The innovative progress of supersonic molecular beam injection for particle and instability control of fusion plasma

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Plasma fueling and its density control are crucial issues for magnetic confinement fusion reactors like international thermonuclear experimental reactor (ITER). High plasma density is favorable for the high-performance operation of fusion plasma. To date, the conventional fueling techniques on magnetic confinement fusion plasmas include the gas puffing (GP), supersonic molecular beam injection (SMBI), and pellet injection (PI). Since SMBI was first proposed in the HL-1 tokamak, it has been soon applied on several tokamaks and stellarator for experimental studies on the high performance plasma related physics such as: density control, transport study, L-H transition, control of edge localized mode (ELM) and disruption mitigation [2-6].

In recently years, innovative progresses on the SMBI techniques have been made, especially the novel techniques for plasma instabilities control. The liquefied impurity SMBI created by an auxiliary cooling system performed well in the disruption mitigation on HL-2A. In addition, the mixture SMBI was successfully applied on the control of ELM for the first time by changing the ratio of the impurity gas and fueling gas without significant degradation of the plasma confinement. More recently, a set of SMBI system has been installed on the outer divertor of HL-2A to create a radiative divertor. It will be used for the investigation of the ELM control accompanying with the original mid-plane SMBI system in the 2021 experimental campaign on HL-2A.

To improve the beam characteristics of the SMBI of the fusion plasma fueling, a schlieren diagnostic system is established on the testing platform to visualize the supersonic molecular beam. This system is designed to detect the gradient of the refractive index, which is proportional to the density gradient of the inhomogeneous gas medium. The density distribution of the supersonic molecule beam under different conditions are measured on the SMBI testing platform with this diagnostic system [7]. The profile of the velocity is also roughly derived with measure density profile and the simulation results.

Several optimized nozzle structures are designed based on the simulation results. The prototypes of these optimized nozzles are manufactured and then its beam characteristics are measured. It has been found that the beam optimized nozzle presents smaller divergence angle and better directionality compared to the normal nozzle as shown in Fig.1. It could be concluded that the cone shape nozzle with a deep throat would significantly reduce the divergence angle of the beam. It could be found that appropriate length of the throat is beneficial for full adiabatic expansion, which generates more oriented particles. This indicates that the new design of the nozzle has better directionality as a localized source or actuator during the investigation of the edge plasma physics. The results also create the fundamental to design the injectors aimed for different working conditions.

References

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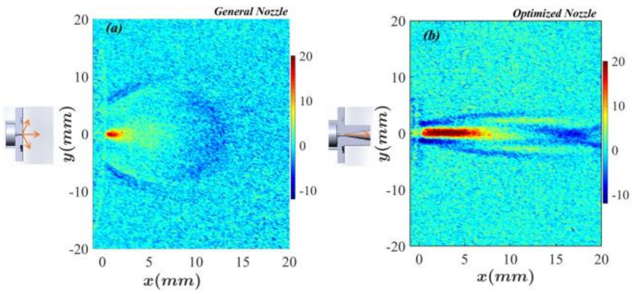

Figure.1 comparison of the testing result for the general nozzle and the optimized nozzle