§9. Experimental Reconstruction of Helical Plasma Equilibria in LHD

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Various important confinement parameters critically depend on the definition of the plasma boundary. In a tokamak with 2-dimensional (2-D) symmetry, the existence of a material limiter or divertor separatrix determines the plasma boundary. In a helical system, a clear definition of the plasma boundary is problematic, especially in the case of high-beta or ergodic divertor discharges. To reconstruct 3-D equilibria experimentally, the free-boundary VMEC code is widely used. This code assumes the existence of magnetic surfaces, and several boundary conditions (i.e., those of one-point-limiter model[, the total-flux-constant model, etc.) can be used starting from a vacuum magnetic surface and proceeding to finite-pressure equilibria.

With regard to self-consistent theoretical equilibrium models including island and ergodic layers, several computer codes, such as MFBE, HINT, and PIES, can be used. However, these time-consuming codes are inconvenient for routine use in experimental data analyses.

A new technique with the VMEC extended virtual coordinate is proposed to reconstruct experimental plasma equilibria. The Pre-TOTAL and TOTAL (Toroidal Transport Analysis Linkage) codes are utilized for this purpose.

In Large Helical Device (LHD) experiments, the rho=1 magnetic surface in finite beta has been defined by using the outer equatorial point of the horizontally elongated last-closed vacuum magnetic surface. However, according to the experimental evidence on LHD, low-temperature finite-density plasma usually exists beyond the initial vacuum last-closed surface, and the radial coordinate describing this boundary region is required to obtain electron density profiles from FIR line-integrated data. Here, we use a toroidal flux ~ 10-20 % larger than that of the vacuum magnetic surface for the VMEC calculation with an initial-guess pressure profile. Then the line-integrated measured density profile is converted to the local density on this extended virtual coordinate, and the radial pressure profile is obtained using experimental radial profiles of electron temperature and density fitted on the real and flux coordinates.After several calculation iterations (usually ~3 iterations) on VMEC, the experimentally fitted equilibrium is obtained up to the virtual boundary. Here, we assume net-current-free equilibia.

This technique involves the usage of virtual flux coordinates expanded even to the magnetic ergodic and/or island regions. The obtained equilibria can be used for defining one-dimensional radial plasma profiles even within the edge ergodic region. The virtual boundary radius defined by toroidal flux should be adjusted from 90% to 120 % of the vacuum toroidal magnetic flux depending on plasma beta values.

In Fig.1, a typical data analysis in LHD is shown. The reconstruction has been performed using the radial pressure profiles by averaging the inner and outer pressure profiles,

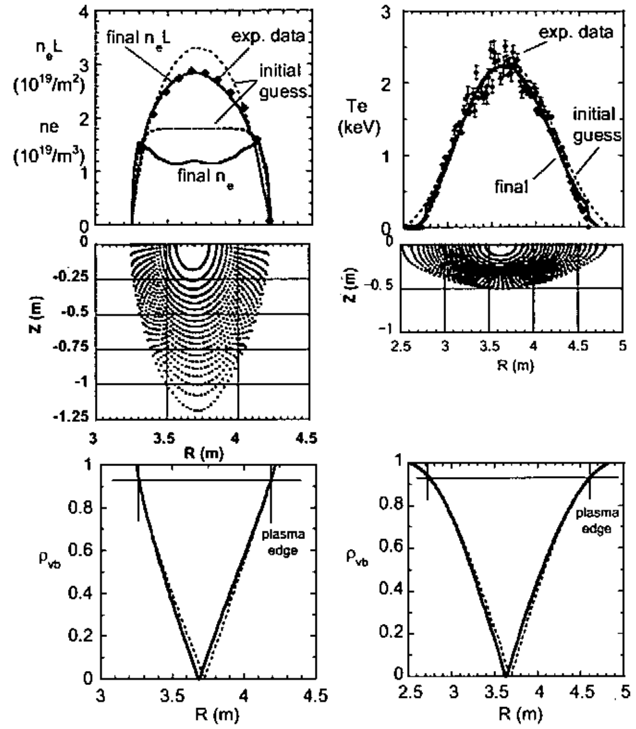

Fig. 1 Reconstruction of LHD equilibrium of a typical LHD shot (# 36199, t=0.7s). Left figures correspond to vertically elongated cross-section, and the right is horizontal one.

which are fitted to the line-integrated density on the vertically elongated cross-section, and the electron temperature profile on the horizontally elongated cross-section. The pressure-less region near the virtual boundary has been automatically included in this VMEC analysis. By this computational iteration, we can obtain the most probable profile within this model, taking care of fitness at three locations; the plasma edge, core, and axis positions. The vacuum magnetic axis of this discharge is 3.6 meters and the field strength is 1.49 T. The initial equilibrium guess with parabolic temperature and flat density profiles is shown by the dotted lines, which correspond to the measured value of diamagnetic energy. Experimental data for FIR line-integrated electron density and Thomson-scattering local electron temperature are shown by solid diamond points. At present, we cannot use the ion temperature profile routinely; we assumed the same profile of electron temperature. The final profiles are indicated by solid lines, which show the hollow density profile. The shape of the obtained magnetic surfaces is shown in the middle figures. The magnetic axis is shifted about 3 centimeters inward by iterations, as shown in the lower figures.

Reference

1) YAMAZAKI Kozo and the LHD Experimental Group *"Semi-Empirical Approach to Determine Plasma Boundary of Toroidal Helical Equilibria in LHD"* J. Plasma Fusion Res. Vol.79, No.8 (2003)739-741.