§24. Development of Neutral Molecular Beam Injector for Two-Dimensional Edge Density Measurement

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It has been known that ELMs and blobs do not always appear symmetrically in toroidal and/or poloidal directions. In order to get the overall picture of the phenomena, the two-dimensional (2D) measurement with a thermal lithium beam probe (LiBP) has been developed in LHD[1-3]. For the precise measurement, the intense, uniform and thin beam is necessary to achieve good time and spatial resolution. We performed evaluation and optimization of the sheet-shaped beam by numerical simulations.

Figure 1(a) shows a schematic of the 2D beam injector. As indicated by arrows, lithium atoms pass through the nozzle of the oven, reflecting at the wall of the nozzle. Some atoms, of course, can pass through the nozzle without any reflection. The lithium beam coming out from the nozzle flies to the slit which trims off the edge of the beam, i.e. excess lithium atoms are intercepted. After passing through some slits, the beam is shaped to be sheet.

Trajectories of lithium atoms from oven to the plasma are numerically simulated using the Mote Carlo technique to optimize the beam injector for the effective injection. In the calculation a source of the lithium atoms is located at the bottom of the nozzle, and atoms are launched in arbitrary directions according to the Monte Carlo manner. Atoms striking the nozzle wall are all reflected in arbitrary directions. No atom is trapped at the nozzle wall, since its surface is hot enough to vaporize it again. Collisions between atoms are not taken into account because the beam density is not so high. The trajectory tracing for an atom is terminated when the atom is intercepted by the slit. By measuring the number of atoms at the target plasma, we can estimate the beam flux and its profile to be injected to the plasma.

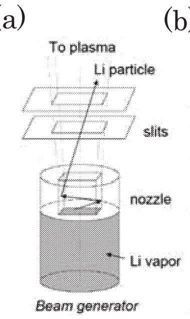
First, the effect of nozzle shape is investigated in four different types of nozzle, as shown in Fig.1(b). The type-1 and type-2 are the single-hole nozzles. The type-3 and type-4 are multi-hole nozzles which consist of 11 small apertures whose diameter is 3 mm, expecting better collimation. Holes of the type-4 nozzle are fanned out to spread the beam rapidly. The length of all nozzles is 20mm. Generally speaking, for the type-3 and type-4 nozzles, the longer and narrower hole has better collimation performance. However it is limited, due to technical reasons, to 20 mm in length and 3 mm in diameter. In the calculation, a slit with a rectangular aperture of 35mm×6mm is set 53mm apart from the nozzle. The 1×10^7 lithium atoms were launched into the nozzle in arbitrary directions. Particle fluxes at the exit of the nozzle Γ_{ex}, slit Γ_{sl} and plasma Γ_{pl} were calculated, and their ratio to the flux at the entrance of the nozzle Γ_{en} are presented in the table in Fig. 1 (b). It is found that the type-2 or type-3 slit has the highest Γ_{pl} / Γ_{en}, i.e. highest beam density at the plasma to be observed.

Another important factor of the beam performance is its divergence after it passes through the nozzle. If the beam divergence is large, most of beam particles (Li atoms) cannot pass through the final slit. In other words, most of particles are intercepted by the slits, which are consequently piled up around the slits. This is an undesirable situation because a stack of Li often troubles the instrument. Furthermore this low efficiency in the beam production means the superfluous consumption of Li. Thus the beam with small divergence is favorable. In order to estimate the beam divergence, the attenuation of the beam flux from the exit of the nozzle was calculated. The results are also presented in the table in Fig.1 (b) with an index of α, where α is an exponent defined by $\Gamma(Z)=\Gamma_{ex}(Z)^{-\alpha}$. Z is a distance from the exit of the nozzle along the beam. If the beam source is a point source on a plane and it is entirely isotropic, α should be ~ 2. It is found that α is larger than 2 in the case of single-hole nozzles, i.e. type-1 and type-2. This can be explained by the fact that quite a few particles pass through the hole diagonally without any collision with the wall of the hole, hence the beam diverges from the exit of the nozzle. On the other hand, α of multi-hole nozzles (type-3 and type-4) is less than 2, which indicates that the beam is well collimated by the hole. This is due to the decrease of particles which pass through the hole obliquely without any collision to the wall.

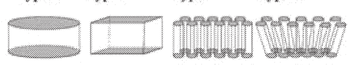
The width of the sheet beam is also important because it affects the spatial resolution. The thin beam can cut out the thin observing plane from the plasma column. For the estimation of the beam width, the full width at half maximum (FWHM) at the observing region was calculated (Fig.1(b)). It can be known that multi-hole type nozzles are also better than single-hole nozzles.

In conclusion, we have decided to use the type-3 multi-hole nozzle for the 2D LiBP in LHD. The distance from the nozzle to the plasma is sufficiently long (more than 3 m) in LHD that the fanned nozzle (type-4) is not necessary.

(a)



(b)



	Type-1	Type-2	Type-3	Type-4
nozzle	Φ25mm	25mm × 5mm	Φ3mm×11	Φ3mm×11
Area of nozzle	490.9mm²	125mm²	77.8mm²	77.8mm²
Γ_{ex} / Γ_{en}	47.7%	31.8%	14.5%	14.5%
Γ_{sl} / Γ_{en}	4.23%	1.63%	0.32%	0.32%
Γ_{pl} / Γ_{en}	0.016%	0.024%	0.022%	0.017%
FWHM at plasma	240.0mm	43.75mm	38.5mm	37.4mm
α : exponent of attenuation $\Gamma(z)=\Gamma_{ex}z^{-\alpha}$	2.43	2.12	1.88	1.92

Fig. 1 Results of numerical simulation for various nozzles

Reference
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