NBI system for reinstalled COMPASS–D tokamak

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COMPASS–D tokamak, originally operated by UKAEA at Culham, UK, will be reinstalled at the Institute of Plasma Physics AS CR. As the major upgrade, apart from many new diagnostics, a new neutral beam injection (NBI) system will be installed. Two beams, each with 40 keV particle energy and 300 kW peak power, will provide routine access to H–mode operation. This will substitute the original ECRH system, which will not be available in the new setup. NBI, together with a lower hybrid wave launcher, will be the only additional heating and current drive system for COMPASS–D.

Possible scenarios of NBI heating are discussed. Co– and counter– injections are considered, as well as on–axis and off–axis beam aiming. The heating and current drive performance is investigated by simulations with NBEAMS, FAFNER and ACCOME codes. Interesting results are obtained, including high absorbed power densities with on–axis incidence or favorable current drive performance with off–axis co–injection.

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1 Introduction

Recently, it was decided to take over the COMPASS–D [1] tokamak, originally operated by UKAEA at Culham in 1989–2001, by the Institute of Plasma Physics AS CR. COMPASS–D is a compact ($R = 0.56\,\mathrm{m}$, $a = 0.18 \div 0.23\,\mathrm{m}$) D–shaped divertor tokamak with flexible design (see Fig. 1). The plasma shape is ITER–like, allowing to study many ITER relevant topics, particularly H–mode physics, plasma–wall interaction and wave–plasma interaction studies.

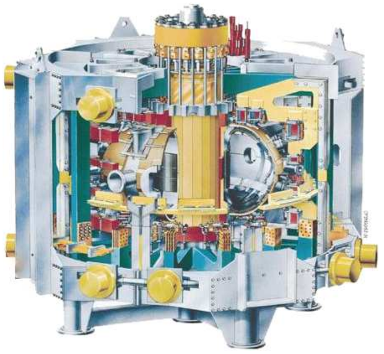
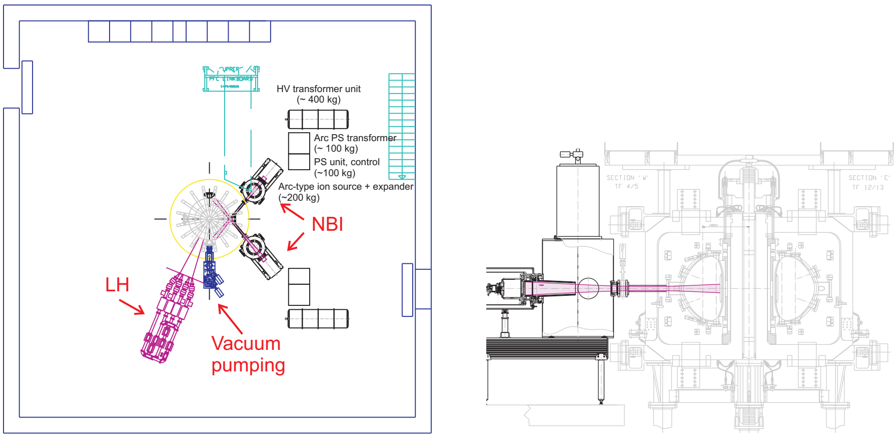


Fig. 1. COMAPASS–D tokamak.

Extensive upgrades are planned for COMPASS–D operation at the Institute of Plasma Physics AS CR, Prague. Only a re-



a) b)

Fig. 2. Possible design and placement of new COMPASS–D NBI system. a) experimental hall with LH, pumping and NBI, b) injector and its connection to the vessel.

stricted portion of original diagnostic systems will be transferred so many new diagnostics will have to be built. Likewise, not all the heating systems will be transferred. COMPASS–D was equipped with a 600 kW lower hybrid (LH) wave system and a 1.5 MW electron cyclotron resonance heating (ECRH) system. Only the LH system will be transferred with the tokamak, whereas the ECRH gyrotrons was kept at UKAEA. To achieve desired plasma performance, i. e. routine ELMy H–mode operation, a new heating system must be installed. Because of its favorable properties in relation to the physical program, particularly direct ion heating, a neutral beam injection (NBI) system will be applied. New ECRH is considered as a next step upgrade.

2 NBI system design

COMPASS–D is a compact tokamak for which, due to short trajectory of interaction between neutrals and plasma, the NBI power, energy and geometry must be chosen carefully. There are also major limitations of the tokamak structure, which can be modified only with difficulty. In particular, the toroidal field coils and the supporting structure inhibit selecting arbitrary injection directions, and the existing ports have to be modified to fit the beam injection. Parameters of the NBI system for COMPASS–D are summarized in Table 1.

The injectors and their power supplies will occupy a substantial area, which will be considered in the building design. Possible arrangement of NBI in the new COMPASS–D experimental hall is shown in Fig. 2. Part of the power supplies will be located further from the injectors in the power supply hall. The injectors are designed to comply with the COMPASS–D construction (Fig. 2). Only the tangential ports will have to be modified to the beam parameters (Fig. 3). Due to

Number of injectors	2
Particle energy	40 keV (adjustable)
Total ion current	2 × 12.5 A
Total power in neutrals	2 × 300 kW
Pulse length	300 ms
Beam diameter	< 7 cm
Total input power	≈ 1.5 MW
Helium consumption	100 ÷ 120 l/week

Table 1. NBI system parameters.

the low weight of all the components, the NBI parts can be relocated for setting up different scenarios without any special equipment like cranes or rails.

The basic configuration (Fig. 4) is optimized for plasma heating. The tangential injection is optimal for absorption due to the longest passage through the plasma achievable on COMPASS–D. Both beams are aimed in co–direction with respect to the plasma current to minimize the orbit losses. Both injectors can be aimed to achieve off–axis heating and current drive. For balanced injection, both injectors can be moved to the same port, aiming in co– and counter–current directions. With proper power modulation to compensate different orbit losses for co– and counter–beams, one can obtain an NBI heating scenario with minimum momentum injection to produce non–rotating, NBI–heated plasmas.

Normal injection is possible as well (Fig. 5). In this case, the port is wide enough to allow adjustment of the beam aiming over a wide range of angles. Normal injection is more suitable for diagnostic purposes, such as charge exchange radiation spectroscopy or motional Stark effect measurements. The outlying possible case of beam passage through the radial port is a tangential injection with partial inner wall crossing (Fig. 5 right).

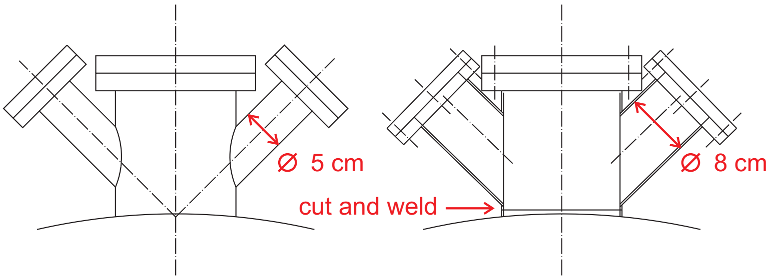
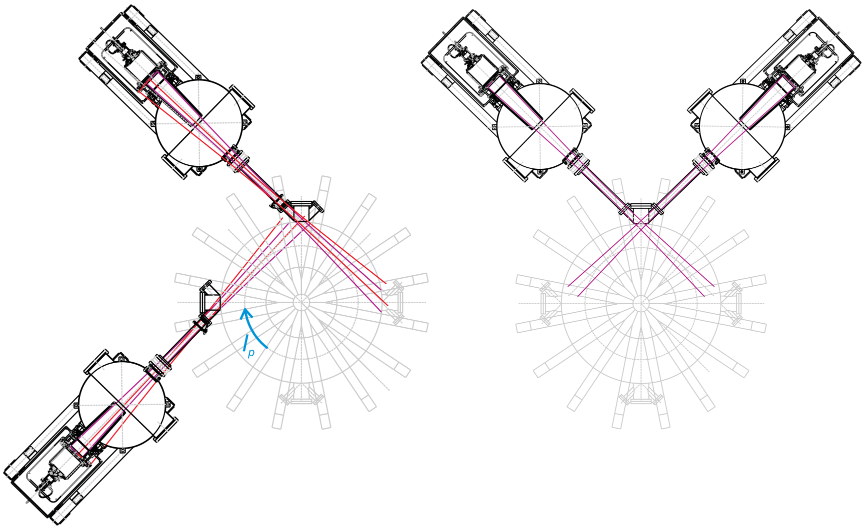
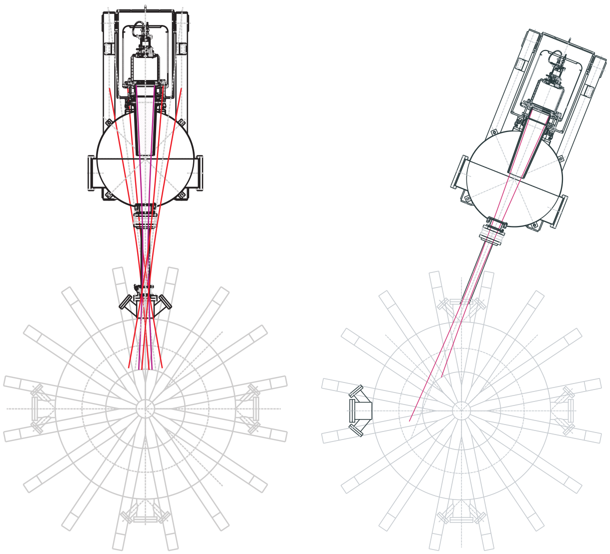


Fig. 3. Former (left) and redesigned (right) tangential port for NBI.



a) b)

Fig. 4. Two possible tangential injection arrangements. The basic co–injection setup – a) is optimized for heating performance, whereas the balanced injection – b) can produce non–rotating plasma.



a) b)

Fig. 5. Schematics of the normal injection. Normal injection – a), tangential injection via radial port – b).

3 Simulations results

Intensive and detailed computations have been performed to simulate NBI behavior in COMPASS–D. Codes FAFNER1), NBEAMS [3] and ACCOME [4, 5] were adopted for these purposes. FAFNER results [2] for tangential injection are shown in Table 2. The shine–through for moderate densities is already only 1 %. NBI in co–injection setup can drive 100 kA of toroidal current, which is 50 % of the total plasma current. In operation with $B_0 = 1.2\,\mathrm{T}$, which limits the plasma current to approximately 200 kA, the orbit losses for counter–injection are around 50 %. The situation greatly improves in the case of $B_0 = 2\,\mathrm{T}$ and $I_\mathrm{P} = 350\,\mathrm{kA}$, where the orbit losses drop to 24 % for counter–injection and 2 % for co–injection. However, operation with $B_0 > 1.2\,\mathrm{T}$ is possible only with sufficient power supplies and a hydraulic compensation system. This is a next step upgrade.

	equilibrium (a)		**equilibrium (b)**		**equilibrium (c)**	
	Co	Counter	Co	Counter	Co	Counter
Shine through	1 %	1 %	0 %	0 %	2 %	2 %
Orbit loss	13 %	52 %	6 %	65 %	2 %	24 %
Charge exchange loss	7 %	3 %	1 %	0 %	7 %	7 %
Power to ions	57 %	28 %	50 %	14 %	61 %	42 %
Power to electrons	22 %	16 %	43 %	21 %	28 %	25 %
Toroidal fast ion current	30 kA	19 kA	12 kA	5 kA	28 kA	22 kA
Current driven by NBI	20 kA	14 kA	8 kA	4 kA	18 kA	15 kA

Table 2. Main resultsof NBI simulations performed by FAFNER. Equilibriums used: (a) SND (Single Null Divertor), $B_0 = 1.2\,\mathrm{T}$, $I_\mathrm{P} = 200\,\mathrm{kA}$, $< n > = 4 \times 10^{19}\,\mathrm{m}^{-3}$, (b) SND, $B_0 = 1.2\,\mathrm{T}$, $I_\mathrm{P} = 200\,\mathrm{kA}$, $< n > = 8 \times 10^{19}\,\mathrm{m}^{-3}$, (c) SND, $B_0 = 2.0\,\mathrm{T}$, $I_\mathrm{P} = 350\,\mathrm{kA}$, $< n > = 3.5 \times 10^{19}\,\mathrm{m}^{-3}$.

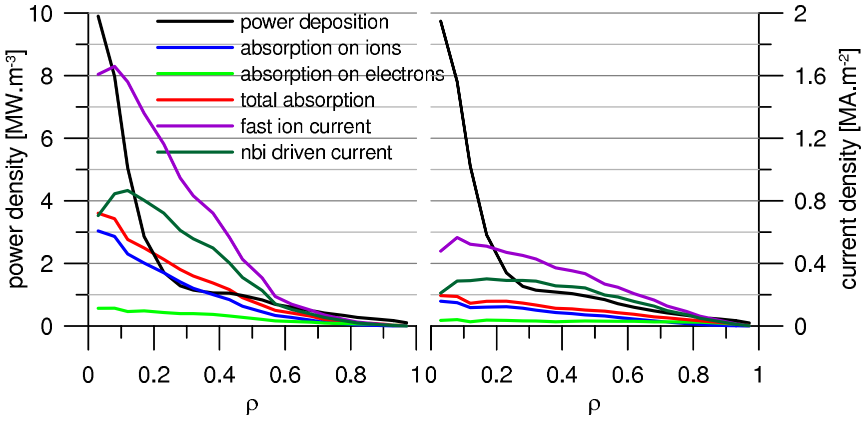


Fig. 6. Power deposition (ionization) and driven current profiles for co– and counter–central tangential injection, equilibrium (a) – SND, 1.2 T, $< n > = 4 \times 10^{19}\,\mathrm{m}^{-3}$.

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1) All simulations performed by Max–Planck–Institut für Plasmaphysic, Garching

Power deposition profiles for co and counter beams with SND equilibrium (a) are shown in Fig. 6. Substantial differences in performance are caused by the large difference in orbit losses, whereas the power deposition (ionization) profile remains similar for both cases. Off–axis current drive was examined by ACCOME code. The results (Fig. 7) show that NBI can drive sizable off–axis current, resulting in a reversed shear equilibrium with safety factor $q > 1$.

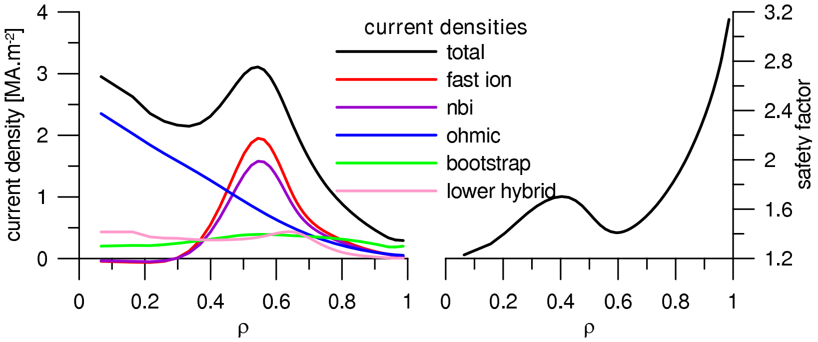

Fig. 7. Current density profiles with off–axis NBI co–injection (left) and resulting safety factor (right) for SND equilibrium (a).

4 Summary

NBI heating will be a major upgrade for COMPASS–D tokamak. Its main purpose is to enable routine ELMy H–mode operation with $T_e \approx T_i$. Numerical simulations show good performance of the $2 \times 300\,\mathrm{kW}$, 40 keV system, especially in the basic, heating optimized setup. In addition, the design is very flexible. The injectors can be moved to balanced injection or normal injection positions relatively easily. One has to be aware of different losses channels, especially orbit losses for counter–injection. However, these losses should be much lower with $B_0 > 1.2\,\mathrm{T}$.

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