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Simulations and validations of the fast and slow components of SMBI on HL-2A

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Plasma fueling is essential to tokamak's operation, realization of high stored energy and finally the application of the fusion energy. In order to control plasma density, compensate particle loss and improve the plasma confinement at core, it requires the fueling particles penetrating the last-closed flux surface (LCFS) and injecting as deeply as possible into the plasma core with a high fueling efficiency. It is very significative to further improve the penetration depth and fueling efficiency of supersonic molecular beam injection (SMBI) which is a kind of very important plasma fuelling method and has been applied in many tokamaks at home and abroad. Two components, a fast component (FC) and a slow component (SC), have been widely observed by tangential D_α array and CCD camera in the HL-2A SMBI experiments for several years[1], and the FC can penetrate much more deeply than the common SMBIs which motivate us to do a further study for developing a better fueling method.

Although the FC and SC have been observed in experiment for years, the theory and simulation works of them have never been done and the physical mechanism has not well understood. It is the first time to the FC and SC of SMBI have been simulated and interpreted in theory and simulation in this paper with the trans-neut module[2] of the BOUT++ code. As a special model of SMBI, the transport simulations of trans-neut module has been benchmarked with other codes and validated with experiments. In order to verify and improve the physical model and increase its credibility of predictions for fueling efficiency improvement, the trans-neut module is further validated with experiment on FC and SC of SMBI in HL-2A.

With the realistic geometry of the HL-2A tokamak, the linear profiles and real HL-2A experimental profiles of plasma density and temperature are applied separately as the initial profiles in the simulation of FC and SC. Simulation results are consistent with the experiment. Both the spatial and temporal evolution of D_α intensity is calculated self-consistently in the simulation by using Atomic Data and Analysis Structure (ADAS) database. So that simulation results can be compared directly with experimental measures of the D_α array.

The simulation with linear profiles verified that although the difference in the injection velocity has some effect on the penetration depth difference between the FC and SC, it is mainly caused by the self-blocking effect of the first ionized SMB[3]. We also discuss the influence of the initial plasma density on the FC and SC, and the variation of the SC penetration depth with its injection velocity for better understanding of FC and SC[3].

Temporal distribution of injection density of FC and SC has been considered in the simulations with experimental profiles and the simulation results of typical features are consistent well with experimental measurements especially the temporal separation and spatial distribution of D_α intensity of FC and SC and the relationship of the penetration depths between them. For the two adjacent SMBI pulse with short time interval, the blocking effect of the first pulse on the second FC has also simulated and validated.

References

[1] Yu D L, Chen C Y, Yao L H, et al. Nuclear Fusion, 2010, 50(3): 035009.
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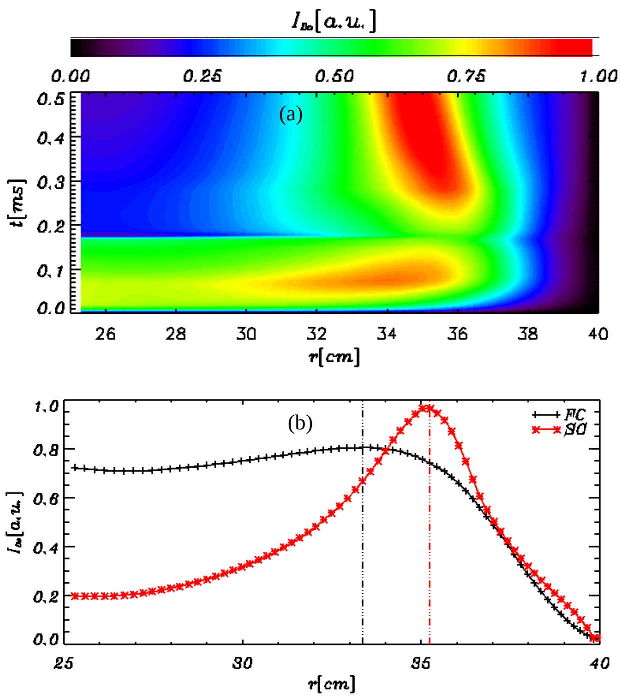

Figure 1 Simulation results of D_α intensity for FC and SC of SMBI. (a) Spatio-temporal evolution of D_α intensity during SMBI, (b) radial profiles of D_α intensity for FC and SC.