Toroidal Alfven Eigenmode study on the Globus-M Spherical Tokamak

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Investigation of the toroidal Alfvén eigenmodes (TAE) identified earlier in the experiments with NBI heating on Globus-M [1,2] were continued at increased values of magnetic field and plasma current. The auxiliary heating was performed using the deuterium beam (energy E_b=28 keV, power P_b=0.75 MW), that was injected into deuterium plasma with the plasma current of 180-250 kA. We studied the dependence of fast particle losses on the magnetic field and plasma current. Dependence of the charge exchange (CX) neutral flux drop on the amplitude of TAE at four different combinations of the magnetic field and plasma current values is shown in Fig.1. The energy of the CX neutrals is 28.5 keV (close to the injected particle energy), so the flux drop qualitatively reflects the value of losses and redistribution of fast particles induced by the TAE burst. The largest losses were recorded at magnetic field, B_t=0.4 T and plasma current, I_p=180 kA (black squares in Fig.1). With the increase of B_t from 0.4 to 0.5 the mode character has changed: the TAE bursts became more frequent. It happened probably due to better fast particle accumulation associated with increase of the slowing down time because of the electron temperature rise. But the TAE induced losses practically did not change (blue triangles in Fig.1). The increase of the plasma current from 180 to 240 kA at fixed magnetic field of 0.4 T lead to decrease of the fast particle losses (red circles in Fig.1), but the strongest effect was reached at simultaneous increase of

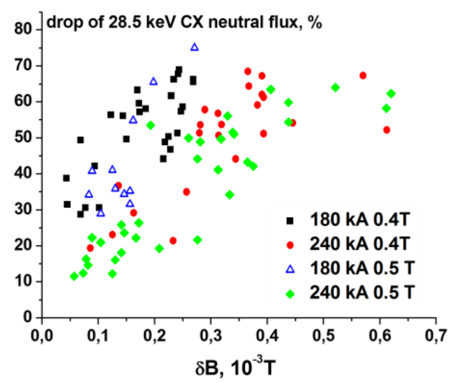

Fig. 1. Dependence of the CX neutral flux drop on the amplitude of TAE at different plasma currents and magnetic fields.

the field and current up to 0.5 T and 240 kA correspondingly (green diamonds in Fig.1). So, we can conclude that the decisive role in reduction of the TAE induced losses plays the plasma current increase, probably due to a decrease of the fast particle Larmor radius in the poloidal magnetic field. The toroidal magnetic field increase gives a weaker effect, but we have to increase the current and field simultaneously to conserve the safety factor value. The obtained dependence is promising for CFNS on the base of a spherical tokamak, but should be checked in a wider parameter range: that is one of the tasks to a new tokamak Globus-M2, which has started operation recently.

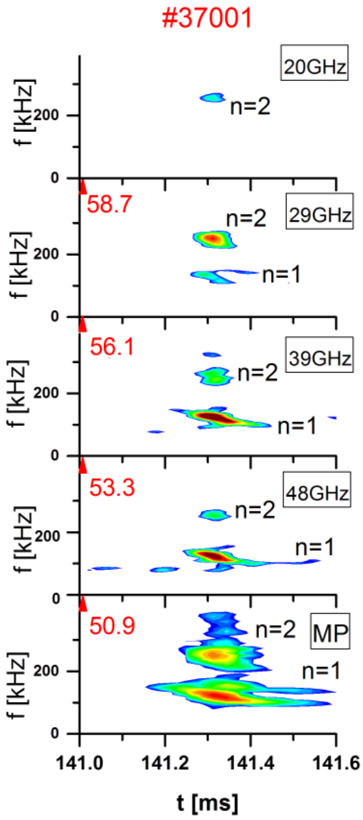

Fig. 2. DBS signal and Mirnov probe spectrograms during a TAE burst in shot #37001

During the last experimental campaign on Globus-M, the multichannel Doppler backscattering reflectometry (DBS) was used for the first time to study TAE allocation. The description of the method can be found in [3] and its first application on Globus-M - in [4]. Multichannel probing at frequencies of 20, 29, 39 and 48 GHz was applied. It allowed us to observe the TAE fluctuations at four locations on major radius simultaneously. An example of such registration is presented in Fig.2. Fig.2 shows spectrograms of four DBS signals in channels of 20, 29, 39 and 48, GHz (four upper frames) and the Mirnov signal spectrogram (lower frame) during the TAE burst at 141,2 ms in shot #37001. Red numbers show major radius of the cutoff surfaces for the correspondent frequency. One can see existence of two harmonics in the spectra. By means of four Mirnov probes spread in toroidal direction we identified the toroidal numbers of the modes n=1 and n=2. The measured velocity is the drift velocity in the crossed radial electric and toroidal magnetic fields. So we can

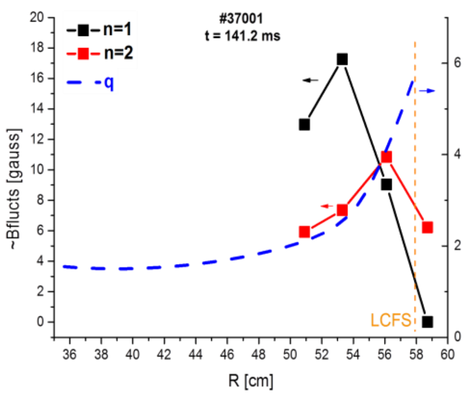

Fig. 3. Localization of the TAE modes, measured with DBS and q profile in shot #37001, 141.2 ms.

estimate the amplitude of the radial electric field oscillations in the Alfven wave through the relation $\tilde{E}_r = \tilde{V}_\perp \cdot B,$ where $\tilde{V}_\perp$ is the measured oscillations of the drift velocity. Using the relation between the radial electric and poloidal magnetic fields in the electromagnetic Alfvén wave, $\tilde{B}_\theta = \tilde{E}_r/V_A$ (V_A is the Alfven velocity), the magnetic-field amplitudes $\tilde{B}_\theta$ can be calculated. Fig. 3 demonstrates radial profiles of the magnetic fluctuation amplitudes obtained by the described method for the TAE modes n=1 (black curve) and n=2 (red curve) at 141.2 ms of shot #37001. The dashed line shows the q profile obtained from the EFIT code. So, from our measurements we can conclude that the TAE are localized at the periphery of the plasma column, in the region of normalized minor radii ρ from 0.6 to the separatrix, the modes with different n have different localization.

Modeling of the Alfven continuum and TAE mode structure for Globus-M conditions were performed with the modified KINX and CAXE codes [5]. For the simulation shot #37001 was selected (at the time 141.2 ms) for which the spectrograms are shown in Fig. 2 and the n = 1 and n = 2 mode radial localization in Fig.3. Using the experimental mass density profile for the deuterium plasma several global *n*=1 TAE were found in the Alfvén continuum gap (the specific heat ratio Γ=0) assuming fixed boundary condition. One of them, shown in Fig. 4 with the frequency 155 kHz, seems to agree with the experimental data also with respect to the mode localization. However, with free boundary condition for the eigenfunctions and taking

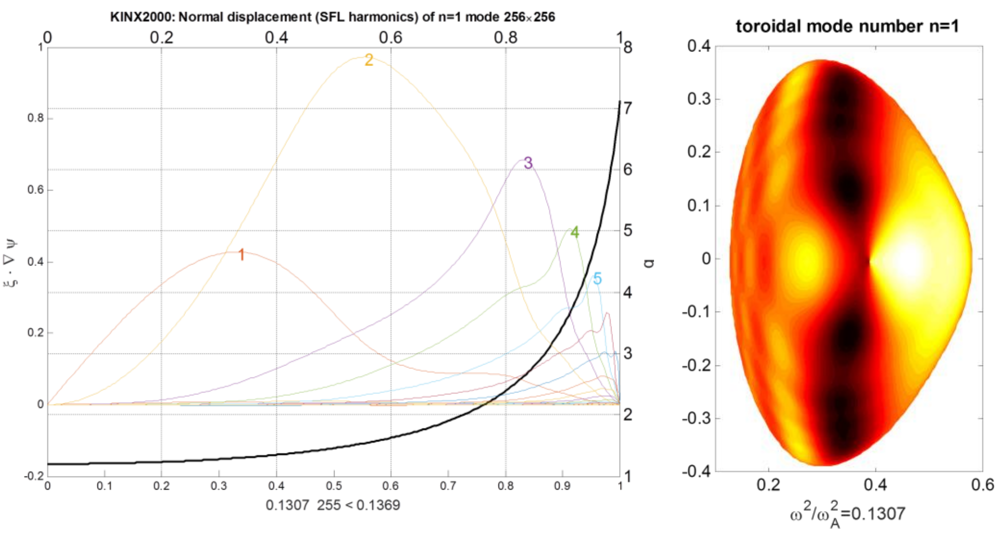

Fig. 4. The structure of TAE mode with fixed boundary condition in Alfvén continuum gap, frequency 155 kHz. Harmonics in straight field line coordinates and level lines of normal plasma displacement are shown.

into account plasma compressibility (Γ=5/3, continuous spectrum in Fig. 5) the corresponding frequencies rise above the experimental range. In the frame of the same free boundary compressible plasma model there are global modes (like shown in Fig. 6) with

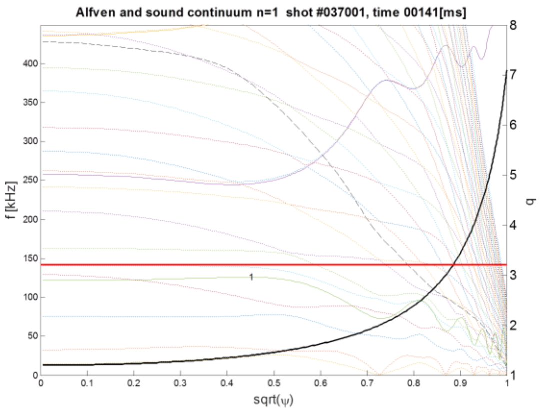

Fig. 5. The structure of continuous Alfvén/sound spectrum for the toroidal wave number n = 1; q profile – black solid line, normalized experimental density profile – black dashed line, colored solid curves – Alfvén continuum in the slow sound model. Red horizontal line corresponds to the frequency of the mode in fig. 6.

experimentally relevant combination of the poloidal harmonics m>2 localized near the plasma boundary in the region of magnetic surfaces with safety factor values q=2-4. On the other hand, this mode features the dominating m=1 harmonic not detected in the experiments yet. Besides, the mode frequencies fall into continuous Alfvén/sound spectrum, which can lead to its coupling to the continuum and an enhanced dissipation.

In our next experiments on the new tokamak Globus-M2 we are going to apply additional reflectometer channels with higher frequency to penetrate deeper into the plasma. So we will be able to check experimentally the existence of the central m=1 harmonic.

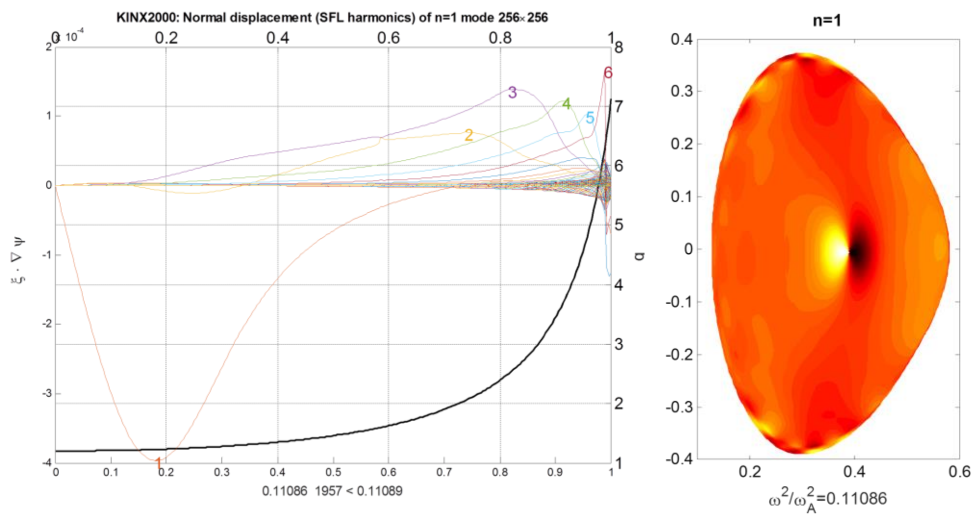

Fig. 6. The structure of the TAE mode from Alfvén/sound spectrum for shot #37001 (time 141.2 ms) with the free boundary condition, frequency 142 kHz.

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1. Petrov Yu.V. et al, Physics Reports 37 (2011) 12 1001-1005
2. Petrov. Yu.V. et al, J. Plasma Phys. 81 (2015) 515810601
3. Yashin A.Y. et al., JINST **10** (2015) p. 10023
4. Bulanin V.V. et al, Tech. Phys. Lett. 43 (2017) 12, pp. 1067–1070
5. Gusev V.K. et al, Tech. Phys. Lett. 44 (2018) 1, pp. 67-69