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Experiments on ST40 towards burning plasma conditions

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Experiments on ST40 towards burning plasma conditions
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Spherical Tokamak (ST) path to Fusion has been proposed in R Stambaugh et al, Fus. Tech. 33 (1998) 1, and experiments on STs have already demonstrated feasibility of this approach. Advances in High Temperature Superconductor (HTS) technology (M Gryaznevich et al, Fus. Eng. & Design 88 (2013) 1593) allows significant increase in the Toroidal Field (TF) which was found to improve confinement in STs. The combination of the high beta, which has been achieved in STs, and high TF that can be produced by HTS TF magnets, opens a path to lower-volume fusion reactors, in accordance with the fusion power scaling ˜ betaˆ2Btˆ4V. High field spherical tokamak ST40 (design parameters: R=0.4-0.6m, R/a=1.6-1.8, Ipl=2MA, Bt=3T, k=2.5, pulse˜1-2sec, 2MW NBI, 2MW ECRH/EBW, DD and DT operations) is the first prototype on this path and is now operating, Fig.1.

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Plasma current > 0.5MA at 2T TF, electron and ion temperatures in a several-keV range produced using merging-compression formation, solenoid-assisted ramp-up and 1MW of 25kV NBH, and densities up to 2x10ˆ20mˆ-3 have been achieved in the first experimental campaigns in 2018-2020. At the flat-top, measured Ti increases with TF, in agreement with observations on other STs. However, on ST40, at TF > 1 −1.1T we observe sharp increase in Te, Ti and W(EFIT), Fig.2.

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TF Cu magnet in ST40 and some PF coils are LN2 cooled and research is on-going on development of full-HTS magnets. HTS prototype magnet with 24.4 T (at 21 deg K) has been built, Fig.3, and now we are planning to increase the field. LN2 cooling of present Cu magnets, installation of the second 1MW 50kV beam and upgrades of power supplies are on-going and will allow increase of TF to 3T and the pulse duration from ˜0.3sec (at present) to 1-2sec.

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Experiments are carried out to study transport properties in ST at higher TF, higher heating power (up to 4MW), low collisionality, in aim to bring plasma parameters close to burning conditions. Transport simulations with ASTRA, NUBEAM and TSC codes have been performed to model ST40 parameters and to support the physics basis of the compact high field ST path to Fusion. We show that high confinement regimes with just collisional (neoclassical) transport can be expected even when only ohmically heated. In an auxiliary heating regime, we find a hot ion mode with Ti in the 10keV range to be achievable in ST40 with as low as 1MW of absorbed power, Fig.4.

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Issues connected with specific features of the high field ST are discussed, i.e. limitations of applicability of confinement scalings for prediction of performance of ST40. However, we show that if the performance achieved on other spherical tokamaks can be extended to ST40 conditions, up to 1 MW of Fusion power can be expected in DT operations. Studies of fast ions and alpha particle transport, heating and current drive, torque deposition and momentum transport have been performed using ASCOT, NUBEAM, Monte Carlo code NFREYA and the Fokker - Planck code NFIFPC. Different NBI energies and launch geometries have been studied and optimised. The confinement of thermal alphas in ST40 3T/2MA scenario is studied with full orbit following (which is necessary because of the large, compared to the plasma size, alpha particle gyro radius). The first orbit losses are seen to be above 60% even in the high-performance scenario illustrating that the alpha confinement in a small device is very difficult even at the highest available fields and plasma currents. However, DT experiments on ST40 will provide useful information for verification of such simulations.

We are intensively working on the design of our next tokamak, ST-F1, with plasma volume ˜0.5 of JET. This device is aimed to demonstrate Q>3, will have HTS magnets, tritium blanket, and the goal is to build it by 2025.

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