Fast particle losses induced by Toroidal Alfven Eigenmodes on Globus-M

Yu.V. Petrov, N.N. Bakharev, V.K. Gusev, V.B. Minaev, V.A. Kornev, G.S. Kurskiev, A.D. Melnik, M.I. Patrov, N.V. Sakharov, S.Yu. Tolstyakov, F.V. Chernyshev, P.B. Shchegolev

Ioffe Institute, St.Petersburg, Russia

In experiments with NBI at the early stage of a Globus-M [1] discharge instabilities excited by fast ions in the frequency range of 50–200 kHz were observed, which were identified as toroidal Alfvén eigenmodes [2]. Hydrogen and deuterium were used as target plasma and injected beam for isotopic effect study. The spectrograms of Mirnov signal for different combinations of the injected beam and target plasmas are shown in fig.1. The spectrograms demonstrate different character of mode behavior for different isotopes. At deuterium injection (two upper spectra in Fig.1), the mode develops in the form of short bursts of 0.5 ms duration with fast frequency drop during the burst, so-called chirping modes. Such an evolution character is, obviously, described by the predator-prey model. In accordance with that, the mode development leads to the losses of the fast particles which induce it, and the mode frequency drops to conserve effective particle-wave energy transmission. At hydrogen injection (two lower spectra in Fig.1), the mode starts from short bursts, and then, as a rule, transforms into a long-lasting mode approximately constant amplitude, which is, probably, provided by better confinement of protons as compared with deuterons (it will be discussed below). As is seen from Fig.1, the TAE frequency in all four cases remains approximately at the same range ~ 100 kHz, with exception of the case of hydrogen injection into hydrogen plasma, when first bursts of the mode appear at essentially higher frequency. However, the main intensive mode exists at the frequency ~ 100 kHz as before.

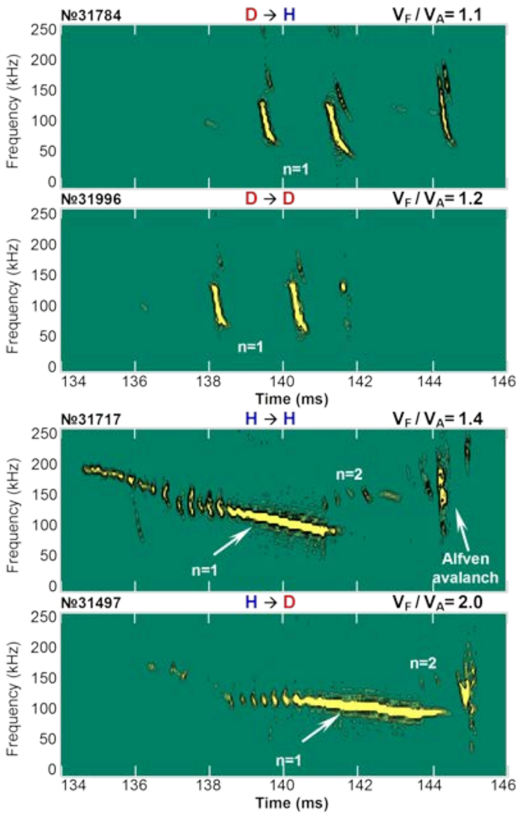

Fig.1 Spectrograms of Mirnov signal with different beam-plasma isotopes

Correlation analysis of signals of four fast Mirnov probes spread in toroidal direction has shown that most of the modes are the single modes with n=1, that lays in the frame of the linear theory [3,4], in accordance with which the maximum toroidal number of the TAE in a tokamak is defined as $n_{max} = \frac{r\omega_{cf}}{q^2 V_A}$, where r – is the minor radius, ω_{cf} – cyclotron frequency of fast particles, q – safety factor, V_A – Alfven velocity. For the Globus-M conditions n_{max} is about 1-1.5. A weak n=2 mode, which character differs from the TAE behavior, appears only sometimes. In two lower spectra Fig.1 are shown these modes with growing in time frequency, that are, probably, Alfven cascades. In separate strong mode bursts it was able to identify m number with a set of 26 poloidally spread probes. In all realizations it turned out equal 3.

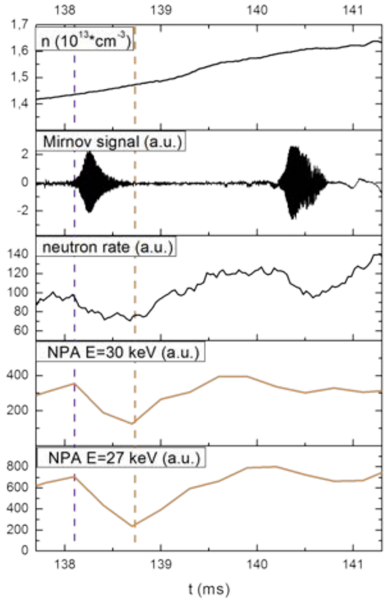

Fig.2 Correlation of TAE with neutron rate and NPA fluxes in shot #31996

In the recent experimental series correlation between TAE and fast particle losses was established for the first time on Globus-M due to improved diagnostic temporal resolution. Influence of the modes on the fast particle confinement was recorded by means of a tangentially directed NPA and neutron detector. The largest losses were recorded at deuterium injection. Waveforms of shot #31996 are shown in Fig.2. It is seen that the TAE bursts (Mirnov signal) coincide in time with drops of neutron rate and NPA fluxes with energy close to the injection one, which was 27 keV. The NPA spectra at the moment before the mode burst (138.1 ms) and in the drop minimum (137.7) are shown in In Fig.3. It is seen that the particles with injection energy undergo the largest losses (75%), the drop spreads down to energy of 18 keV (corresponded to Alfven velocity for current plasma parameters),

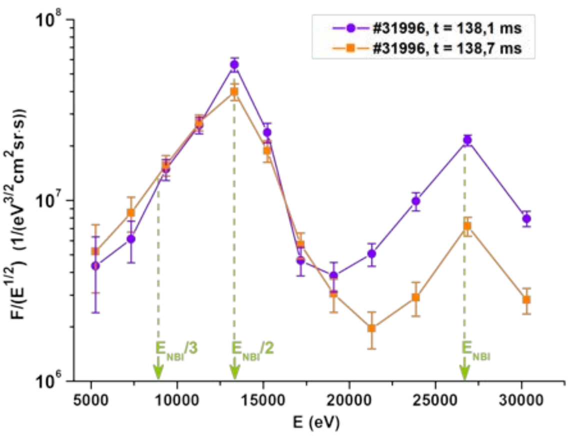

Fig.3 NPA spectra at TAE burst in shot #31996

decreasing in relative measure. Similar drop is seen in the neutron rate waveform. Dependences of neutron rate and CX fluxes of high energy on the relative TAE amplitude are shown in Fig.4. The both dependencies demonstrate the loss increase at the mode intensity growth, with tendency to saturation at high mode amplitudes. The neutron rate decreases not more than by 25-30% that, obviously, corresponds to real fast particle losses at TAE

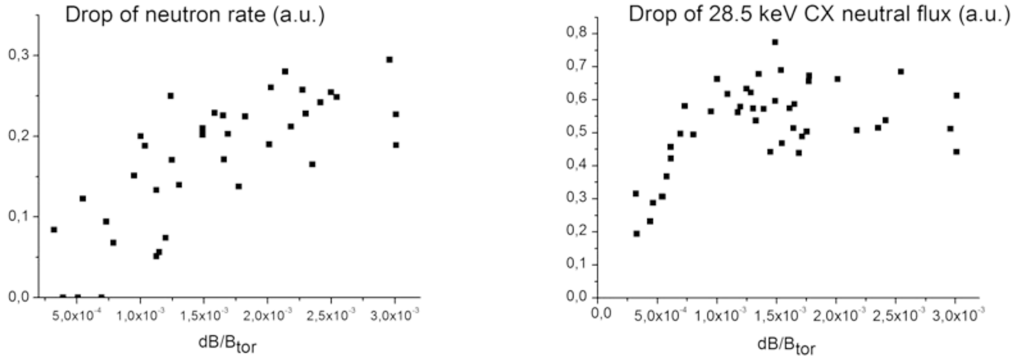

Fig.4 The portion of losses: left – neutrons, right – CX neutrals with the energy of 28.5 keV versus relative TAE amplitude

development, or their energy decrease due to slowing down at interaction with the mode. At the same time, the CX fluxes in the range of injection energy decrease essentially stronger. Two possible explanations exist: either fast particles leave the central zone, or they change their pitch angle (turn in velocity space) in such a way that they miss the NPA. In all other cases, except deuterium injection into deuterium plasma, neutron flux is absent, therefore, one can judge about particle losses by the drops of the CX fluxes only. At deuterium injection into hydrogen plasma, the same strong modes were exited as for deuterium to deuterium injection that led to yet stronger drop in CX fluxes of high energies (up to 80%). Different picture is observed at hydrogen injection. First, the TAE intensity is lower on average, than at deuterium injection. Secondly, fast particle losses reflected in the drop of the CX fluxes in the range of injected energy are essentially lower. At the long-lasting mode developing, one could observe only smooth decrease of the fluxes no more than by 20%. Even in the case of the most intensive mode flashes, the CX flux drop did not exceed 25%. Lesser losses of protons, as compared to deuterons, are associated, apparently, with a smaller Larmor radius and an orbit width defined by the Larmor radius in poloidal magnetic field. These values for deuterons in Globus-M, born at the plasma periphery, are comparable with the minor radius of the tokamak.

Starting from the data obtained, it is interesting to estimate the losses, which will be in compact fusion neutron sources designed on the base of a spherical tokamak (FNS-ST). As an example, a project from paper [5] was chosen with the following parameters: R=50 cm, a=30 cm, B=1.5 T, I_p=1.5 MA, $n_e=10^{20}$ m^{-3}, the atomic deuterium beam energy E_b=130 keV. The corresponding parameters for Globus-M are: R=36 cm, a=24 cm, B=0.4 T, I_p=0.2 MA, $n_e=3\times10^{19}$ m^{-3}, E_b=26 keV. Values of the Larmor radius, ρ, and orbit width of fast ions turning on the last confined orbit for Globus-M at such parameters are 6 cm and 10 cm correspondingly. The ratio of Larmor radii for FNS-ST and Globus-M may be expressed by the formula:

$$\frac{\rho^{FNS-ST}}{\rho^{Globus-M}} = \frac{\mathrm{B}^{Globus-M}\sqrt{\mathrm{E}^{FNS-ST}}}{\mathrm{B}^{FNS-ST}\sqrt{\mathrm{E}^{Globus-M}}},$$

where $\mathrm{B}^{Globus-M}, \mathrm{B}^{FNS-ST}$ – are magnetic fields, $\mathrm{E}^{Globus-M}, \mathrm{E}^{FNS-ST}$- are deuteron injection energy in Globus-M and FNS-ST correspondingly. The ratio for the listed above parameters is 0.55. Taking into account slightly larger minor radius of the FNS-ST as compared with Globus-M, one can anticipate somewhat less losses of the fast particles in the FNS-ST associated with TAE. Nevertheless, the final answer can be done by experiment in conditions close to FNS-ST ones. Experiments on the upgraded tokamak Globus-M2 and hydrogen prototype Globus-3 may be considered as successive steps in this direction.

All results of this report have been obtained with the help of the unique scientific device spherical tokamak Globus-M.

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