RECENT ADVANCES AT THE GLOBUS-M2 TOKAMAK

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The Globus-M2 spherical tokamak (R=0.36 m, a=0.24 m, achieved B_T=0.95 T, I_p = 450 kA) serves as an experimental platform for advancing our understanding of hot plasma physics, with particular emphasis on plasma confinement, heating, fast ion behaviour, instability phenomena, and diagnostic innovations. Over the past two years, a series of experiments were conducted to study the hot ion mode in D plasma. It was found that the injection of a D beam significantly increases ion temperatures (T_i>4 keV), compared to heating with an H beam ($T_i \approx 2.5$ keV). Energy balance analysis and linear gyrokinetic modeling revealed that the ion thermal conductivity χ_i remains close to the neoclassical level due to the dominance of the ion temperature gradient instability, practically suppressed by the rotational shear [1]. In contrast discharges with H injection exhibited a 3-4 fold increase in the average χ_i compared to the neoclassical estimate. In these experiments transport is dominated by the trapped-electron mode, with a growth rate exceeding the rotational shearing rate. Energy balance analysis supports this observation, as an anomalous ion loss channel has been identified. Notably, electron thermal conductivity was found to be anomalous across all analyzed discharges [2]. In addition to the NBI studies, first experiments with the minority ICRH were conducted demonstrating up to 15% increase in T_i as compared to OH discharges.

The formation of high-field side high-density (HFSHD) in the inner divertor is demonstrated using divertor Thomson scattering (DTS) in a wide range of parameters during both Ohmic and NBI heating [3]. The electron density (n_e) in the plasma center varied from $2 \cdot 10^{19}$ to $1.4 \cdot 10^{20}$ m^{-3}. Measured n_e in HFSHD was 1.5-3 times higher than in the equatorial plane at the same magnetic flux coordinate, while T_e was roughly the same. This phenomenon was confirmed in simulations using the SOLPS-ITER 3.0.8 code with kinetic neutral description and drifts turned on. Another set of experiments focused on measuring SOL width (λ_q) using IR imager within the following parameter range: I_p=155-400 kA and B_T=0.5-0.95 T. The experimental dependence $\lambda_q \sim I_p^{-1}$, also observed in SOLPS-ITER simulations, aligns with the established scaling laws.

Various types of Alfvén instabilities were studied over a wide range of experimental conditions. Drift velocity fluctuations in the crossed radial electric field of the Alfvén wave and tokamak magnetic field were detected using Doppler backscattering (DBS). Multi-frequency DBS was employed to investigate the localization of different Alfvén instabilities and study turbulence behaviour during these modes [4]. A multi-diagnostic approach was utilized to examine energetic ion transport and losses during long living toroidal Alfvén eigenmodes (TAEs), short TAE bursts and energetic particle modes in the v_{fast}/v_a-$\beta_{fast}/\beta_{total}$ domain (0:2.5)-

(0:0.55), which overlaps with the operational domain of ITER [5]. A resonance transport mechanism was identified.

Edge-localized modes (ELMs) were seen to cause an increase in turbulence amplitude, rotation velocity and radial electric field up to 8 cm in the confinement region. However, using standard reflectometry, it was estimated that the ELM development region is limited to approximately 3 cm inside the separatrix. Filament structures were detected as quasi-coherent bursts in DBS signals during both intra- and inter-ELM periods. Two-dimensional full-wave modelling using the IPF-FD3D code found that nonlinear scattering off filaments can lead to an overestimation of the velocity measured using DBS. Poloidal correlation reflectometry allowed to observe their propagation in a top-down direction at velocities of 7-8 km/s. Disruptions are occasionally triggered by tearing modes (TMs), the localization and island width of which were determined using DBS. It was shown that these TMs develop near the q = 2 magnetic surface, indicating their m/n = 2/1 mode structure. Narrow TMs, with an estimated island width of 3 cm, did not cause significant plasma degradation, but wider TMs with island widths of 8–10 cm lead to H-L transitions and even disruptions. Lastly, the impact of locked MHD modes on the efficiency of NBI heating was also investigated.

The stability of the edge plasma under conditions of low aspect ratio and triangularity δ was studied. Experiments with δ=0.2 exhibited the presence of ELMs with f_{ELM} = 2 kHz at a pedestal pressure of approximately 1 kPa in discharges with I_p of 0.3 MA and B_T of 0.7 T. Numerical analysis of the peeling-ballooning mode stability was carried out using BOUT++. The peeling-ballooning stability boundary at low triangularity is characterized by the decreased pressure and low (n=5) toroidal numbers of the unstable mode [6]. In weakly shaped discharges with δ up to 0.2 and a high safety factor ($q_{95} \lesssim 6$) Edge Harmonic Oscillations were observed. Their development at the plasma edge confirmed using DBS [7].

Some of the considered experimental studies were made possible due to the tokamak diagnostic system development. Two new diagnostic tools, based on the prototype equipment for the ITER diagnostics, were successfully utilized: DTS [3] and the ITER-like U^{235} fission chamber [8]. Additionally, a Silicon Precision Detector array for the radiation measurements in a broad spectral range and charged fusion product detector [5] were also installed. Core Thomson scattering, neutral particle analyzer, gamma-ray [9], laser interferometer and pyrometer diagnostics have been upgraded. Furthermore, the development of digital real-time plasma control systems, incorporating algorithms for equilibrium recovery and magnetic configuration control, has begun. Finally, a boron micro-pellet injector based on a plasma gun has been developed.

The conceptual design of Globus-3, the next iteration in the Globus path towards a compact neutron source based on a compact spherical tokamak, is currently under development [10]. The machine will retain the main features from its predecessors, including a relatively small size (R=0.775 m, a = 0.44 m) and extreme beam heating of 11.5 MW, aiming to achieve thermonuclear ion temperatures of ~20 keV. The machine will begin operation with B_T=1.5 T, I_p = 800 kA, and will switch to B_T=1.8 T, I_p = 2 MA after a power supply upgrade. Planned supplementary auxiliary heating and current drive systems include ICRH, LHCD and ECRH.

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