STUDY OF FAST ION TRANSPORT AND LOSSES DURING ALFVÉN TYPE MHD INSTABILITIES AT GLOBUS-M2

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INTRODUCTION

Low losses of fast ions, arising during additional plasma heating and thermonuclear fusion reactions, are a necessary condition for steady-state operation of a thermonuclear reactor. The development of various magnetohydrodynamic (MHD) instabilities in plasma leads to losses and redistribution in the phase space of high-energy particles, which reduces plasma heating, current-drive and fusion performance, while increasing the thermal load on the in-vessel tokamak components. One type of instabilities that is dangerous to future thermonuclear facility are Alfvén-type instabilities [1], such as the TAE – Toroidal Alfvén Eigenmode and EPM – Energetic Particle Mode. At Globus-M/M2 spherical tokamaks the study of Alfvén modes can be carried out in a wide range of plasma parameters: I_p = 160-450 kA, B_T = 0.4-0.9 T, $n_e = 10^{19}$-10^{20} m^{-3}, E_{NBI} = 20-50 keV, P_{NBI} = 0.3-1.5 MW. The non-dimensional parameter domain v_{fast}/v_a-$\beta_{fast}/\beta_{total}$ (where v_{fast} is velocity of the injected atoms, v_a is Alfvén velocity, β_{fast} is volume-averaged fast ion beta, β_{total} is the sum of the fast ion and plasma betas) of the experiments with TAEs at Globus-M/M2 covers domain of the future ITER DD and DT experiments (Fig. 1).

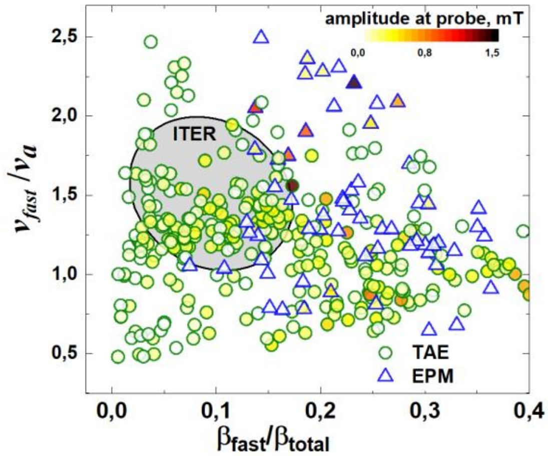

Fig.1. TAE parameter domain of the Globus-M/M2 experiments. Shaded regions—ITER parameter domain. The color differentiation of the dots corresponds to the amplitude of the burst.

DIAGNOSTIC SYSTEM DEVELOPMENT

Studying the influence of TAE (characteristic instability frequency 100 kHz, burst duration ~0.5 ms) on fast particles at Globus-M/M2, a multi-diagnostic approach was used [2]. Using neutral particle analyzer (NPA) measurements with a scanning system in active mode, the transport of fast ion in the center and at the edge of plasma was investigated; silicon precision detectors (SPD) were used to study fast ion losses; the ion flux evolution near the separatrix was studied using the Langmuir probe signal; the effect on the fusion rate was studied by dips in the neutron flux measured using corona boron counters (count rate up to 100 kHz); the Doppler backscattering (DBS) method was applied for the Alfvén eigenmode localization [3].

Over the past two years, tokamak diagnostic complex has expanded significantly: to register fusion products arising from the interaction of fast ions with plasma ions and with each other, with better time resolution, a ITER-like U^{235} fission chamber (counting rate up to 2 MHz) [4] and a fusion proton detector (counting rate up to 4 MHz) [5] were installed; an infrared camera [6] (spatial resolution ~1.3 mm/pixel, time resolution for a frame of 40x64 pixels 0.3 ms) was installed to study the tokamak's first wall heating due to high-energy particle losses during the interaction with toroidal Alfvén eigenmodes, and it became possible to study the time evolution of fast particle losses to the tokamak wall after installing a two-color pyrometer (time resolution up to 2 μs); a compact neutral particle analyzer (CNPA) was installed to study fast ion transport in a wider energy range.

RESULTS

In the study of fast ion transport induced by interaction with TAE [2], a linear dependence without threshold of signal variations from various diagnostics (NPA, SPD, neutron counters) on the mode amplitude during TAE was identified. This observation indicates a resonant ion transport mechanism [1]. During experiments with an infrared camera at Globus-M2 [6], local heating of the outer graphite plates in the equatorial plane due to the fast ion losses caused by

TAE was recorded. A linear threshold dependence of fast particle losses on the mode amplitude was discovered. Based on the simulation, it was shown that this dependence is associated not with the diffusion mechanism for the fast particle transport, but with the characteristic features of their spatial distribution. More detailed studies of fast ion losses during interaction with TAE were performed using a two-color pyrometer, measurements of which were carried out locally (Ø 20 mm) on graphite plates in the equatorial plane of the chamber in the most heated region as measured by an infrared camera.

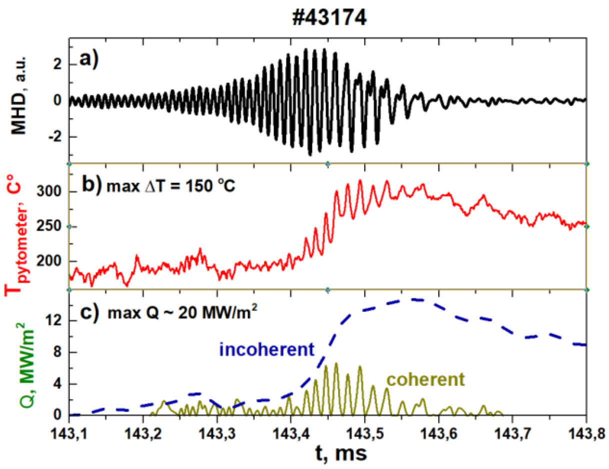

Fig.2. Experimental measurement of wall heating during TAE burst in discharge #43174. From top to bottom: a) MHD probe signal, b) wall temperature measured by pyrometer, c) coherent (solid line) and incoherent (dashed line) heat flux for a film coefficient of 120 W $m^{-2}K^{-1}$. An increase in local wall temperature to 150 °C was experimentally observed, which corresponded to a local heat flux of up to ~20 MW/m^2.

The experimental measurement results of carbon tiles temperature changes during TAE burst are shown in Figure 2. The figure also shows the evolution of the calculated local heat flux due to the fast ions hitting the wall, which can be divided into 2 components: “fast” coherent (relative to the magnetic probe signal) and “slow” incoherent. The time evolution of these components was analyzed, and their dependence on the mode amplitude was considered. The behavior of fast particles interacting with the wave was also simulated. Based on calculations and analysis of experimental data, it was found that the coherent component is associated with the fast ion orbital losses, and the incoherent component is associated with the fact that, as a result of interaction with the wave, fast ions move closer to the plasma boundary, where atom density is high, as a result of which fast ion losses due to charge exchange (CX) increase. It was shown that both mechanisms of fast ion losses - orbital and CX - are caused by the convective resonance mechanism of fast ion transport from the plasma center to the periphery.

In addition to the studies of the interaction of fast ions with TAEs, the study of EPMs was started at Globus-M2. For the first time on Globus-M2 during EPM, a decrease in the flux of CX atoms was recorded using NPA, indicating the transport of fast ions, and an increase in the temperature of the graphite plates of the first wall was detected using a pyrometer, indicating the loss of fast ions.

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