Heating and current drive modeling for the IPP Prague COMPASS tokamak*

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1   Introduction

Neutral beam (NB) and Lower Hybrid (LH) heating and current drive simulations in COMPASS are reported. The COMPASS tokamak (R_0=0.56m, a=0.2m, B_T=0.8-2.1T, I_p<350kA, k=1.6, δ_x=0.5) was recently transported from Culham Laboratory to the Institute of Plasma Physics Prague, and is expected to be operational by the end of 2008 [1]. Plasma transport and heating is here determined from the ASTRA code [2] with NB power deposition from the code FAFNER [3,4] and LH power deposition from the MHD equilibrium and current drive (CD) code ACCOME [5] and the LH ray-tracing and 3-D Fokker-Planck package C3PO/LUKE [6,7] (hereafter LUKE for short). In all simulations we apply the full available NB power of 300kW per NB injector, but only 50%, i.e. 200kW, of the nominal LH power was used, having been made aware of limitations of the LH coupler in past COMPASS LH experiments (M. Valovič, private communication).

The COMPASS tokamak will typically operate in two equilibrium configurations: single null divertor with low triangularity (SND: δ=0.3-0.4) and single null divertor with higher triangularity (SNT: δ=0.5-0.7). Higher triangularity provides access to higher confinement and improved stability and larger $n_\parallel$ up-shifts for better slow LH wave absorption. We present simulations for both SND and SNT at operating regime limits I_p=175kA, B_T=1.2T, and I_p=250kA, B_T=2.1T. A detailed description of the poloidal field coil system and equilibrium setup is given in [8]. Section 2 describes the NBI simulation results from FAFNER, section 3 deals with LHCD simulations, and finally section 4 gives our conclusions.

2   Neutral Beam Injection (NBI) simulations

The COMPASS NBI system is the more powerful of the two planned non-inductive heating and current drive systems. Two injectors are foreseen, each delivering 300 kW power of hydrogen or deuterium beams at 40 keV [3]. The injectors will be connected to tangential ports, with a possibility to switch one of them from co-current direction to counter-current direction. This feature aims to enable non-rotating, NBI-heated plasmas. The Monte-Carlo code FAFNER [4] is used for simulating the NBI behavior in the SND and SNT equilibria (computed by ACCOME), in the operating regimes described above. Energy balance results are shown for SND in **Fig. 1**. For SNT there are no major differences. Three major loss-channels are present. The shine-through, i.e. the portion of neutrals not ionized in the plasma, scales moderately with the central density. For the higher density cases, with $n_e^H = 5 \times 10^{19}\,\mathrm{m^{-3}}$, the shine-through losses drop to approximately 7 %. Charge-exchange losses also decrease with higher density, particularly for the counter-injection cases. Very important are orbit losses, i.e. losses caused by those beam ions, whose orbits cross the plasma boundary, and which thus do not deliver their energy to the confined plasma. Orbit losses are predicted to be around 10 % for co-injection, independent of the plasma density. However, they become very pronounced for counter-injection, where they can be as high as 30 – 50 %. As a consequence, counter-injection is considerably less efficient than co-injection. 60 – 75 % of the injected power is absorbed during co-injection, compared to 40 – 50 % during counter injection.

NBI drives a current in plasma. For the low B-field equilibria, it can be up to 20 kA per beam-line.

With two sources, the driven current can therefore constitute about 23 % of the total 175 kA plasma current. For the high field equilibria, the driven current is even higher, up to 25 kA per beam-line. The percentage of the total plasma current is 20 % in this case.
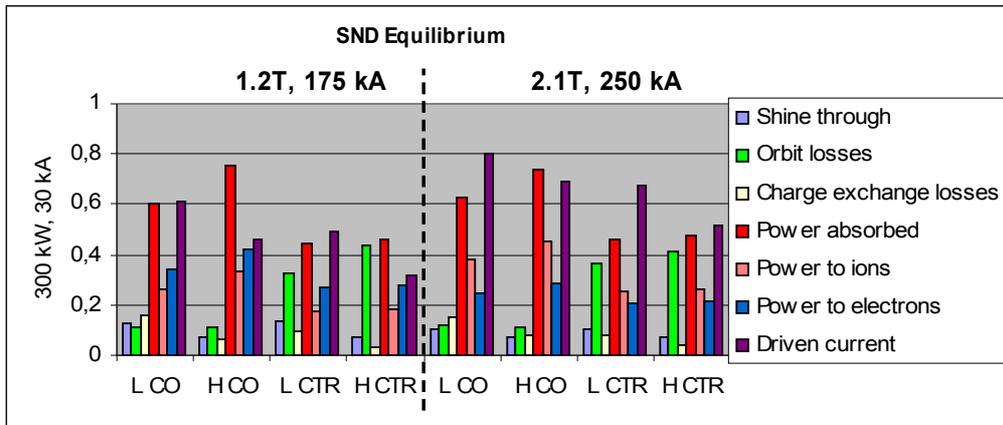

Fig. 1. NBI performance of a single 300 kW NBI source, simulated with SND COMPASS equilibria, magnetic field B=1.2T , plasma current I=175kA (left) and B=2.1T, I=250kA (right). Plotted are configurations with lower (L) and higher (H) central electron densities, $n_e^L = 3 \times 10^{19} \, m^{-3}$ for 1.2T equilibrium and $n_e^L = 3.5 \times 10^{19} \, m^{-3}$ for 2.1T equilibrium, $n_e^H = 5 \times 10^{19} \, m^{-3}$ for both equilibria. CO denotes co-injection with respect to the plasma current direction and CTR denotes counter-injection.

An important effect is that in the low field case the deposited power is deposited slightly more on electrons, while in the high field case ions receive about 50% more energy than electrons (during co-injection). Thus, higher magnetic fields are favorable for preferential heating of ions.

3   Lower Hybrid Current Drive (LHCD)

The COMPASS lower hybrid (LH) grill consists of 8 waveguides having width 14.8mm with septa of width 2mm. At 60° waveguide phasing the fundamental mode lies at $n_{//0}$=2.3, with spectral width $\Delta n_{//0} \cong 2.3$. The source frequency is 1.3GHz, with about 200kW at the plasma. With the two codes, ACCOME and LUKE, we expect to obtain reliable results, usually difficult to come by in the LH range. The reasons for this are several. First, the power deposition profile depends on electron Landau damping, which in turn depends on the toroidal evolution of $n_{//}$ along ray paths. Second, the COMPASS grill spectrum peak is very wide so it is at an advantage to launch many rays so phase-space is well sampled. Third, poor accessibility, which is a problem for some rays launched around $n_{//0}$ = 2.3. Next, ray paths depend sensitively on the magnetic equilibrium. This, together with the second and third points is well handled by ACCOME, which launches many rays and iterates many times between the MHD and LH modules. Finally, quasi-linear damping of the LH wave depends on a generally non-Maxwellian and anisotropic electron distribution function, which is where LUKE provides reference results**.** C3PO/LUKE can also deal with broad power spectra, following the approach delineated in Refs [6,7].

In **Fig. 2** we show results of launching 3 rays in LUKE to cover the COMPASS spectrum. The results are obtained without supra-thermal electron radial transport to better emphasize the LH deposition pattern. The four cases shown cover the operational regime limits (B=1.2T, I=175kA) and (B=2.1T, I=250kA) denoted respectively SND(T)–01 and SND(T)–02:
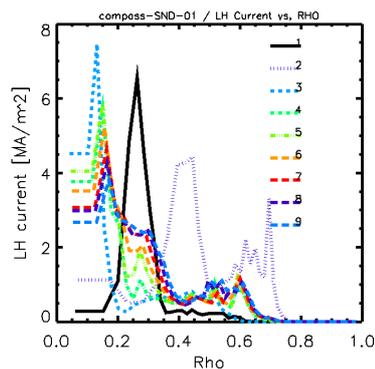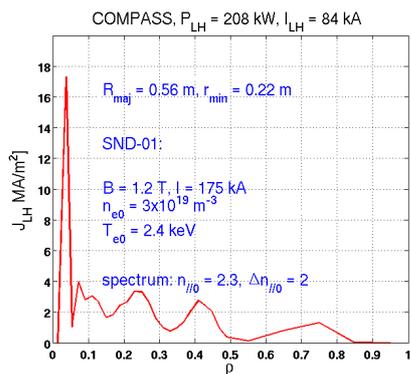
Fig.2a. **SND-01**
LUKE (on the left)
launches 3 rays from
outboard midplane

ACCOME (on the right)
launches 72 rays from
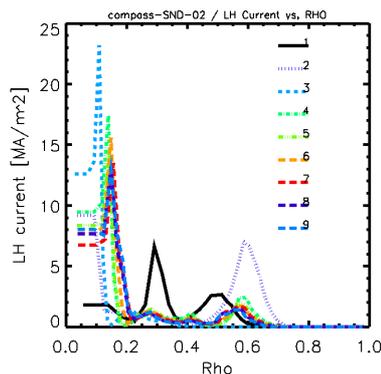outboard midplane. Profile
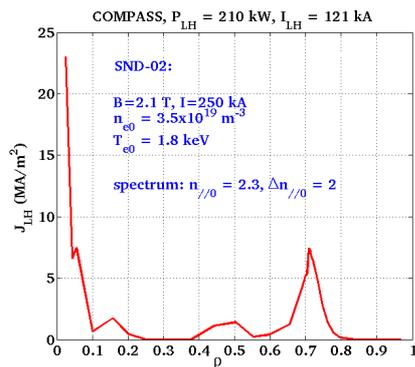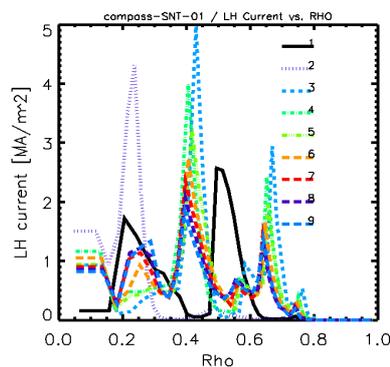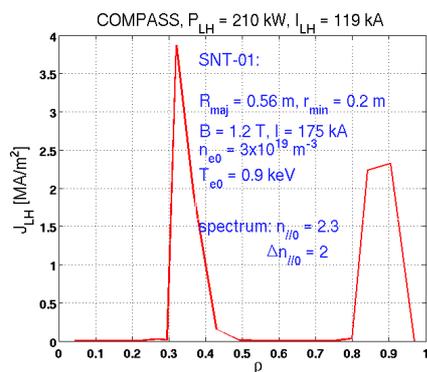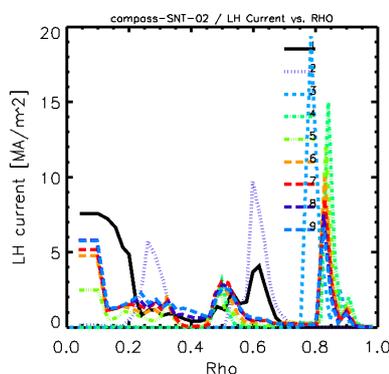converges in 9
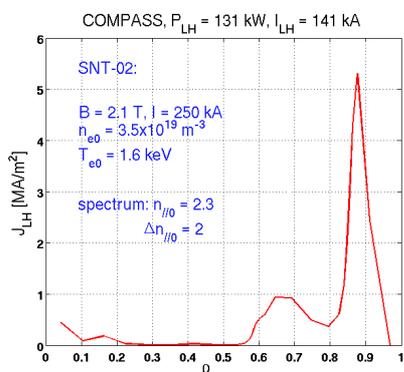iterations between MHD
equilibrium and LHCD.

Fig.2b. **SND-02**

Fig.2c. **SNT-01**

Fig.2d. **SNT-02**

Other main features of these COMPASS LHCD simulations are summarized in Table 1:

Table 1. Summary of LHCD performance for the COMPASS operation regimes SND-01(2) and SNT-01(2) described in section 1, for 210 kW of incident LH power, $n_{//0}$=2.3, $\Delta n_{//0}$=2. The

temperatures are determined from ASTRA simulations **[9]** with a prescribed density profile and with NB and LH power densities taken from the FAFNER and ACCOME/LUKE calculations.

	SND-01	*SND-02*	*SNT-01*	*SNT-02*
n_{e0} [x10^{19} m^{-3}]	3	3.5	3	3.5
T_{e0}[keV] ASTRA	2.43	1.78	0.95	1.65
T_{i0} [keV] ASTRA	1.75	1.55	0.88	1.47
P_{LH} [kW] LUKE	210	210	210	131
ACCOME	165	128	96	190
I_{LH} [kA] LUKE	76	106	119	141
ACCOME	78	109	56	164
I/P [kA] LUKE	0.36	0.51	0.57	1.07
ACCOME	0.47	0.85	0.59	0.86
$I_{NI}=I_{BS}+I_{LH}+I_{NB}$ ACCOME+FAFNER	116	165	140	225

5   Conclusions

We have established that the performance of the NBI and LH auxiliary heating systems described in sections 3 and 4 improves with increasing B and the triangularity of the plasma poloidal cross-section. Thus SNT would be the preferred operating regime. Even though there are some inconsistencies in LH deposition profiles between ACCOME and LUKE, it appears that the SND equilibria prefer central LH power deposition, while off-center LH deposition is more likely to occur in the SNT regimes. This could be an important factor for ELM suppression **[1]**.

References
[1]   R. Pánek, et al., *Reinstallation of the COMPASS Tokamak,* Czech. J. Phys. **56** (2006) B125.
[2]   G. V. Pereverzev and P. N. Yushmanov, *ASTRA - Automated System for Transport Analysis*, IPP Garching report IPP 5/98, February 2002.
[3]   J. Urban, et al., *NBI system for reinstalled COMPASS tokamak.* Czech. J. Phys. **56** (2006) B176.
[4]   G. G. Lister, *FAFNER - A fully 3D neutral beam injection code using Monte Carlo methods,* Max-Planck-Institut für Plasmaphysik Technical Report IPP 4/222, 1985.
[5]   K. Tani, M. Azumi and R. S. Devoto, J. Comput. Phys. **98** (1992) 332.
[6]   J. Decker and Y. Peysson, *On Self-consistent Simulation of Lower-Hybrid Current Drive*, 33rd EPS Conference on Plasma Physics, Roma, Italy, 19-23 June 2006, Vol. 30I.
[7]   Y. Peysson, J. Decker, and V. Basiuk, *On Simulations of Tore Supra Lower Hybrid Current Drive Experiments*, 34th EPS Conference on Plasma Physics, Warsaw, 2-6 July 2007, Vol. 31F.
[8]   O. Bilyková, et al., *COMPASS-D Magnetic Equilibria with NBI and LH Current Drive*, Czech. J. Phys. **56** (2006) B24.
[9]   M. Stránský, et al., *Transport simulations for the COMPASS tokamak with NBI and LH heating and current drive systems*, submitted to European Physical Journal D.