermal load on both first wall and diverter plates [2], [3]. A new approach with Doppler reflectometry application has been proposed to the filament study recently [4]. New results obtained in the filament investigation via Doppler reflectometry on the spherical tokamak Globus-M are presented.

Revealing of filaments by Doppler reflectometry

Doppler reflectometry (DR) is based on microwave backscattering under the oblique incidence of probing microwave. The diagnostics allows us to derive perpendicular rotational velocity from the Doppler frequency shift of the scattered radiation induced by moving density fluctuation. It was shown that the backscattering from filaments such as localized plasma density perturbations manifests itself as bursts of intensive quasi-coherent fluctuations (QCF) of the reflectometer detector signal [4]. The amplitude and frequency of QCF bursts always exceed the relevant values of background fluctuations. It can be seen for example in Figure 1a for time interval from 167.05 up to 167.15 ms. Detector signal analysis makes it possible to determine such filament properties as velocity, size and quasi-toroidal mode numbers.

Doppler reflectometry Globus-M diagnostic utilizes a single antenna setup described in detail in [4]. 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 probing frequencies was varied from 27 up to 36 GHz to localize the scattering region near the pedestal region of the peripheral transport barrier. The backscattered radiation was detected by quadrature (IQ) detection technique which allows one to estimate backscattering spectra in frequency range ± 2 MHz.

The filament investigation with the using of DR were performed on the Globus-M spherical tokamak (with the major and minor torus radii of R = 0.36 m and a = 0.24 m, respectively) operating in the H-mode regime initiated by plasma heating with deuterium neutral beam. The main regime parameters were as follows: plasma current, I_p = 170–200 kA; toroidal magnetic field, B_T =0.4 T; plasma density, n_e = (1–3)·10^{19} m^{-3}; auxiliary heating power, $P \leq$ 1 MW. Spikes of the D_α emission were observed just after the transition to H-mode. The spikes were synchronized with sawtooth oscillations being visible on SXR and microwave interferometer signals. So, the observed D_α emission spikes are regarded as manifestations of type-I edge localized modes (ELMs) initiated by sawtooth plasma density perturbations.

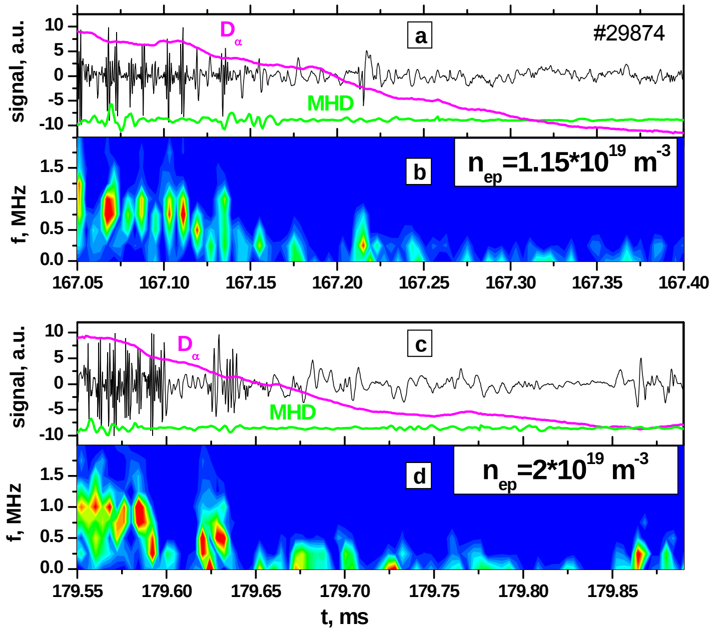

Fig. 1. Filaments during EML phase for different pedestal plasma density IQ detector signals (a,c) and spectrograms (b, d), n_{ep} – pedestal plasma density.

Filament developing at different plasma densities during the H-mode

During the D_α emission spikes, i.e. in ELMs periods the QCFs were observed as a quasi periodical sequence of bursts (see Figure 1a) at relatively low plasma density in a vicinity of a pedestal (n_{ep} < 1.2·10^{19} m^{-3}). These QCFs can be treated as filaments accompanying the ELMs. Characteristic velocity of these filaments is about 12 km/s and quasi-toroidal wave number – n = 12. It is remarkable that this kind of filaments was accompanied by some bursts of magnetic probe signals. However with the pedestal density increase the IQ detector response looks like large chaotic splash at the moment of the type-I ELM event (see Figure 1c). That is probably due to expected crucial deformation of plasma density profile just during the type-I ELM [5] when the backscattering process is transformed to the reflection from strongly perturbed plasma. The filaments were registered as well in periods separating ELMs (see Figure 2). These inter-ELMs filaments (IEFs) were not accompanied by essential magnetic probe oscillations. The IEFs were not developed from the beginning of H-mode formation. The first IEF filaments occurred only when the pedestal density excided 1.5·10^{19} m^{-3}. Then the amplitude and number of the IEFs were drastically increased with the pedestal density growth up to 1.7·10^{19} m^{-3} as can be seen in Figure 2. It should be noted here that inward movement of separatrix can result in some suppression of the IEFs.

Filament distribution in transport barrier

The IEF distribution along the major radius was studied with the probing microwave frequency changing from 29.9 up to 36.8 GHz, i. e. with the changing of cut off radial position from pedestal to separatrix. The frequency was varied from shot to shot, and then the similar discharges were selected to obtain filament parameters at different major radiuses. The process of the IEF excitation is illustrated in Figure 3 with the using of probability distribution functions (PDFs) of separation between filaments in toroidal direction. One can see that the different shapes of the PDFs correspond to different distance from separatrix. A peak value (most likely) of separation between filaments is approximately the same (relevant quasi toroidal number n ≈ 25) for different distance from separatrix. However a mean value of separation is higher for pedestal region. It means that filaments occur near separatrix more often than in a vicinity of pedestal.

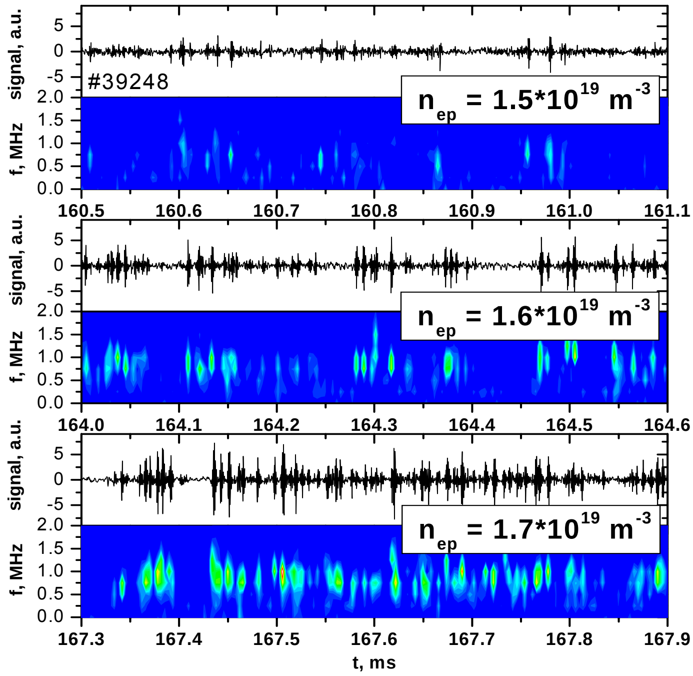

Fig. 2. InterELM QCF and relevant spectrograms for different time in a phase of plasma density increasing during H-mode, n_{ep} –pedestal plasma density.

MHD activity impact to inter-ELM filament excitation

The detailed analysis of the detector signals shows that the filaments in the Ohmic H-mode are appeared as packages of the QCFs bursts during strong MHD activity as can be seen in Figure 4. The packages appear in a phase of MHD low frequency perturbations when O-point of magnetic island

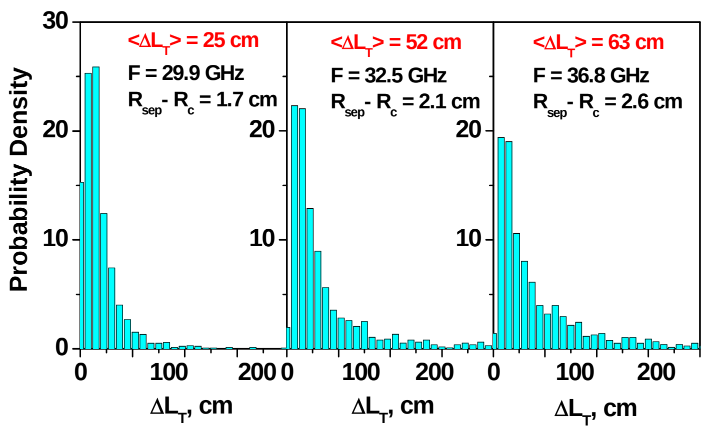

Fig. 3. Histograms of filament separetion in toroidal direction ΔL_T, F – incident frequency, R_{sep}-R_c – distance between cut off and separatrix

(m/n=2/1) is located at low magnetic field side just opposite to antenna mouth. The new phenomena of the MHD influence on filament developing was observed in relatively narrow plasma density interval (averaged density from 2 up to $3.5\cdot10^{19}$ m^3). It could be assumed that plasma periphery conditions at these densities are closed to a threshold of ballooning type instability when a small transient local pressure gradient increasing due to MHD perturbation results in filament developing.

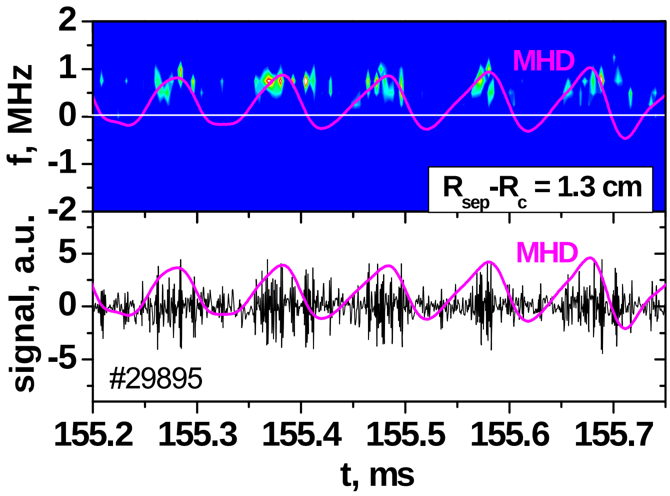

Fig. 4. Packages of QCF presented as IQ signals and spectrograms under strong MHD activity

Conclusion

The filaments associated with ELM can be revealed by DR only at relatively low plasma density. On the contrary the inter-ELM filaments were discovered to be excited only when pedestal plasma density exceeded some boundary value during the initial stage of the H-mode triggered by NBI. The decreasing of the plasma pressure gradient expected during inward separatrix movement is associated with some suppression of the IEFs. The IEFs can be excited as packages of QCFs when local plasma pressure gradient increases due to MHD perturbations. The IEFs arose more often near the separatrix than in a vicinity of pedestal. All these data could be useful for identification of ballooning type instability developed in inter ELM periods.

Acknowledgements

This work was a part of investigations of Research Laboratory on Physics of Advanced Tokamaks (RLPAT) at SPbSPU supported by the Russian government grant 11.G34.31.0041 and partly funded by RF Ministry of Education and Science contract No. 16.552.11.7002.

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