Alfvén Eigenmodes in the Globus-M2 Spherical Tokamak

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Globus-M2 is a modernized version of the spherical tokamak Globus-M in which the vacuum chamber is preserved (minor radius a = 0.24 m, major radius R = 0.36 m, R/a = 1.5), and a new electromagnetic system is significantly strengthened in order to withstand higher currents and, accordingly, increased mechanical loads. The tokamak was designed to reach the toroidal magnetic field as high as $B_T = 1$ T and the plasma current $I_p = 0.5$ MA.

As the fast ions in Globus-M2 are superalfvenic, they excite Alfvén instabilities, which, in turn, can provoke additional fast particle radial transport and losses. The study of Alfvén modes (AM) was started yet on Globus-M [1,2] and continued on Globus-M2 during the reported period. First of all, we were interested in the loss of fast particles caused by AM. As was shown earlier, the largest losses are induced by chirping TAEs of high amplitude [1]. For observation of the losses we used two diagnostics: a neutron spectrometer and ACORD-24M NPA with a line of sight directed tangentially to a circle with a radius equal to the impact parameter of the injected beam. A drop in the neutron rate reflects losses and radial transport of fast particles induced by TAE. Fig.1 shows the drop at three different combinations of magnetic field and plasma current. One can see that the drop decrease with increase of the field and current, and practically disappear at B_T=0.7 T, I_P=340 kA. So, the neutron spectrometer turned out to be useless for studying dependences at large values of fields and currents.

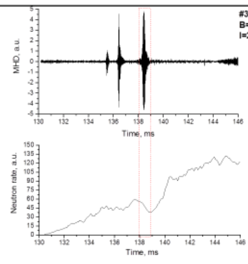
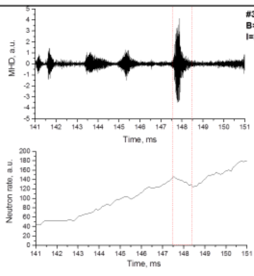
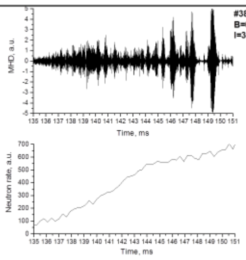
B_T=0.5 T, I_P=245 kA	B_T=0.6 T, I_P=290 kA	B_T=0.7 T, I_P=340 kA
		

Fig.1 The drop in neutron rate induced by TAE at different values of toroidal field and plasma current.

For a more detailed study of the loss dependence on the field and current value, we, as in the previous research, used the NPA. The flux of charge-exchange atoms with energies of 28.5 keV (close to the energy of injected particles) was measured. A drop in the flux at the time of the TAE burst indicated losses of fast ions. In our previous experiments, we found that the loss of fast particles decreases with increasing magnetic field and plasma current [2]. The data obtained on Globus-M2 made it possible to study this dependence in a wider range of parameters $B_T = 0.4 - 0.8$ T and $I_p = 0.18 - 0.4$ MA. The regression fit of the Globus-M/Globus-M2 data yields the following scaling for the relative fast particle losses (NPA flux drop, $\Delta N/N$) on $(I_p \cdot B_T)$ and the relative TAE amplitude $(\delta B/B_T)$:

$$dN/_{N} = A \cdot \left(\frac{\delta B}{B_T}\right)^{0.51 \pm 0.15} \cdot (B_T I_P)^{-0.94 \pm 0.27} \qquad (1)$$

where A is a constant, δB is measured with an invessel Mirnov probe at the low field side. The scaling includes the dependence of losses on the product of I_p and B_T, since in a tokamak, the field and current are usually changed proportionally to maintain a safety factor value. The experimentally measured relative drops in the fluxes of charge exchange atoms with the energy of 28.5 keV in comparison with the obtained scaling are shown in Fig. 2. The simultaneous increase in the current and magnetic field is most efficient, because it reduces both the Larmor radius and the width of the fast ion orbit, while the safety factor remains the same. The ions moving in more compact orbits are less subject to losses, because their transition into unconfined trajectories requires a stronger TAE impact. The dependence obtained is promising for the operation of future compact FNSs based on a spherical tokamak.

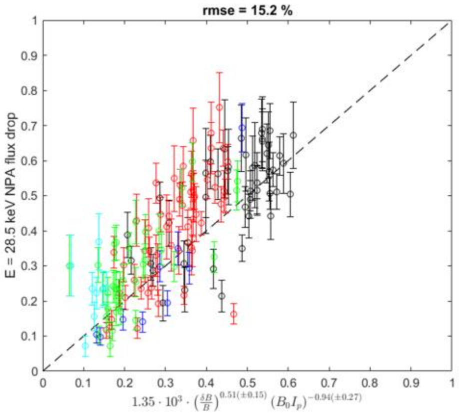


Fig.2 Regression fit for relative fast particle losses

An increase in the plasma parameters and better fast particle confinement led to a change in the nature of AM and the expansion of their frequency spectrum. Together with single toroidal Alfvén eigenmodes (TAE), observed earlier on Globus-M, multiple TAEs and so-called Alfvén cascades (AC or reversed shear AE,) were identified. Observation of ACs made it possible to apply the method of MHD spectroscopy to determine the evolution of q_{min}

in a discharge [3]. Typical spectra of the Mirnov probe signal for a discharge with AC is shown in Fig. 3a.

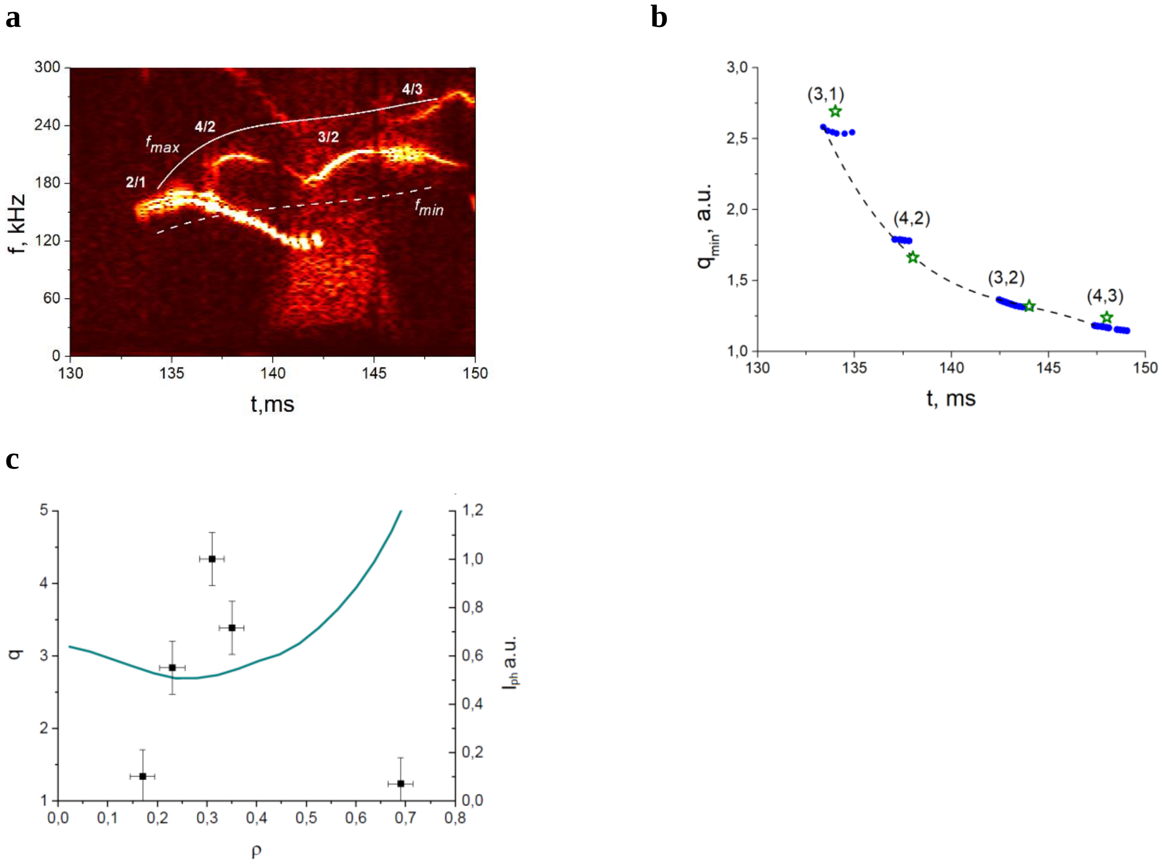


Fig. 3 a) - Spectra of the Mirnov probe signal for shot #38035 with AC. Mode wave numbers m/n are shown. The dotted lines show theoretical frequency limits. b) – q_{min} evolution in shot #38035 (triangles – MHD spectroscopy data, asterisks – ASTRA computation result). c) Spatial localization of Alfvén cascades. Black rectangles - the amplitude of the Doppler shift fluctuations at the AC frequency in relative units. Discharge # 39060, 140 ms. The solid line is the calculated q profile obtained using the ASTRA code.

The AC frequency in linear approach is determined by:

$$\omega_{AC} = [\left(\frac{m}{q_{min}} - n\right)^2 \frac{V_A^2}{R_0^2} + \frac{2T_e}{M_i R_0^2}\left(1 + \frac{7}{4}\frac{T_i}{T_e}\right)]^{1/2} \qquad (2)$$

where m and n are the mode wave numbers, V_A is the Alfven velocity, R_0 – major radius, q_{min} – minimal value of the safety factor and the second term in square brackets is the square of the GAM frequency. Formula 2 is used for calculation of q_{min} from measured values of the AC frequency. Data on T_e and T_i profiles were obtained from Thomson scattering and NPA measurements. The mode wave numbers were determined with magnetic probes. Localization of the modes was established by means of the Doppler back scattering (DBS) diagnostic [4].

The profile of the Doppler shift fluctuation amplitude at the AC frequency in relative units in shot # 39060 is shown in Fig.3c. It is seen from the figure that the mode maximum approximately corresponds to the minimum of the q profile calculated using the ASTRA code. A comparison of data obtained by means of the MHD-spectroscopy method with results of the ASTRA modeling (shown in Fig. 3b) demonstrates reasonable agreement.

In experiments on current drive by the lower hybrid (LH) waves, modes with a frequency of about 1 MHz were detected [5], They frequency significantly exceeds the frequencies in which toroidal Alfvén eigenmodes and Alfvén cascades were previously observed, but their amplitude, on the contrary, turned out to be much smaller. Later, the same disturbances were found in ohmic discharges without LH waves. A connection was established between high-frequency oscillations and the presence of a fraction of suprathermal electrons in the plasma. The Mirnov signal spectrogram and the HXR waveform are shown in Fig.4. One can see correlation of the AM bursts with the HXR peaks induced by sawtooth oscillations. The detected instability, most likely, has an Alfvén nature, since the oscillation frequency correlates well with the scaling for the Alfvén frequency. The temporal behavior of the mode (frequency chirping) can be explained using the so-called “hole-clump” model [6]. The mode structure, localization and excitation mechanism require additional study.

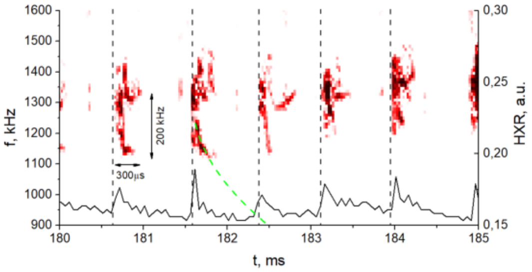


Fig.4 Red – Mirnov signal spectrogram, black – HXR waveform.

Acknowledgements

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