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Energy Confinement in a Spherical Tokamak Globus-M2 with a Toroidal Magnetic Field Approaching 0.8 T

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The presentation is devoted to the thermal energy confinement study at the compact spherical tokamak (ST) Globus-M2 that was designed to reach toroidal magnetic field as high as B_T =1 T and plasma current I_p = 0.5 MA having a small plasma minor radius *a* = 0.22-0.23 m. The first neutral beam heating experiments on Globus-M2 were carried out using one deuterium beam with particle energy 28 keV and heating power 0.8 MW in a plasma with I_p=0.25-0.35 MA and B_T=0.7-0.8 T.Plasma magnetic configuration was lower null with aspect ratio *A* = *R/a* = 1.5-1.6, triangularity δ ~ 0.35 and moderate elongation κ~1.9. The loss power is Globus-M2 is significantly higher than the empirical threshold [1] in spite of almost double increase of B_T (in comparison with Globus-M) providing easy access to H-mode: transition occurs a few milliseconds after NBI (neutral beam injection) starts if the discharge line average density is higher than $1.5 - 2\ 10^{19}\ m^{-3}$. Transition is accompanied with strong increase of poloidal rotation in the vicinity of the separatrix and simultaneous fluctuation intensity drop according to reflectometer measurements. Plasma total stored energy measured by diamagnetic loop (W_{DIA}) reached 7 kJ that is 3 times higher than it was observed at the Globus-M in discharges at B_T=0.4 T and I_p= 0.2 MA with the same plasma size and the input heating power. The contribution of the fast particles perpendicular pressure on W_{DIA} was within the 10% range according to Monte Carlo simulation NUBEAM and full orbit modelling using 3D fast ion tracking algorithm. The main origin for energy content rise was an increase in energy confinement time ($_E$) by 2.5 times. The obtained $_E$ values are higher than those predicted by IPB98(y,2) and are in good agreement with the Globus-M scaling due to the strong $_E$ dependence on the toroidal magnetic field. The regression fit of the Globus-M/Globus-M2 data yields the following scaling for energy confinement time:
$_E$ ~ $I_p^{0.58\pm0.11} B_T^{1.23\pm0.07} P_{abs}^{-0.66\pm0.12} n_e^{0.63\pm0.05}$,
with rather good mean absolute percentage error (MAPE = 8.4%). Here P_{abs} is the absorbed heating power (the contribution of the ohmic heating power is approximately the half of the P_{abs}) and n_e is the line average density. The dedicated current scan for the fixed B_T=0.7 T and n_e=4.5·10^{19} m^{-3} confirms weak $_E$ dependence on I_p that emphasize the major role of B_T on heat perpendicular transport in STs. Enhanced plasma parameters allowed to extend the dependence of the normalized energy confinement time (B_{TE}) on collsionality (* ~ n_e/T^2) down to significantly lower * values. This dependence turned out to be rather strong B_{TE} ~ $*^{-0.8}$ for a fixed values of safety factor *q* ~ B_T/I_p, normalized ion gyroradius * ~ $T^{0.5}/B_T$ and parameter $_T$ ~ W/B_T^2. Power balance analysis carried out using ASTRA transport code indicates the reduction of both electron and ion heat diffusivity with collisionality decrease while the ion heat diffusivity remains the neoclassical level.
This presentation represents a first careful analysis of the energy confinement properties for NBI H-mode plasma in a high toroidal magnetic field ST. The obtained experimental result demonstrates that ST scaling trend achieved at MAST, NSTX and Globus-M machines in the narrow range of the toroidal magnetic field (B_T=0.3-0.55 T on NSTX [2], B_T=0.34-0.50 T on MAST [3] and B_T=0.25-0.5 T on Globus-M [4]) persists within the range B_T<0.75 T. The obtained result is quite promising for plasma parameters extrapolation towards fusion neutron source device that should operate in the low collisionality range. Furthermore, low aspect ratio is also preferable for advanced tokamak operation scenario [5,6] due to strong $_E$ dependence on B_T and weak on I_p that should allow to achieve a high bootstrap current fraction (due lowering I_p and consequently beta poloidal increase) without significant energy confinement degradation that is crucial for high aspect ratio tokamaks IPB98(y,2) $_E$ ~ $I_p^{0.93} B_T^{0.15}$.
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