6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Influence of ICRF and NBI synergy on plasma performance and fast ion distribution on EAST

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Plasma heating with radio-frequency (RF) waves in the Ion Cyclotron Range of Frequencies (ICRF) and Neutral Beam Injection (NBI) are two main heating methods widely used in current magnetic confinement fusion devices. They are robust in ion heating and will be further applied in future machines, such as ITER [1]. With both ICRF and NBI heating, a fusion power of 10MW and 15MW had been achieved in TFTR and JET, respectively [2]. They can have synergy owing to the acceleration of NBI beam ions by RF wave fields close to the Ion Cyclotron (IC) harmonics, due to the finite Larmor radius (FLR) effects. Understanding the ICRF-NBI synergy are of great importance to the improvement of plasma performance as well as the generation of fast ions and fusion neutrons.

To understand the ICRF-NBI synergy, a series of experiments were carried out on EAST. It is shown that in a typical H-mode plasma with 1.0MW NBI power and 1.5MW ICRF power, ICRF-NBI synergy increases the poloidal beta, plasma stored energy, core ion temperature and neutron yield by ~35%, 33%, 22% and 80%, respectively. In addition, increasing the NBI beam energy and ICRF power can significantly increase the total number of fast neutrons and the fast neutron tail with energy larger than 2.5MeV. Injecting the NBI beam ions more vertically and moving the resonance position closer to the magnetic axis is more favorable for ICRF-NBI synergy and fast ion generation.

In line with the experiments, TRANSP [3] simulations with various parameter scans are performed, including the H minority concentration, D 2nd harmonic resonance position, ICRF power and NBI beam energy. The case with n(H)=1%, B_t =2.4T, P_{IC} =1.5MW and E_{beam}=60keV is considered as the reference case. The simulations results are consistent with the experimental findings. They indicate that by increasing the total amount of RF power absorbed by NBI beam ions at their 2nd harmonics, the ICRF-NBI synergetic effects become more prominent. The ICRF-NBI synergy can be enhanced by decreasing the minority ion concentration, decreasing the distance between magnetic axis and resonance position, increasing the ICRF power and NBI beam energy. As a result, not only the fast ion population and the energy of the fast ion tail are increased, but also the plasma performance, including the total neutron yield, the poloidal beta, the total ion heating and the plasma kinetic pressure, are improved. For instance, for a fixed P_{IC}=1.5MW, the NBI beam ions with initial energy of ~60keV can be accelerated to 300keV, 450keV and 600keV by ICRF when n(H) is 5%, 1% and 0.1%, respectively (see Fig. 1). For a fixed n(H)=1%, the largest energy of fast ions can be increased from 300keV to 600keV when P_{IC} increases from 0.5MW to 3.0MW.

In conclusion, good progresses in experiments and simulations have been made to understand the influence of ICRF-NBI synergy on fast ion distribution and plasma performance on EAST. By optimizing the plasma and heating parameters, the ICRF-NBI synergetic effects can be made stronger. Further efforts will concentrate on understanding the ICRF-NBI synergy induced fast ion distribution in different plasma scenarios, and their effects on energetic particle modes.

References

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Figure 1