Neutral beam current drive simulations on MAST

O. Asunta[1], R. Akers[2], G. Corrigan[2], D. Keeling[2], T. Kurki-Suonio[1], D. Muir[2], M. Romanelli[2], A. Salmi[1], and M. Turnyanskiy[2]

[1] *Aalto University, Assn. Euratom-TEKES, P.O. Box 14100, FI-00076 AALTO, Finland*

[2] *EURATOM/CCFE Fusion Assn., Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK*

Introduction

Steady-state operation of a tokamak requires the toroidal current to be driven non-inductively. Moreover, driving current off-axis is of vital importance for the steady-state (or advanced) operating scenario in ITER where it is needed for tailoring the q-profile in order to avoid detrimental magnetohydrodynamic (MHD) activity. One means foreseen for driving off-axis current is using neutral beam injection (NBI). In MAST (Mega Ampere Spherical Tokamak) [1] experimental evidence of off-axis neutral-beam driven current has been observed and reported in [2].

In this work, neutral beam injection and current drive in MAST is modelled with two codes: ASCOT [3] and NUBEAM/TRANSP [4]. Both are test-particle Monte Carlo -codes, but they use different methods for following the particles: NUBEAM follows particles' guiding-centre, but includes a Finite Larmor Radius (FLR) correction, whereas ASCOT is able to follow either one [5]. Since MAST is a small aspect ratio tokamak with a relatively low magnetic field, FLR-effects are assumed to play a role in particles' overall behaviour.

In addition to studying NBI current drive, the purpose of this work is to establish ASCOT as NBI module of JINTRAC [6] suite of codes for MAST simulations and perform a benchmark between ASCOT and TRANSP.

MAST and simulated discharges

MAST [1] is a spherical tokamak with major radius $R \sim 0.85$ m, minor radius $a \sim 0.65$ m, plasma current $I_p \sim 1.3$ MA, and toroidal magnetic field at the magnetic axis $B_t \sim 0.5$ T. It is designed to study highly elongated ($\kappa > 2$) low aspect-ratio plasmas. The two identical neutral beam injectors installed on MAST can produce up to 4.0 MW of NBI power for 0.5 seconds, and make MAST ideal for power scaling studies.

MAST is also good for fast ion studies because its neutron emission is dominated by neutrons from beam-plasma fusion reactions. Due to the high energy of the beams ($\sim$60 keV) and low plasma ion temperature ($\sim$2 keV), the cross-section for beam-thermal fusion reactions is substantially larger than that for thermal-thermal fusion reactions. Therefore, measuring the neutron flux with neutron camera (NC) [7] provides valuable information on the fast ion distribution.

Two co-NBI heated MAST L-mode discharges with I_p ~0.8 MA were used as a basis of this study; #26864 (P_{NBI} ~3.0 MW) and #26887 (P_{NBI} ~1.5 MW). In TRANSP simulations of the P_{NBI} ~1.5 MW discharge, the simulated neutron flux matched well with the experimental findings. For the P_{NBI} ~3.0 MW discharges, on the other hand, an additional *ad hoc* radial fast ion diffusion coefficient, D_{ano}, was needed to make the simulations match the experiment.

ASCOT vs. NUBEAM/TRANSP

Both ASCOT [3] and the NBI module of TRANSP, NUBEAM [4], are test particle following Monte Carlo (MC) codes. They integrate particles' equation of motion in time and model its collisions with the background plasma using MC collision operators for energy diffusion and pitch angle scattering. In the simulations performed for this work, the same T and n profiles were used in both codes. The magnetic equilibria, however, were slightly different, because ASCOT uses the equilibrium from the experiment (EFIT), whereas TRANSP calculates its own equilibrium. The flux surface structure used by ASCOT, and the last closed flux surface used by TRANSP, are shown in the upper panel of Fig. 1. Differences in flux surface structure causes discrepancies in volume elements and, consequently, the profile shapes.

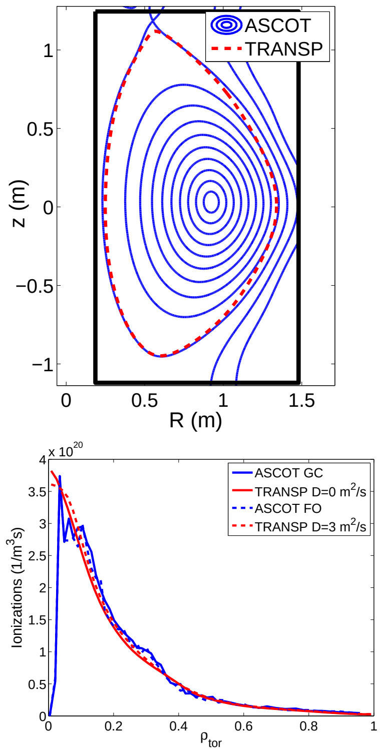

Figure 1: ASCOT flux surfaces and TRANSP separatrix (top), and initial distribution of ionized particles (bottom).

Another potential source of initial difference between the two codes is the NBI particle source, as both ASCOT and TRANSP have their own built-in NBI models. However, as the lower panel in Fig. 1 shows, the source profiles produced by the two codes are nearly identical. Other discrepancies between the codes include toroidal rotation, that is not (yet) taken into account in ASCOT, and FLR correction used in TRANSP.

Beam profile comparisons

Fast ion density, fast ion current density and power deposition to ions and electrons for the P_{NBI} ~3.0 MW discharge are depicted in Fig. 2. They show that TRANSP without anomalous diffusion produces similar profiles to guiding-center following ASCOT (ASCOT GC). The toroidal rotation, included in TRANSP, probably causes the difference in NBI slowing down velocity distribution and, consequently the fast ion current distribution depicted in Fig. 2(b).

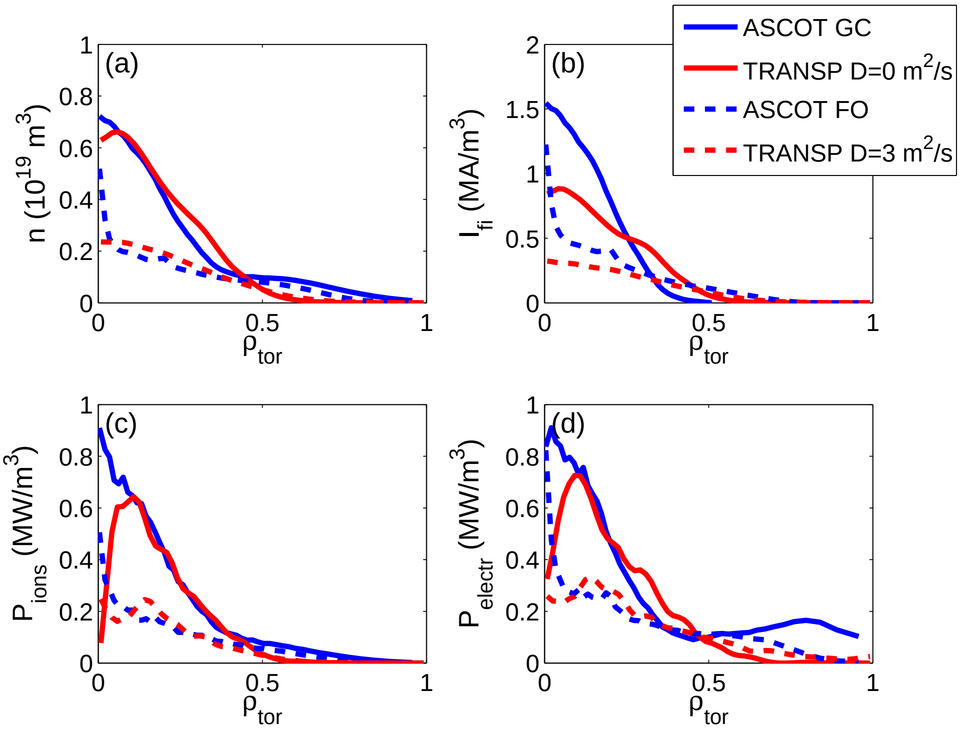

Figure 2: Fast ion density (a), current density (without electron shielding) (b), and power deposition to (c) ions and (d) electrons in the $P_{\mathrm{NBI}} \sim$3.0 MW discharge. Guiding-center simulation with ASCOT gives profiles comparable to TRANSP without anomalous diffusion, whereas the profiles from full-orbit ASCOT simulation are similar to TRANSP simulation with $D_{\mathrm{ano}} = 3\,\mathrm{m}^2/\mathrm{s}$.

The difference from ASCOT GC to full-orbit following ASCOT (ASCOT FO) is striking. With ASCOT FO, radial particle transport is strongly increased, leading to increased losses and, therefore, lower particle density throughout the plasma. The results from TRANSP with $D_{\mathrm{ano}} = 3\,\mathrm{m}^2/\mathrm{s}$ and full-orbit following ASCOT (ASCOT FO) resemble each other.

For the $P_{\mathrm{NBI}} \sim$1.5 MW discharge, in which the best match with experiment was achieved in a TRANSP run with $D_{\mathrm{ano}} = 0\,\mathrm{m}^2/\mathrm{s}$, the results are in stark contrast to the discharge with $P_{\mathrm{NBI}} \sim$3.0 MW: ASCOT FO gives much lower fast ion densities than what would be needed to match the experiment. This discrepancy is still under investigation.

Summary and discussion

ASCOT was established as NBI module of JINTRAC [6] for MAST simulations. Beam profiles from ASCOT GC were similar to those produced by TRANSP. The differences, particularly in fast ion current, could be at least partly explained by toroidal rotation of the plasma. It has central value of ~190 krad/s (~160 krad/s) in the $P_{\mathrm{NBI}} \sim$3.0 MW ($P_{\mathrm{NBI}} \sim$1.5 MW) discharge, and is not yet taken into account in ASCOT. This will soon be amended.

ASCOT FO results of the two discharges suggest that FLR effects have a significant effect in MAST. However, consistency with experimental findings has not been achieved and more work

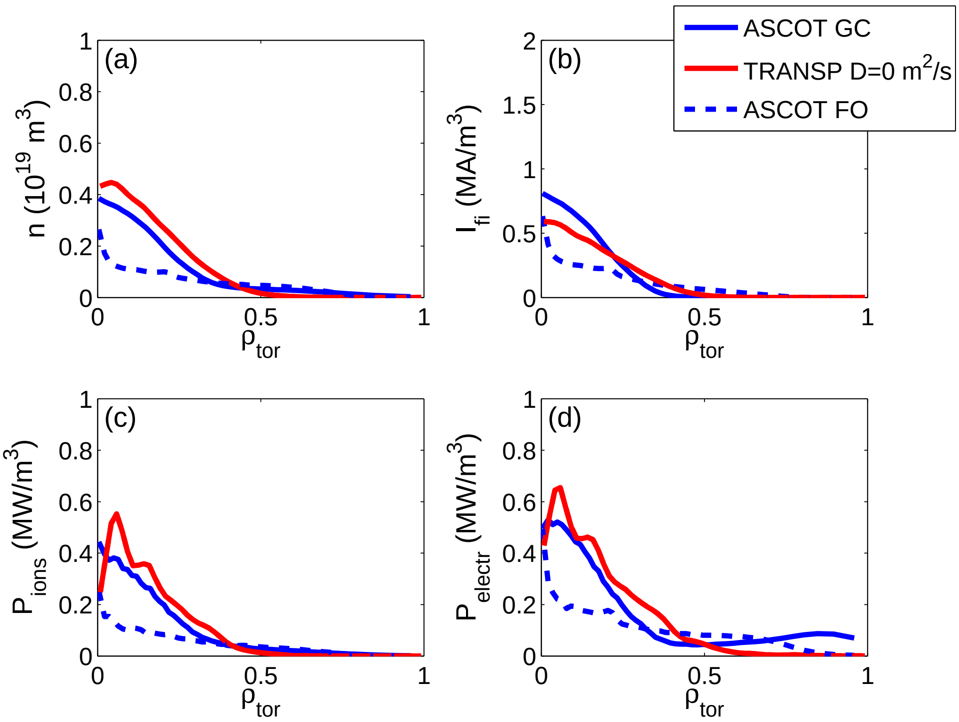

Figure 3: Fast ion density (a), current density (without electron shielding) (b), and power deposition to (c) ions and (d) electrons in the P_{NBI} ~1.5 MW discharge. Guiding-center simulation with ASCOT gives profiles comparable to TRANSP without anomalous diffusion, whereas the profiles from full-orbit ASCOT simulation are similar to TRANSP simulation with $D_{ano} = 3\,m^2/s$.

is needed to understand the results. To this end, future comparison between ASCOT FO and full-orbit following code LOCUST [8] will be very educational.

References

[1] B. Lloyd *et al.*, Nucl. Fusion **43**, 1665 (2003)

[2] M. Turnyanskiy *et al.*, Nucl. Fusion **49**, 065002 (2009)

[3] T. Kurki-Suonio, *et al.*, Nuclear Fusion **49**, 095001 (2009)

[4] A. Pankin *et al.*, Comput. Phys. Commun. **159**, 157 (2004)

[5] A. Snicker *et al.*, IEEE Transactions on Plasma Science **38** 2177 (2010)

[6] S. Wiesen, *JINTRAC – JET modelling suite*, http://www.eirene.de/JINTRAC_Report_2008.pdf, (2008)

[7] M. Cecconello *et al.*, Rev. Sci. Instrum. **81**, 10D315 (2010)

[8] R.J. Akers *et al.*, Nucl. Fusion **42**, 122 (2002)

This work was partially funded by the Academy of Finland projects No. 121371 and 134924, and by the UK Engineering and Physical Sciences Research Council. This work, supported by the European Communities under the contract of Association between Euratom and Tekes, and Euratom and CCFE, was carried out within the framework of the European Fusion Development Agreement. The supercomputing resources of CSC - IT center for science were utilized in the studies.