§28. Magnetic Field Line Measurement by Electron Beam in LHD

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Clean nested magnetic flux surfaces are essential for good plasma confinement in helical/stellarator devices. A technique for measuring magnetic field line structures by tracing electron beam was proposed and carried out in Tokamak and stellarator devices. Electron beam released along magnetic field lines from an aperture of the electron gun interacts with ambient gas in the vacuum vessel. It has been found that the traces of emission caused by the electron-gas interaction process approximately correspond to that of the magnetic field lines.

In order to check the applicability of this technique to a large sized helical machine (like a LHD), magnetic field line structures were measured using a vertically movable electron gun (4.5-L) and a peltier cooled CCD camera (6-T). A lanthanum hexaboride cathode specially designed for magnetic surface measurement in LHD under high magnetic fields (up to 4T) was used for an electron emitter in the electron gun. The measurements were carried out in a standard inward magnetic axis shift configuration (R_{ax}=3.60m, γ=1.254, B_t=-1.5T, B_q=100%). Argon gas was enclosed in the vacuum vessel with no active pumping in order to keep an ambient gas pressure stably during the measurement. The gas pressure was controlled by changing the total pulse length of gas puffing (Argon).

Figure 1 shows the observed images of the traces of the electron beam under four different ambient gas pressures (3.5×10^{-4}Pa~2.7×10^{-2}Pa) when the vertical position of the aperture of the electron gun was fixed to Z=-470.0mm. It was found that the Argon gas injection is very effective to enhance the emission of the electron beam trajectories compared to that in Hydrogen gas puffing cases. In the highest gas pressure condition ($P_{V/V}$~2.7×10^{-2}Pa), only two toroidally circulating traces were detected. The number of the traces increased in the gas pressure drop ($P_{V/V}$~6.8×10^{-3}Pa). But, the number was not changed in a further low gas pressure case ($P_{V/V}$~1.0×10^{-3}Pa). In this vacuum condition, a thin dim layer was observed in the space between four bright traces. For a further lower gas pressure condition ($P_{V/V}$~3.5×10^{-4}Pa), the traces became unclear (not observable), and the structure of the thin dim layer became clearly observable.

Figure 2 is a tangential view of calculated magnetic field lines which are traced from different vertical positions (-480.0mm<Z<-440.0mm). The structure of the measured traces is in good agreement with the calculated magnetic field line started from a position Z=-440.0mm. Small blue dots indicate the magnetic surface calculated by tracing a magnetic field line started from Z=-470.0mm. The image of the calculated magnetic surface qualitatively agrees with the measured structure of the thin dim layer in the low gas pressure conditions. Considering the position and the structure of the magnetic field lines for Z=-440.0m, the magnetic surface traced from this position seems to be more consistent with the measurement.

For detailed analysis of the magnetic field line structure by the electron beam, the exact vertical position of the electron gun must be measured three-dimensionally as precise as possible (within several millimeters). Additionally, installation of some benchmarks in the vacuum vessel is essential, and the exact position of the camera and the benchmarks has to be measured in order to compensate the effect of distortion by optical lenses, etc.

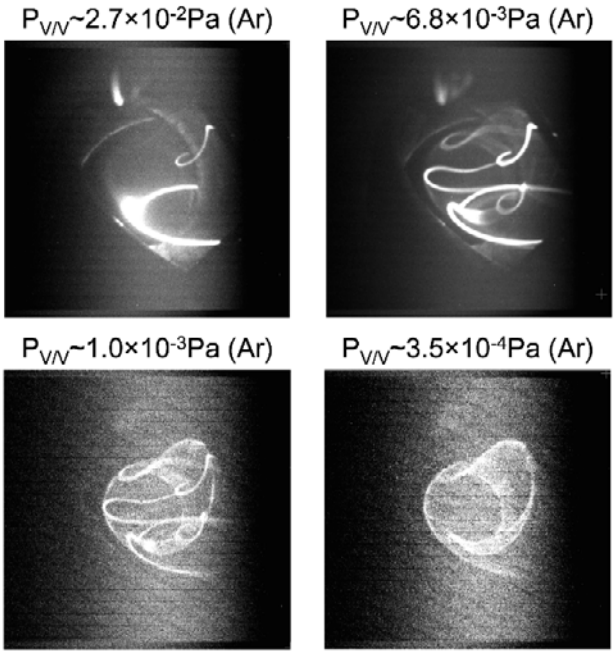

Fig. 1 Observed images of the traces of the electron beam in four different ambient Argon gas pressure (3.5×10^{-4}Pa~2.7×10^{-2}Pa) cases (the right side corresponds to the inboard side of the vacuum vessel).

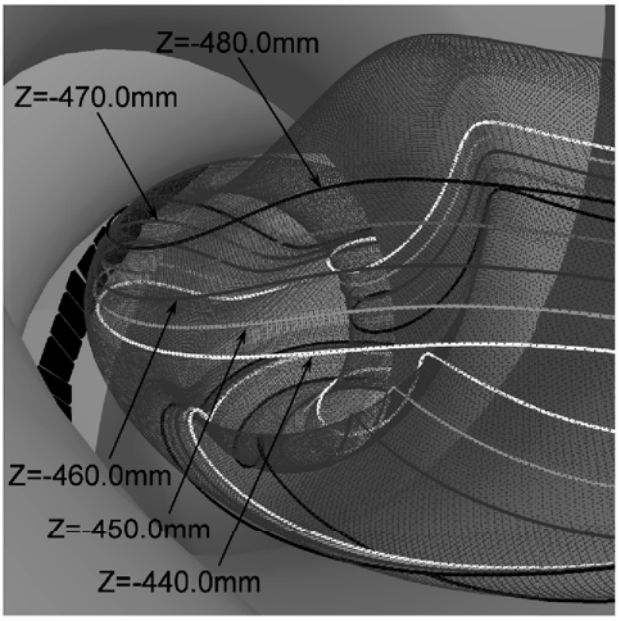

Fig. 2 Tangential view of calculated magnetic field lines which are traced from different vertical positions of the electron gun, and a magnetic surface (blue dots).