§25. Fueling Characteristics of Supersonic Gas Puffing Applied to Large High-temperature Plasma in LHD

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Development of fueling methods is a critical issue for realization of fusion DEMO reactor. Recently, supersonic molecular beam injection (SMBI) in HL-2A [1,2], supersonic pulsed gas injection (SPGI) in Tore Supra tokamak [3] and supersonic gas injector (SGI) in NSTX [4] have been developed as new fueling methods. For example, a fueling efficiency of 30 ~ 60 % has been achieved by SPGI in the Tore Supra tokamak [3]. Supersonic gas puffing (SSGP) also has been applied to large high-temperature plasma and its fueling characteristics have been investigated in the Large Helical Devise (LHD). The SSGP injection method, where a high-pressure hydrogen gas is ejected through the fast solenoid valve equipped with Laval nozzle, has been developed as a new fueling method for LHD [5, 6].

The SSGP system has been installed on the lower port of LHD. The distance from valves to the plasma is about 4 m. The solenoid valves used in the SSGP system are characterized by the shorter response time of < 1 ms and the higher working pressure of < 8 MPa than those of piezoelectric valves used in ordinary gas puff system in LHD. Three solenoid valves are equipped with different Laval nozzles of 0.1, 0.3 and 0.6 mm throat diameter, respectively. By selecting the nozzles and the backing pressure, the flow rate of SSGP can be adjusted from 1 to ~1000 Pam^3/s. In order to investigate the fueling characteristics, density ramp-up experiments have been carried out using these Laval nozzles.

Figure 1 shows typical temporal evolutions of the line-averaged electron density and radial density profiles fueled by the three Laval nozzles. In a series of experiments, the magnetic field strength on the magnetic axis was fixed to 1.5 T. The major radius and the minor radius of the plasma were 3.6 m and 0.6 m, respectively. The line-averaged electron density was increased by 1 × 10^{19} m^{-3} (ϕ0.1 mm), 2.5 × 10^{19} m^{-3} (ϕ0.3 mm), and 3.5 × 10^{19} m^{-3} (ϕ0.6 mm) after SSGP, where SSGP was injected at t = 3.765 s with a pulse length of 200 ms (ϕ0.1 mm), 50 ms (ϕ0.3 mm) and 20 ms (ϕ0.6 mm), respectively (see Figs. 1 (a), (c), and (e)). The hatched region shown in Figs. 1 (a), (c), and (e) denotes the valve open time. Figures 1 (b), (d), and (f) show radial profiles of electron density before (t = 3.766 s) and during/after (t = 3.800 s) SSGP, measured by a YAG Thomson scattering system. Figures 1 (d) and (f) show that large increase in the electron density profile was observed at ρ = 1.02, where ρ is the normalized minor radius. In the case of ϕ0.6 Laval nozzle, a hollow density profile with steep inward gradient was formed after SSGP, as shown in Fig. 1 (f). According to these observation, SSGP deposits the particles in the plasma edge region (ρ ~ 1.02), which is the region outside last closed flux surface (LCFS), independent of the type of Laval nozzle. Rapid increase of line-averaged density in the cases of ϕ0.3 and ϕ0.6 Laval nozzle after SSGP was caused by the edge density increase.

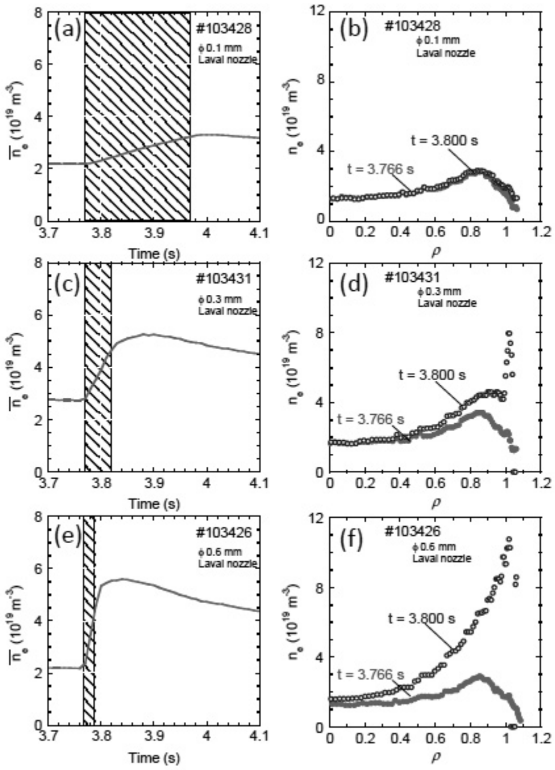

Fig. 1 Typical temporal evolutions of the line-averaged electron density n_e (a), (c), and (e) and radial electron density profiles (b), (d), and (f) of three types of Laval nozzles. In radial profiles, closed and open symbols denote before and after SSGP, respectively. The hatched region in (a), (c), and (e) indicates the valve open time.

Figures 1 (c) and (e) show that the line-averaged density kept increasing after SSGP. In density increasing process after SSGP, core density is increased by the diffusion from the edge region. The electron density increase including this diffusion process after SSGP should be considered to evaluate the fueling efficiency of SSGP. In this study, fueling efficiency is defined as a ratio of increase in the total electron number including the density increase after SSGP to the injected electron number by SSGP. This definition is similar to those used in Refs. 2-3. In the case of ϕ0.3 Laval nozzle, the fueling efficiency is 10 ~ 30 % and two times higher than that of ordinary gas puffing.

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