First results of the experiments with two-fold increase in NBI power on the TUMAN-3M tokamak

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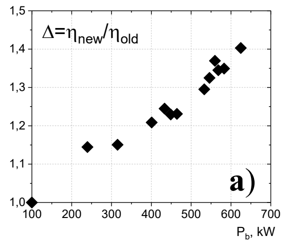
Introduction

The idea of creating a powerful neutron source based on a compact tokamak concept is discussed [1, 2, 3]. Due to the small size of the compact tokamak, there may be difficulties both with the transportation of a high-power neutral beam to tokamak and with the fast ions confinement in the plasma [4, 5]. Thus it is necessary to investigate the physical processes leading to the fast ions losses in the plasma and to determine ways to improve their confinement. The losses of fast particles and their thermalisation in the TUMAN-3M tokamak plasma were studied using neutron diagnostics. The use of a more powerful ion source of the injector has required the modernization of the connecting port. The experiments with the new connecting port have demonstrated a 1.5 - 2 fold increase in the neutron flux intensity.

Experiment

In the first experiments on NBI heating of a deuterium plasma with a deuterium beam at the TUMAN-3M tokamak, in which a low-power IS-2 ion source was used, a saturation of the plasma ion temperature T_i with an increase in P_b was observed already at $P_b \sim 300$ kW. The intensity of the neutron flux R_n also saturated at $P_b > 300$ kW. A neutron detector consisting of a ^{3}He gas-discharge counter and a polyethylene moderator was used to measure the 2.45 MeV neutron flux R_n [6]. Measurements of R_n demonstrated a significant discrepancy between experiment and simulation results for $P_b > 300$ kW [7]. For further studies of the efficiency of plasma injection heating and neutron generation, a new, more powerful ion source IS-1 was installed at the TUMAN-3M tokamak. With the same beam energy E_b, the power of the beam of the IS-1 source P_b is almost twice of the previous ion source IS-2 power. Doubling the power of IS-1 compared to IS-2 is achieved by increasing the emission surface of the ion source. However, the expected twofold increase in R_n was not observed experimentally.

It was conjectured that, due to the increase in the beam cross-section of IS-1 ion source, the injected fast atoms can be lost in the connecting port between the injector and the tokamak.



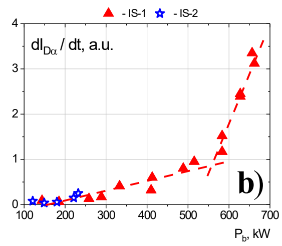


Figure 1. **a)** relative behavior of the beam transmittance η in the new transport tract depending on the beam power P_b for the IS-1; **b)** dependence of the growth rate of the line intensity $I_{D\alpha}$ on the P_b beam power on the new connecting port

The estimation of the loss of the deuterium beam in the connecting port was carried out using the model described in [4]. The parameters of the IS-1 ion source were used in the calculation. The size of the new connecting port was changed to minimize the growth of residual gas pressure in the port during the beam injection. According to the calculation, the transmission coefficients of the neutral deuterium beam η were obtained for two configurations of the connecting port. Figure 1-a shows the dependence of $\Delta = \eta_{new}/\eta_{old}$ on the beam power P_b, where η_{new} is the simulated transmittance of the new connecting port, η_{old} is the simulated transmittance of the old one. An analysis of the obtained dependence $\Delta(P_b)$ shows that when the beam power $P_b \sim 600$ kW is reached, the transmittance efficiency in the new connecting port becomes 1.4 times higher than with the old configuration of the connecting port.

The new connecting port is equipped with a diagnostic port for measuring the intensity of the D_α line $I_{D\alpha}$. $I_{D\alpha}$ arises as a result of the interaction of the particles of the deuterium beam with the deuterium atoms of the residual gas in the connecting port. Figure 1-b shows the dependence dI_{D_α}/dt in the connecting port on the beam power P_b. The rate of $I_{D\alpha}$ increases during NBI pulse, dI_{D_α}/dt, grows relatively slowly with P_b until P_b exceeds ~ 500 kW. A further increase in P_b leads to a strong increase in $I_{D\alpha}$ inside the port, which indicates an increase in the losses of the beam atoms in the connecting port.

A decrease in the loss of beam particles during transportation in a new connecting port was confirmed by measurements of the integral neutron flux R_n during injection of a deuterium beam into deuterium plasma. Figure 2-a shows the $R_n(P_b)$ dependence in the old and new connecting ports and the IS-1 ion source. The main plasma parameters were as follows: $B_t = 1$ T, $I_p = 175$ kA and $n_e \geq 2 \cdot 10^{19}$ m^{-3}. For the IS-1 ion source, the new connecting port allowed increasing the neutron flux R_n by 1.5 times in comparison with the old connecting port. This is direct evidence of a decrease in the losses of energetic particles of the beam during its transportation into the plasma.

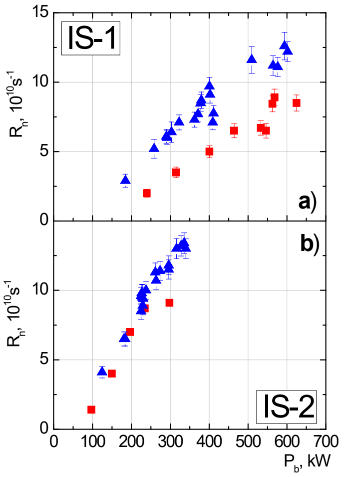


Figure 2 Dependence of the integral neutron flux R_n on the beam power P_b at the exit from the injector when using the old connecting port (■) and the new connecting port with a large cross section - (▲) for IS-1 (**a**) and IS-2 (**b**)

Figure 2-b shows the $R_n(P_b)$ dependence for a less powerful ion source IS-2. When the old connecting port and ion source IS-2 were used, a saturation of the neutron flux was observed at $P_b > 200$ kW, R_n did not exceed $\sim 9 \cdot 10^{10}$ s^{-1}. R_n increased significantly at $P_b > 200$ kW after the installation of the modernized connecting port and no saturation was observed in $R_n(P_b)$ dependence. The new connecting port allowed to reach the record for the TUMAN-3M tokamak value of the neutron flux: $R_n \sim 1.4 \cdot 10^{11}$ s^{-1}.

Earlier, with the old connecting port, power-law scaling of the neutron dependence of R_{EMP1} on the plasma density n_e, toroidal magnetic field B_t, plasma current I_p, heating-beam energy E_b, and injection energy P_b was constructed [7]. Neutron measurements obtained after the modernization of the connecting port made it possible to extend the scaling to higher values of R_n (see figure 3), with slightly clarified exponents:

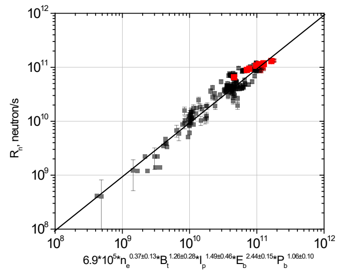


Figure 3 Measured neutron emission R_n versus scaling (1) predictions. Red squares - R_n obtained after the modernization of the connecting port

$$R_{EMP2} = 6.9 \cdot 10^5 \cdot n_e^{0.37\pm0.13} \cdot B_t^{1.26\pm0.28} \cdot I_p^{1.49\pm0.46} \cdot E_b^{2.44\pm0.15} \cdot P_b^{1.06\pm0.10} \quad (1).$$

Conclusion

This paper describes the results on improving the transportation of the heating beam into the plasma on the compact TUMAN-3M tokamak. To improve the conditions for the transportation of the heating beam, a new connecting port was manufactured with a double cross-section area compared to the old one. The parameters of the new connecting port were selected based on the calculation of the beam power transmittance η in the transport tract. Taking into account the loss of the beam power in the connecting port made it possible to explain the observed difference in the neutron yield for both IS-2 and IS-1. The new connecting port allowed to reach the record for the TUMAN-3M tokamak value of the neutron flux: $R_n \sim 1.4 \cdot 10^{11}$ s^{-1}.

Acknowledgments

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