DEMONSTRATION OF MODELLING AND OPTIMIZATION IN NEUTRAL BEAM HEATING AND CURRENT DRIVE WITH HL-3 PARAMETERS

Baolong. Hao, Wei Chen, Ting Long, Peixuan Yu, Shuo Wang, and HL-3 physics team

Southwestern Institute of Physics, Chengdu 610041, China
Email: haobalong@swip.ac.cn

NBI is a common auxiliary heating and current drive method in tokamak, whose effects have been approving since early 1970s, early heating results include PLT, ORMAK, T11, TFR, PDX, ASDEX et al [1-3]. NBCD has been investigated comprehensively in TFTR, JET, JT-60U, DIII-D and other facilities [4-5]. NBI is a natural priority in present facility design due to heating efficiency and engineering availability. HL-3 is a new tokamak operating in Southwestern Institute of Physics (SWIP), whose objectives include high beta, high density, high plasma current (Ip), high bootstrap current fraction, high confinement, and instability control in high heating power operation. During the past two years, HL-3 has achieved the 1 MA H-mode and 1.5 MA divertor configuration discharge. The main parameters of HL-3 are shown in Tab. 1. Equilibrium of HL-3 has large triangularity and elongation, used carbon first wall and divertor configuration in recent experimental campaign. The capacity of plasma current Ip and toroidal magnetic field Bt can be up to Ip = 3 MA and Bt = 3 T. The near future experimental database of HL-3 will provide a reactor relevant platform and support for solving the key scientific and technical problems of ITER and CFETR.

Total power planned for heating and current drive (H/CD) is up to 40 MW, including 6 MW ion cyclotron resonance heating (ICRH), 4 MW lower hybrid resonance heating (LH)，10 MW electron cyclotron resonance heating (EC), and 20 MW NBI. NBI system have three beam lines, two of them based on PNBI and working with deuterium gas. Geometry and ion source types of the third beam line have been discussed, NNBI (negative beam ion source) is also in view. The decision of the third beam line depends on experiment performance of previous two PNBI beam lines. According to objective plasma parameters, HL-3 decided to have four positive beam ion sources with 80keV/45A/5s for each beam line. The maximum injected power of two co-current beam line is about 14 MW. Elevation of the ion source injector is 50 cm above or below the equatorial plane, as shown in Fig. 1. The injection angle of the beam line is about 41 degree when it intersects the magnetic axis, as is shown in Fig. 1

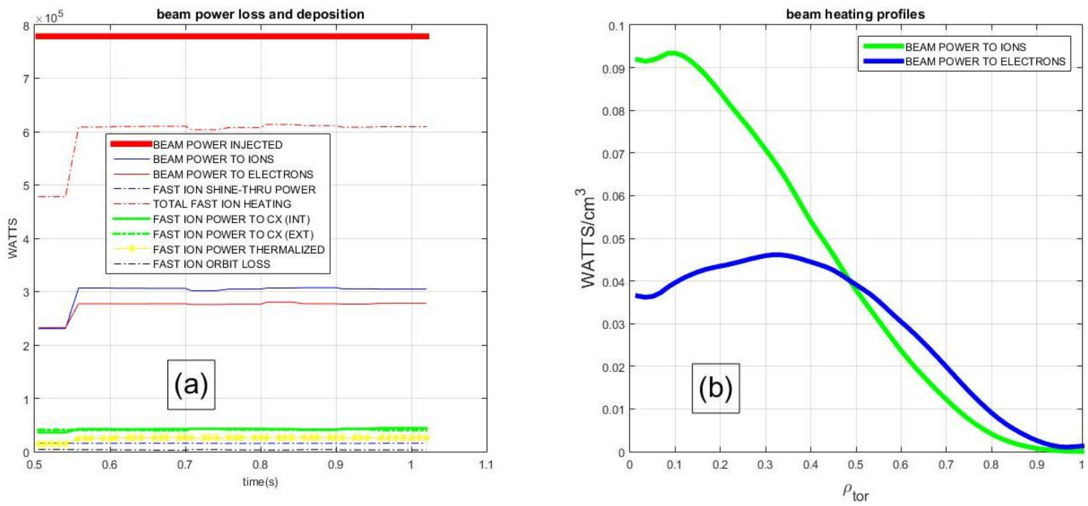

Fig.1 (a) beam power deposition and loss terms during discharge, (b) beam heating profiles.

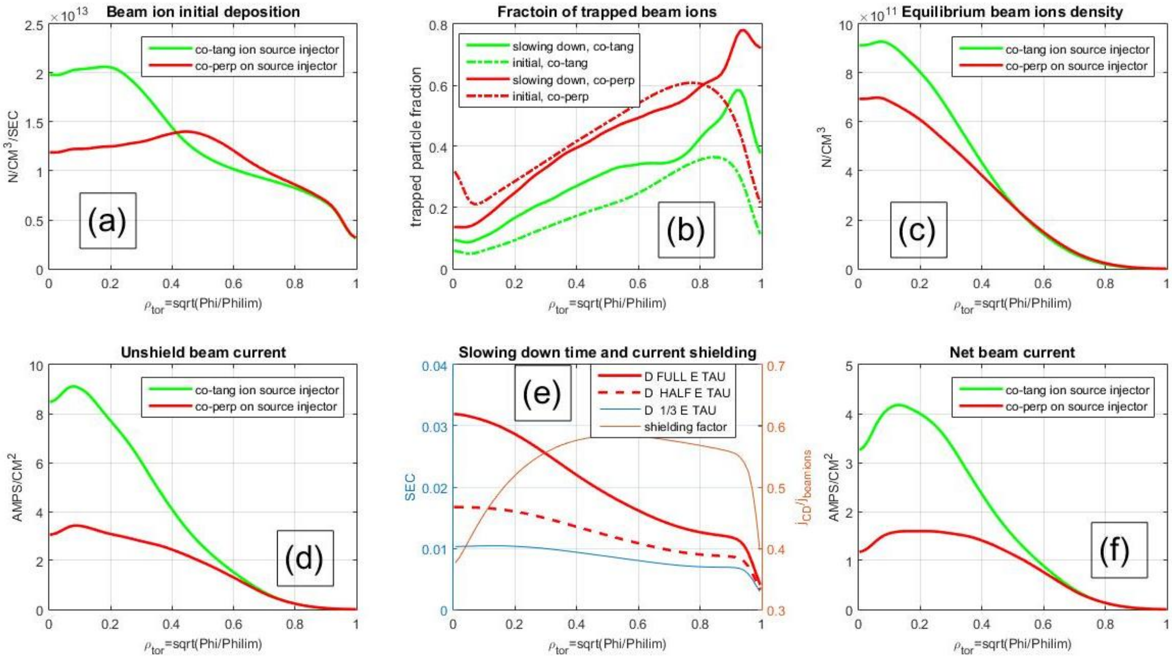

Fig.2 Analysis of NBCD details for co-tang and co-perp downward steered injectors, (a) initial deposition profiles, (b) trapped particle fraction profiles of initial and slowing down beam ions, (c) steady state beam ion density, (d) flux averaged unshielded beam ion current, (e) slowing down times of three beam energy components and shielding factor, (f) net beam current with TRANSP/NUBEAM shielding current calculations.

The ion thermal diffusivity in turbulence transport analysis is much lower than neoclassical transport within rho~0.25, which means the possibility of ITB and a large ion temperature gradient in the centre, whereas the diagnostic of Ti is missing in the first stage of HL-3 running. The beam power shine through loss from co-perp injection has been given with a large range of beam power and plasma density, which is very helpful to facility operator. Only the more perpendicular beam injector has shine through loss on the inner wall, otherwise, tangential beam injection has no concern on it. The hot spot from shine through loss and power loss fraction are easily determined with the simulation results. The beam heating efficiency depends on good fast ion confinement, where prompt loss and toroidal field ripple loss exist all the time. The work gives a rapid and accurate method in energetic particle phase space in plane of _Pzeta and _mu, where the orbit types, prompt loss and ripple loss regions can be easily determined for scenario optimization. With investigation of different beam tangency radius, it was shown the present beam geometry has the best beam heating efficiency. The workflow of beam ion confinement evaluation in phase space can be applied to rapid iteration of scenario optimization.

HL-3 has three beamlines with four ion sources each. The slightly off-axis NBCD profile is observed and peaked around rho~0.34 due to up-down asymmetry equilibrium. The same reason led to the little different NBCD from two upward and downward steered injectors. There is no visible difference of Bt direction on NBCD in HL-3, which is unlikely in the situation on DIII-D, where the ion source elevation can be vertically steered to a relatively large angle. In order explore the possibility of high efficiency off-axis NBCD for hybrid scenario, the work investigates different ion source elevations and Bt directions. Increasing ion sources' vertical position up or down to 100cm have an optimized off-axis NBCD, which has a peaked profile around rho~0.38 and acceptable CD efficiency. This conceptual design for off-axis NBI could be considered in future upgrade of HL-3. It was noted the radial profiles of NBCD are more diffusive than ECCD, both of them has been used for CD control in HL-3 scenario development.

REFERENCES

[1] Eubank, H., Goldston, R. J., et al, 1979 Neutral-beam-heating results from the Princeton Large Torus. Phys. Rev. Lett. 43(4), 270-274. https://doi.org/10.1103/PhysRevLett.43.270
[2] Stroth U., Adamek J., et al.,2013 Overview of ASDEX Upgrade results, Nucl. Fusion 53 104003
[3] ITER Physics Expert Group on Energetic Particles, 1999 Heating and Current Drive and ITER Physics Basis Editors Nucl. Fusion 39 2495
[4] Reinders, L.J. 2021 The Big Tokamaks: TFTR, JET, JT-60. In: The Fairy Tale of Nuclear Fusion. Springer, Cham. https://doi.org/10.1007/978-3-030-64344-7_8