NEUTRAL BEAM INJECTION FOR ELECTRON HEATING OF GLOBUS-M2 SPHERICAL TOKAMAK'S PLASMA

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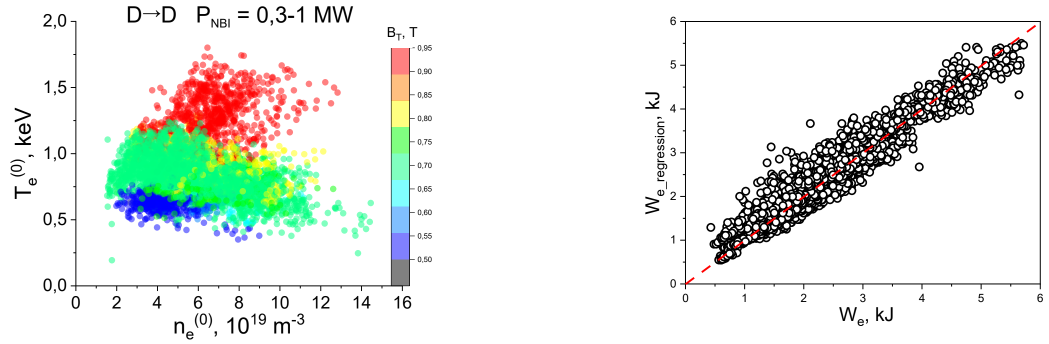
Electronic heat loss is usually one of the main channels of heat loss for tokamak plasma. To study the behaviour of Globus-M2 [1] tokamak plasma's electron component during its additional heating by the neutral beam injector NBI-2 [2], we caried out experiments using a wide range of the tokamak's operating parameters, i.e., the I_p plasma current from 0.150 to 0.425 MA, B_T toroidal magnetic field in the center of the vacuum chamber from 0.50 to 0.95 T, and n_e electron plasma density from 1 to 9 10^{-19} m^{-3}. The NBI-2 created a beam of high-energy deuterium atoms with a 25-50 keV energy and 0.25-1.0 MW power. To determine the plasma parameters, we used Thomson scattering (TS) diagnostics for measuring the electron density n_e and temperature T_e and active charge exchange spectroscopy (CXRS) diagnostics for measuring the ion temperature T_i and other systems [3]. We performed a thorough screening of discharges; as a result, the database comprised about 300 discharges made of more than four thousand profiles of electron temperature and density.

The analysis of TS diagnostics data combined with the results of magnetic equilibrium reconstruction made it possible to determine the thermal energy W_e of plasma electron component. It should be noted that, for all discharges comprising the database, W_{MHD} is more than two times as high as W_e, reaching 6 kJ. This circumstance indicates a noticeable excess of ion temperature over plasma electron temperature, which is confirmed by the CXRS data. Figure 1a displays experimental points of electron temperature in the plasma centre $T_e(0)$ for central electron density $n_e(0)$ at different toroidal magnetic fields B_T shown in color graphics. Experimental results emphasize the effect of plasma-confining magnetic field on plasma's electron temperature, which reaches 1.8 keV, while $T_i(0)$ is 2.5 keV. We explored the shape of plasma electron temperature and density profiles. We showed that the peaking of the density profile depends mainly on the safety factor of the plasma column, and the electron temperature profile is related to the electron density profile by the dependence $T_e = const \cdot n_e^{1.57}$.

We analysed the effect of plasma current, toroidal magnetic field on the plasma column, electron density, and input power of the atomic beam P_{NBI} on plasma heating efficiency. Linear regression of data shows strong dependence of W_e on plasma current and moderate dependence on toroidal magnetic field (see Figure 1b): $W_e \sim I_p^{1.07} B_t^{0.6} n_e^{0.63} P_{NBI}^{0.08}$, whereas the effect of injected beam power on electron temperature and, consequently, on electron energy content is negligible. To discover what caused this effect, we selected modes with fixed n_e = $5 \cdot 10^{-19}$ m^{-3}, whereat maximum ion temperatures are achieved, from the sampling: B_T = 0.7 T, I_p = 300 kA and B_T = 0.9 T, I_p = 400 kA with 2.5-3x difference in P_{NBI} values. For the selected modes, we calculated absorbed power from the atomic beam using a modified orbital code tracking the trajectories of fast particles [4] and the NUBEAM code [5]. We calculated plasma loop voltage taking into account inductive corrections, ohmic power of its heating, as well as the efficiency of auxiliary heating of plasma electrons, using the ASTRA transport code [6]. Based on these data, we performed comparative analysis of the energy balance, calculated particle and thermal diffusivity coefficients, and determined energy confinement time τ_E. With B_T and I_p going up by a factor of 1.3 and P_{NBI} staying the same, the energy confinement time τ_E exhibits a 1.6-fold increase, which is consistent with scaling predictions [7]. In the cases under consideration, the thermal insulation of ions is significantly better than that of electrons, since the energy confinement time of ions is 2.5-4x higher than that of electrons, which means that τ_E is determined primarily by the plasma's electron component.



a) b)

Figure 1. (a) Comparison of T_e^0 with n_e^0 for all time points of discharges from the database, (b) Linear regression of W_e by plasma current, toroidal magnetic field, its average density, and input injection power

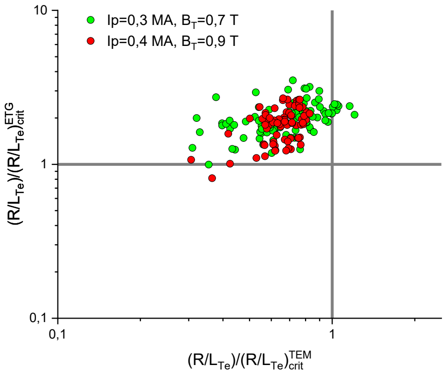


Figure 2. Discharge susceptibility to TEM and ETG development

Figure 2 shows discharge stability under microturbulence. Our analysis indicated that β_e was below 3%. Therefore, the development of electromagnetic instabilities was highly unlikely. However, the comparison of the normalized temperature gradient R/L_{Te} with threshold values of trapped electron mode (TEM) development and electron temperature gradient (ETG) instabilities shows that the electrostatic ETG is unstable, and it likely determines electron transfer in these modes. To check this hypothesis, we performed gyrokinetic modeling using the GENE code [8].

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