§3. Optimization Study of Super-high Speed Neutral Particle Flow Injector for LHD by Using CT Injection Technology

Fukumoto, N., Nagata, M., Kikuchi, Y. (Univ. Hyogo),
Takahashi, T. (Gunma Univ.),
Masamune, S., Himura, H., Sanpei, A. (Kyoto Inst. Tech.),
Takahashi, T., Asai, T. (Nihon Univ.),
Hirano, Y. (AIST),
Inomoto, M. (Univ. Tokyo),
Irie, M. (Waseda Univ.),
Miyazawa, J., Yamada, H., Narushima, Y.

We have developed the Compact toroid (CT) fueler of SPICA (SPheromak Injector using Conical Accelerator) for LHD at NIFS. Recently, production and injection of extremely super-high speed neutral particle flow by using a CT injector has been studied. We have then proposed the neutral particle flow injection as a new application of CT injection technique to more efficient fueling. In a series of research on SPICA, CT parameters were effectively improved and achieved at a speed of more than 200 km/s and a density of 10^{21} m^{-3}, owing to optimization of the conical accelerator length. This resulted in long CT transport through the 1.8 m drift tube with a density on the order of 10^{21} m^{-3}.[1)] For the parameter, CT plasma can penetrate into an LHD plasma at a magnetic field of B = 0.8 T. By using the improved SPICA injector, we launched the study on production of supersonic neutral particle flow. The experimental scenario is as follows; SPICA accelerates a CT plasmoid and injects it into a long drift tube as a neutralizer cell (a length of 1.8 m, a volume of 0.055 m^3) filled with hydrogen gas, then super-high speed neutral particle flow is produced through charge-exchange (CX) reaction between CT plasma and neutral gas. The realistic target is to efficiently product low energy and high particle flux with a high speed of 200 km/s (equivalent to about 200 eV) and a high density of 10^{21} m^{-3}. Such a neutral particle fueling method is expected to achieve deeper penetration of fuel particles and higher efficiency of fueling than the conventional fueling method and a super-sonic gas puffing.

However, for practical use of SPICA on LHD, the CT injector and its power supplies should be simple for easy operation and maintenance. SPICA has two-stage coaxial electrodes for CT formation and acceleration to obtain the high performance. The power supplies equipped with ignitron switches are rather difficult to deal with. We have thus attempt single-stage operation of SPICA by connecting only the acceleration bank unit to both electrodes as shown in Fig.1, and have investigated the acceleration performance. We measured CT parameters with PIN diodes (L1-4) for the observation of CT transit and a He-Ne laser interferometer for CT density at the muzzle of SPICA. Figure 2 shows the typical time evolution. CT speed achieved between L2 and the interferometer was ~100 km/s, and CT density was $\sim 1\times10^{22}$ m^{-3} at the peak. The CT performance was rather low to penetrate into the depth at a magnetic field of only 0.3 T. The density was, however, remarkably high. The particle inventory was calculated at $\sim 2\times10^{20}$ from the full-width at half-maximum of the electron density signal and at $\sim 5\times10^{20}$ from the full-width at base. These values correspond to respective density increment of about 7×10^{18} m^{-3} and 2×10^{19} m^{-3} by the high-speed neutral particle injection in a LHD plasma with a volume of 30 m^3.

The neutralization process has been also studied by a Monte-Carlo simulation to investigate the conditions for high neutralization efficiency at the Gunma University.[2)] As a result, dependence of neutralization efficiency on transit time of CT traveling into the neutralizer cell was found. The transit time at a speed of 50 km/s requires 100 μs at a pressure of 1×10^{-4} Torr and 20 μs at a pressure of 5×10^{-4} Torr, to completely neutralize a CT plasma in the neutralizer cell. Here the length of neutralizer is 1.8 m in the experiment. The transit time is 18 μs at a CT speed of 100 km/s. It is also found that the efficiency decreases by only about 10 % with increment of the speed from 50 km/s to 200 km/s. Therefore, the CT plasma generated on the SPICA with a single-stage accelerator can be fully neutralized, passing through the neutralizer at a pressure of 5×10^{-4} Torr. In future work, we intend to make quantitative measurement of the neutralization efficiency, and also compare the experimental result with this calculation.

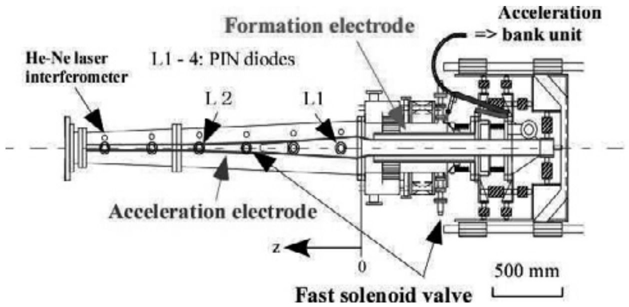

Fig. 1 Schematic draw of the SPICA CT injector.

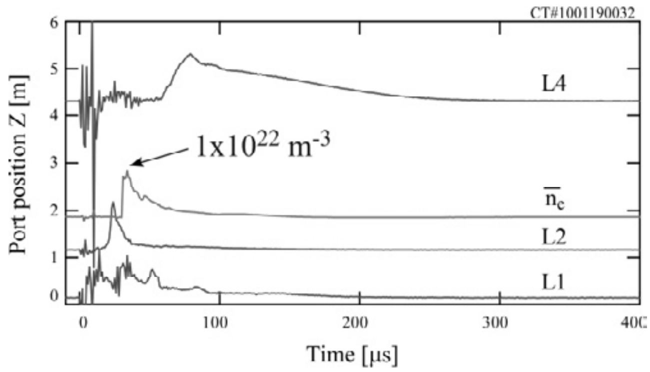

Fig. 2 Typical evolution of PIN diode signals and line-averaged electron density in the acceleration region. The vertical offsets are proportional to the axial location each measurement.

1) Liu, D. et al.: J. Plasma Fusion Res. SERIES 8 (2009) 999.
2) Fujii, S. et al.: IEE Trans. Plasma Sci.(accepted for publication).