Beam Ion Driven Instabilities on the Spherical Tokamak Globus-M

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1. Experiment

Theoretical predictions and numerous experiments show that fast ions can produce global plasma instabilities, which lead to their own confinement degradation by the orbit transformation. A detailed review of theoretical and experimental papers refering to this problem may be found, for example, in the report on the ITER project [1,2]. The present paper is devoted to the first results of observation of that type instabilities on the spherical tokamak (R=36 cm, a=24 см, A=1.5) Globus-M [3], at the toroidal magnetic field B_T=0.4 T and the plasma current I_p=200 kA. The neutral beam injector was used on the tokamak [4], capable to produce beams of atomic deuterium and hydrogen with energy up to 30 keV and maximum power of 1 MW. The coinjection is done tangentially in equatorial plane. The beam axis is tangent to the circumference of the 30 cm major radius.

Two branches of fast ion driven instabilities were observed at NBI on spherical tokamak Globus-M: a low frequency mode in the range of 5-30 kHz and a high frequency one in the range of 50-300 kHz. The low frequency modes with relatively high amplitude to the toroidal field value ($B^{\sim}/B_t$) up to 5×10^{-3} were measured by a usual Mirnov probe. The amplitude of the high frequency mode was much lower, ($B^{\sim}/B_t$) ~ 2×10^{-4}. For their registration on the background of stronger signals and pickups a band amplifier was used with maximum amplification in the range of 100-200 kHz. A detector represents a loop, which we will call Alfven loop, of the square 200 cm^2, placed inside the vacuum vessel in the equatorial plane and aligned to measure the radial magnetic field.

The low frequency EPM (energetic particle modes) excited by fast particles were observed in various operation regimes of Globus-M, as during plasma ramp-up, so on the plateau, and mostly represent classical fishbones (see fig.1), observed for the first time on PDX [5]. Until recently we could not record alfven eigenmods (AE) on Globus-M. For the first time they were observed in experiments with the beam injection during the plasma current ramp-up. The Alfven eigenmodes were recorded under conditions of a flat or hollow current density profile, hence the central q did not drop lower than 1, and sawteeth were

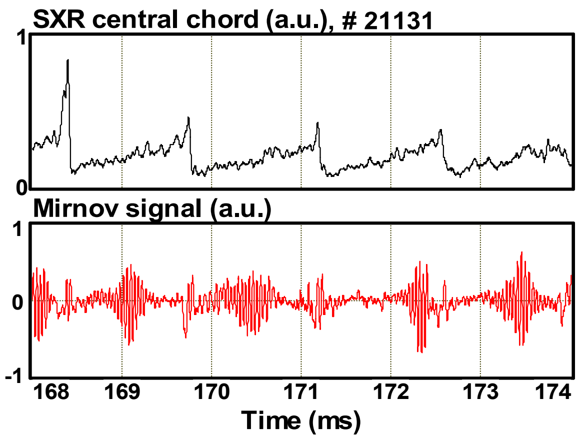

***Fig.1**. SXR and Mirnov signal demonstrating low frequency EPM, fishbone*

absent. The recorded modes were identified as toroidal AE (TAE) due to their frequency range and behavior features [6]. The waveforms of shot #27328 demonstrating TAE development in the shot with deuterium neutral beam injection of 26 keV energy and 0.75 MW power to the deuterium plasma are shown in Fig. 2. Typical bursts of the mode appear in the Alfven loop signal from the time when due to density increase the relation is satisfied $V_f/V_A>1$ where V_A is the Alfven velocity and V_f is the fast ion longitudinal velocity. In the experiments the ratio of the beam particle velocity to the Alfven velocity for the central region of the plasma column $V_{b0}/V_A(0)$ was about 1.8. Usually the TAE existed until $q(0)$ did not drop to 1 and the strong MHD event (IRE or sawteeth) did not appear. The fact that q(0) does not drop lower unity is supported by equilibrium reconstruction with the EFIT code [7,8] and indirectly by the hollow electron temperature profile measured by the Thomson diagnostic and by absence of the sawteeth. Mostly, the TAE mode arose in the form of single or periodic bursts of 1 ms duration with the growth time of several hundred microseconds. Under favorable conditions a regular burst lasted up to several ms at approximately constant amplitude. During one burst the TAE frequency can change smoothly or exhibit chirping. Typical waveforms and spectrograms for the two cases (shots #27328 and #27498) are shown in Fig.3. In the both cases the NB was injected into the deuterium plasma on the plasma current ramp-up. In shot #27328 the deuterium beam with 26 keV energy and 0.75 MW power was injected, and in shot #27497 – the hydrogen beam with 26 keV

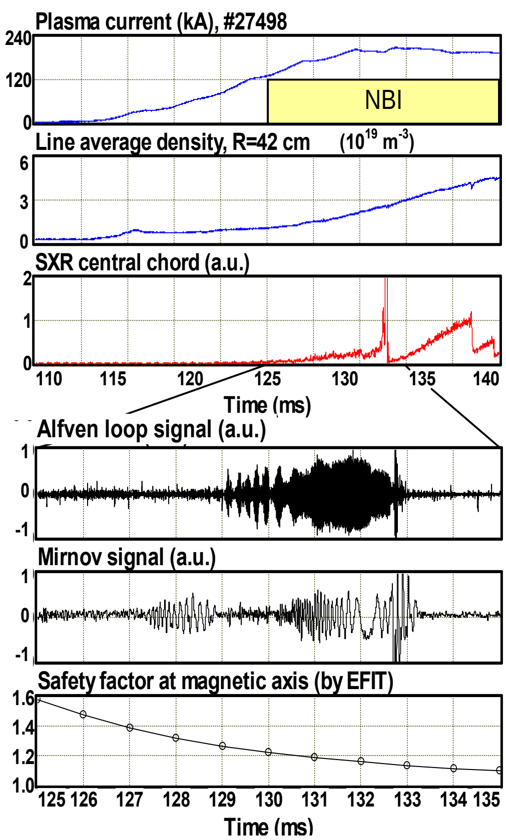

***Fig. 2**. Waveforms of shot #27328 with development of TAE*

energy and 0.85 MW power. In the shot with hydrogen beam the mode arose at lower density, as due to higher hydrogen atomic velocity the condition $V_f > V_A$ is satisfied earlier.

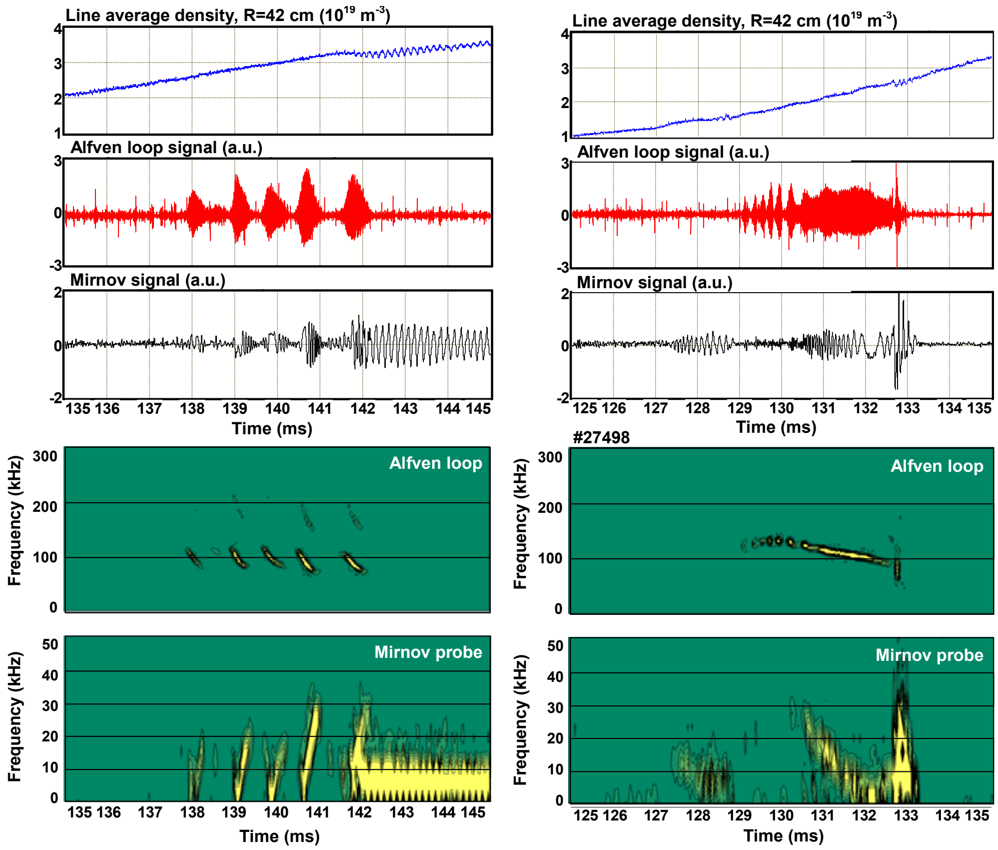

***Fig. 3**. Waveforms and spectrograms of the shots with different peculiarities of TAE: left –deuterium beam, right – hydrogen beam*

2. Discussion and conclusions.

The fast ion driven mode behavior on Globus-M demonstrates both some similar characteristics with analogous modes observed on NSTX and MAST spherical tokamaks, and a row of peculiarities. Although the bursts of the EPM arose synchronously with TAE, they reveal absolutely different temporal behavior. As it is seen from figure 3 (shot #27328), the EPM frequency during the burst first sharply drops, then increases, while the TAE frequency monotonously drops. Unlike experiments on NSTX [9], forming of the toroidally localized TAE wave packet in a fixed position with respect to EPM perturbation did not occur. Another peculiarity concerns the TAE. Only one mode with toroidal number n=1 exists in the perturbation spectrum, as a rule, in contrast to NSTX and MAST, where several modes at once with n=1−6 were observed. Perhaps it is explained by different experimental conditions on Globus-M, where relation $V_{b0}/V_A(0)$ was about 1.8, unlike on NSTX, where it was much higher.

If we use the estimation formula for the mode frequency from [10]: $\omega_{TAE}=V_A/2q(r)R$, then, substituting to this relation the values of frequency and density from the experiment, we obtain the safety factor in the range of the mode existence $q(r)$=1.4-1.8 i.e. $q(r)$~1.5. Then the estimate of the maximum mode number by means of the formula from paper [11]: $n_{max}\approx r\omega_{cf}/q^2V_A$, where ω_{cf} – the cyclotron frequency of the fast ions, gives $n_{max} \approx 1$. Thus, in the experimental conditions of Globus-M, perturbations with n=1 have to develop predominantly. That is confirmed by the Fourier spectrum, in which only single rather narrow line for the first harmonic and essentially weaker second harmonic exist (see Fig. 3). As shown in paper [10], the relation should be satisfied $q(r) = (m_1+m_2)/2n$, so $q(r) = 1.5$ corresponds to $m_1=1$, $m_2=2$ *u* n=1.

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