§63. Long-Pulse Experiment in ATF

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Steady-state operation is widely accepted as one of the primary goals of fusion reactor research and development. The Advanced Toroidal Facility (ATF) is the only existing experimental helical device which can realize steady-state operation even though it utilizes water-cooled copper coils. The techniques required for plasma control, wall conditioning, and power handling for long-pulse operation differ from those in pulsed devices. The long-discharge experiments of more than 1 hour employed 28 GHz ECH at 0.5 T at a power of ≤70 kW. Even with reduced power, the temperature of the vacuum vessel reached 100° C after a 30-minute discharge. The maximum plasma density was determined by the cut-off condition for X-mode (less than 4.8×10^{18} m^{-3} for 28 GHz). The electron density was usually controlled by gas feedback controlled by a 2-mm interferometer signals and feedback on the vessel neutral pressure was also employed. The demand for both feedback schemes can be changed during discharges. Helium was the usual working gas since recycling control is easier than with hydrogen. A discharge with a pulse length of 4667s (1 hour and 17 minutes) was achieved (see Fig.1). This pulse length is slightly longer than the longest achieved in tokamaks. The density was controlled below 3×10^{18} m^{-3}. Usual density feedback control with the interferometer was used for this discharge. Reduction of low-Z impurities was observedduring the discharge; however, the fuel and impurity partial pressures gradually increased as the vessel temperature rose, which enhanced radiation loss. The neutral pressure was also watched during the shot and the demand for feedback control was reduced manually to avoid a collapse. Density-control reductions eventually made the impurity partial pressure comparable with the fuel partial pressure. Although a plasma density decreases in the longest discharge, control of density for 1 hour was successful in the lower density region with 1.4×10^{18} m^{-3}. The ECH power was controlled at ≤70kW, which resulted in tolerable temperature increase for the vacuum vessel. The total amount of energy input reached 330MJ, which exceeds that in the large tokamak experiments. In this discharge, oxygen burn-out was not achieved and the electron temperature was limited to a couple of tens of eV. The power balance was dominated by atomic processes rather than transport. Higher temperature can be obtained by reducing the atomic-physics related losses. Indeed, the combination of pressure feedback, hydrogen gas, and higher power (120kW) led to achievement of 70-s long discharges with a temperature close to 200eV when the electron density was $2\times10^{18}m^{-3}$. Although hydrogen discharges had higher electron temperature, these discharges could not be maintained longer than 20 minutes due to wall desorption and recycling. While this experimental campaign was limited by available resources, valuable experience and encouraging results for future experiments planned for LHD were obtained.

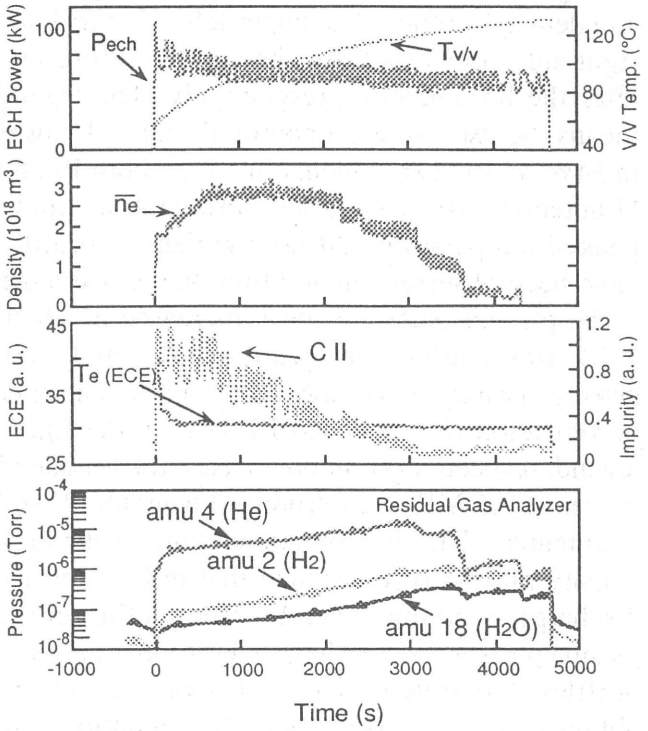

Fig.1Discharge waveforms for the longest shot. Top: ECH (28GHz) power and temperature of vacuum vessel, Upper middle: Line-averaged electron density, Lower middle: ECE emission and impurity line emission (C II), Bottom: Partial pressure from the residual gas analyzer.