Study of electron component dynamics during neutral beam injection into spherical tokamak Globus-M

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Introduction.

Transport barriers are of considerable importance in plasma thermal insulation and minimization of particle losses. The external transport barrier (ETB) is a feature of high confinement regime (H-mode) which considerably reduces requirements for auxiliary heating sources. Internal transport barriers (ITB) are important for the advanced tokamak scenario achievement with high fraction of noninductively driven current, but unlike the H-mode they are characterized by the nonstationary plasma current profile distribution. The algorithm elaboration of the barrier formation is a key to drive the spatial distributions of electron temperature and density to get their specified high values in the plasma center and increase the energy confinement time. In the paper we present the data on the research of dynamics of an electronic component on the Globus-M tokamak during the neutral beam injection (NBI). The emphasis was made on the experiments on the NB injection at the phase of the plasma current ramp-up. The regimes with the early beam injection create advantages for a reversed magnetic shear configuration. Also such regimes are generally accompanied by increased toroidal plasma rotation. The transport barriers might be formed in such conditions inside the plasma column. Due to the low density specific for the current ramp-up phase it was previously impossible to achieve a stable discharge on Globus-M with above scenario.

Diagnostics.

The key tool of the research is the upgraded Thomson scattering (TS) diagnostics. It provided 20 measurements of temperature $T_e(R)$ and density $n_e(R)$ during one shot in up to 10 spatial points, located from inner to outer plasma border in an equatorial tokamak plane [1]. The TS data were supplemented by a movable Langmuir probe to get the n_e , T_e distributions at the separatrix vicinity. Besides, a wide set of diagnostics tools, including two analyzers of neutral particles (NPA) with a tangential and radial view direction [2] was applied. The Doppler reflectometer [3] provided the data on the periphery plasma rotation.

On the basis of the diagnostics set and an equilibrium reconstruction code EFIT the dynamic modeling was performed using the ASTRA transport code [4] expanded by the NCLASS module [5].

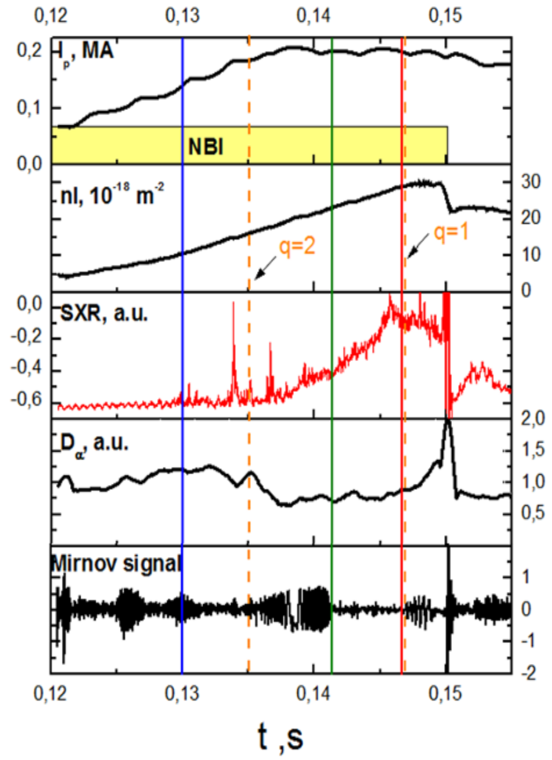

Fig.1. Waveforms of shot #26626

Experiment and modeling.

In the discussed experiments on Globus-M the injection of hydrogen beam (energy 27 keV, power 0.8 MW) began 5 ms after the plasma current start. The basic characteristics of the discharge are shown in Fig. 1. The rate of the plasma current was as high as 8 MA/s. The growth of density, signals of soft x-ray and D_α emission are observed at the stage of current ramp-up. The transition to the H-mode is observed at 133 ms and is accompanied by falling D_α emission during the density grows. Fig. 2 demonstrates the TS data – 3D temporal/spatial electron density and temperature distribution. What we see here is formation of peaked density profile with rather high values in a maximum ~$9 \cdot 10^{20}$ m^{-3} and wide profiles of temperature peaked as $T_{e0}/\langle T \rangle \approx 1.6$ with the maximum values 450 eV. Under these conditions the total energy content was as high as 3.6 kJ with the energy confinement time 3.2 ms, which correlates with the ITER scaling for H-mode [6] τ_{ITER}=3.5 ms.

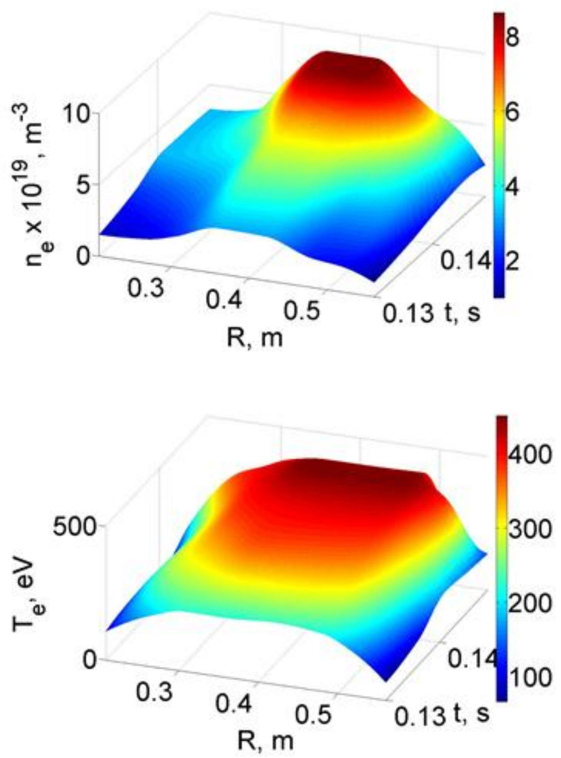

Fig.2. TS data, shot#26626.

For this discharge the dynamic simulation by the ASTRA code has been performed assuming that the boundary value condition for poloidal flux comes from the condition relation that the total plasma current should be equal to the calculated value, for the conductivity using the neoclassical expression value calculated by NCLASS. The last close flux surface is set by its center R_0 , half-width a_b , Shafranov shift Δ_b , elongation λ_b and triangularity δ_b . These values are taken from equilibrium reconstruction performed with the help of EFIT code [7], subscript index b denoted boundary values. The transport coefficients were fit in such a way that the density and temperature profiles agreed with the experimental data. The value of the loop voltage was chosen to match the experimental one by variation of the effective charge of plasma. Its values were fixed along small radius. Fig. 3 demonstrates spatial distributions of electron density and temperature at 146 ms (the red line in Fig. 1). The points in Fig.1 correspond to the experimental data, curves result from the simulation for the diffusion and thermal conductivity coefficients presented lower (Fig. 3 c, d). The spatial areas are seen to have the reduced particle and energy transport. In addition to the transport barrier in the periphery conventional for H-mode, there arises the lowered transport of particle, that is placed deep inside the plasma column (internal diffusive barrier). The temperature profile demonstrates only a single barrier, located around the small radius midpoint.

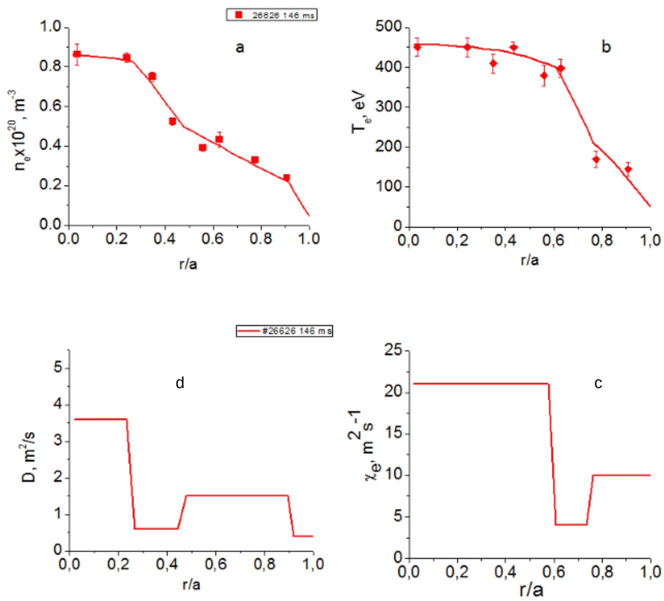

Fig.3. a, b -TS profiles, shot#26626.
Points- TS experiment, lines –ASTRA fitting
d, c – coefficients of diffusion and thermal conductivity

The magnetic shear r/q·(dq/dr) was calculated by solving the equation of the poloidal magnetic field diffusion with ASTRA code. Its distribution in plasma is presented in Fig.4. From the data in Figs. 2 and 3, the maximal temperature gradient is observed in the region of the weak positive shear, whereas the maximal density gradient is in the negative shear close to its minimal value. The both transport barriers are associated with regime of the weak magnetic shear [8], whose lifetime is limited by forming a magnetic surface q=1. Fig.1 shows that just after the forming of surface with q≤1 at 147 ms, the SXR and D_α intensities start dropping, the line averaged density growth comes to end, which indicates the confinement degradation. Thereafter the strong MHD instability emerges (hypothetically m/n=1) followed by the internal reconnection effect, which results in the plasma “mixing” in the central area. The disturbance of magnetic configuration was observed on plasma periphery too. The measurements of plasma velocity rotation codirectional with diamagnetic drift of charged particle measured by Doppler reflectometer have demonstrated that the beginning of the confinement degradation is accompanied with a fast change of rotation direction. The new rotation direction appears to be the same as the direction of the ion diamagnetic drift. This fact is likely to be evidence that positive electric field is suddenly initiated on plasma periphery. In turn, this field variation may originate due to the strong disturbances of the magnetic field on the plasma border.

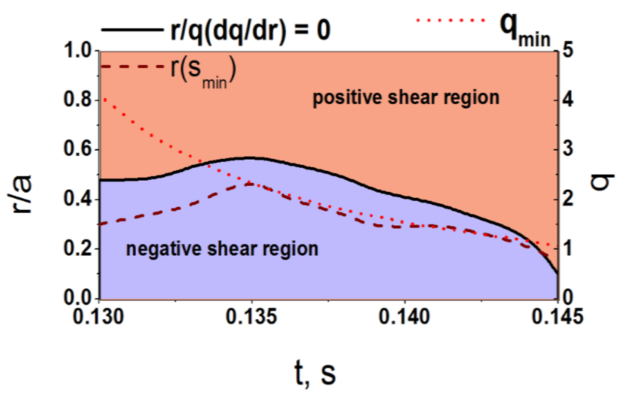

Fig.4. Magnetic shear r/q·(dq/dr) distribution

Conclusions.

The TS upgrade provided measurements of full n_e and T_e profile dynamics on the Globus-M tokamak. Confident basis for transport simulation is created. The first results on early beam heating are presented and discussed.

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The work is supported by the Ministry of Education and Science of Russian Federation as well as by the RFBR grants: 08-02-00511, 08-02-00992, 09-02-00984, 10-02-01421, 10-02-00746 and by Russian Federation President Program for State Support of young Russian scientists Grant No. MK-3435.2009.2