§7. Development of a New TESPEL Injector with a Variable Injection Angle Mechanism in LHD

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Even now, it is still highly important to investigate the transport property of heat and particle in magnetically confined high temperature plasmas. In such studies, it is significantly important to perform a dynamic (perturbative) analysis, as well as a static (power-balance) analysis, because it is well known that high-temperature turbulent plasmas exhibit a fast and global response (sometime beyond the standard local diffusive paradigm) to a change in plasma parameters at a location. In the experiments for the dynamic transport analysis, electron temperature and/or density are usually perturbed by modulations of heat and/or particle source. In LHD, a Tracer-Encapsulated Solid Pellet (TESPEL)[1] is extensively utilized as a plasma perturbation tool and produces significant results. The one of the disadvantages of the TESPEL method as the plasma perturbation tool is that a large electron temperature perturbation, which can be invoked only by the large TESPEL injection is accompanied by a large electron density perturbation. This is because the current TESPEL injection axis is set on the equatorial plane of LHD aiming the LHD plasma center. In order to solve this problem on the TESPEL injection, we adopted an oblique injection of the TESPEL to the LHD plasmas. Since the current TESPEL injector has no room for being added such a function, we decided to install a new dedicated TESPEL injector on LHD. A basic design of the new TESPEL injector is almost the same as the existing one[2], which consists of the TESPEL injection system and the differential pumping system. In the TESPEL injection system, the TESPEL will be accelerated through the gun barrel by a helium gas at high pressure. The differential pumping scheme works for preventing the high-pressure helium gas for the TESPEL acceleration from penetrating into the LHD vacuum vessel. Here, a three-stage differential pumping system is installed. The 1st expansion chamber is connected with the 2nd expansion chamber through an ultrafast shutter valve (closing time, less than 10 milliseconds), and then the 2nd expansion chamber is connected with the 3rd expansion chamber through a gate valve (closing time, 1 second). After the ejection of the TESPEL, these valves will be closed immediately. In order to realize effectively the oblique injection of the TESPEL, the final guide tube (i.e. nearest to the LHD plasma) for the TESPEL is installed in the vacuum vessel of LHD, as shown in Fig.1. And this final guide tube can be moved up and down by a remote-controlled drive mechanism for controlling precisely the penetration depth of the TESPEL. As can be seen in Fig. 1, the TESPEL injection axis can be set only in the edge ergodic region. This will be extremely useful for the study of an edge-radiation-enhanced operation scenario. Figure 2 show waveforms of the first shot by using the new TESPEL injector with the variable injection angle mechanism. As can be seen in Fig. 2, a successful injection of the TESPEL into the LHD plasma with the new injector was confirmed in the 18th LHD experimental campaign.

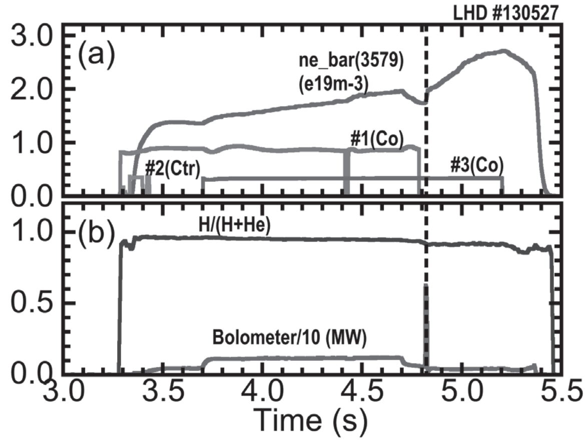

Fig. 2. Waveforms of a first shot by using the new TESPEL injector with the variable injection angle mechanism. The TESPEL injection time is set at t = 4.8 s. In this case, the penetration time into the LHD plasma is at t ~ 4.85 s as indicated by the vertical dashed line.

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1) Sudo, S.: J. Plasma Fusion Res. **69** (1993) 1349.
2) Sudo, S. and Tamura, N.: Rev. Sci. Instrum. **83** (2012) 023503.

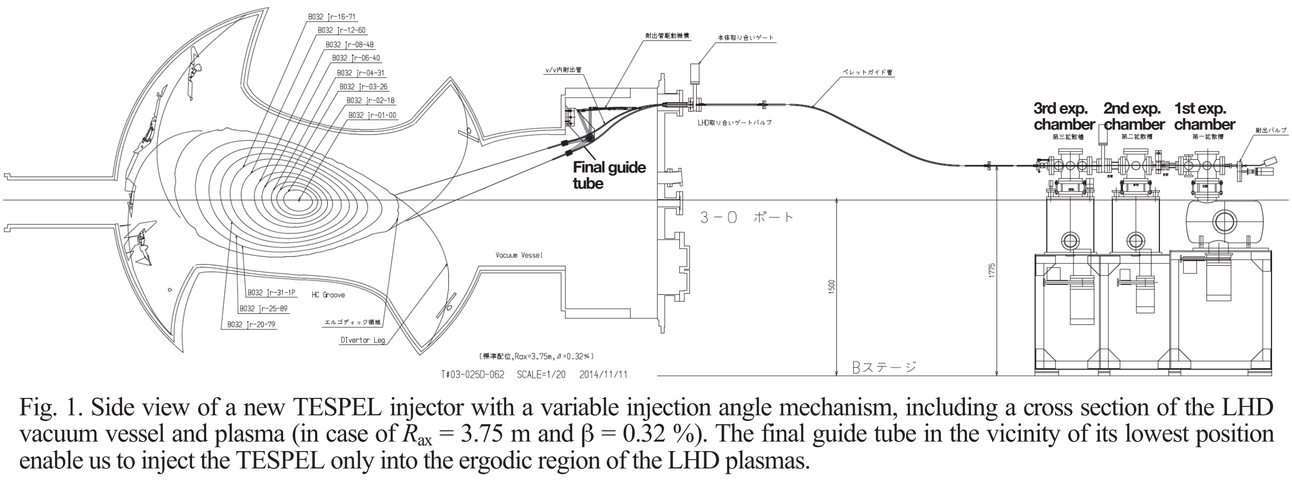

Fig. 1. Side view of a new TESPEL injector with a variable injection angle mechanism, including a cross section of the LHD vacuum vessel and plasma (in case of R_{ax} = 3.75 m and β = 0.32 %). The final guide tube in the vicinity of its lowest position enable us to inject the TESPEL only into the ergodic region of the LHD plasmas.