§1. High Density Discharges and Related Physics

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Experimental study to achieve high density with confinement improvement has vigorously been performed in LHD. After the discovery of the internal diffusion barrier (IDB), a superdense core (SDC) plasma with a central electron density n_{e0} of more than ~ 10^{20} m^{-3} has been obtained routinely with multiple pellet injection. In the 12th experimental campaign, experiments aiming for higher n_{e0} were, of course, tried under new experimental conditions. Some physics-oriented experiments related to the high density discharge were also carried out.

For the better plasma confinement, superconducting helical coils were operated under the subcooled condition to obtain higher magnetic field strength B_T. In addition, the aspect ratio represented with a parameter γ was slightly changed to enlarge the plasma volume. Owing to the newly employed conditions expressed above and the optimized pellet injection scheme and magnetic configuration, following parameters were recorded in the 12th experimental campaign: the highest n_{e0} of 1.2×10^{21} m^{-3} (R_{ax} = 3.95 m, B_q, = 100 %, γ = 1.254, B_T = 2.506 T), the highest central plasma pressure of 155 kPa (3.80 m, 100 %, 1.259, -2.763), the highest plasma stored energy of 1.64 MJ (3.63 m, 100 %, 1.259, 2.893 T) and the highest fusion triple product of 5.2×10^{19} m^{-3}skeV (3.80 m, 100 %, 1.259, 2.763 T), where R_{ax} and B_q are magnetic axis position and quadrupole component parameter associated with plasma shape, respectively.

During the high density discharges, the central pressure becomes high, thus the large Shafranov shift takes place. According to the HINT2 calculation, it is expected that the magnetic structure in the edge region is strongly ergodized. In order to investigate the edge stochasticity and its effect on particle and energy transport, a resonant magnetic perturbation (RMP) was applied during the high density discharge. The RMP with m/n = 1/1 and 2/1 modes was induced with 10 pairs of small loop coils, and applied prior to the breakdown, where m and n are poloidal and toroidal mode numbers, respectively. Figure 1 shows the comparison of electron temperature T_e and density n_e profiles between (b) with and (a) without RMP. The ratio of RMP to B_T was 0.12 %. The most significant difference between two is the central electron temperature T_{e0}. The T_{e0} with RMP is ~ 0.75 keV, while it is ~ 0.37 keV without RMP. Since the central electron densities n_{e0} in both cases are in the same range, the consequent plasma pressure at the center is about two times higher in the case with RMP than that without RMP. This is reflected in the larger shift of the magnetic axis, as shown in Fig. 1 (b). On the other hand, edge electron density with RMP is low, compared to that without RMP. This indicates that the particles are pumped out with the application of RMP. This phenomenon is very similar to the tokamak RMP experiment$^{1)}$ which is expected to be a candidate of the ELM suppression technique. It has been found, from the HINT2 calculation, that the edge stochasticity is increased by RMP. It is expected that the increased stochasticity in the edge region enhanced the edge particle transport, in other words, transport properties were changed by the modification of the magnetic field structure. This decrease in the edge density leads to a change of the power deposition profile of the neutral beam heating (NBH). The most of NBH power usually deposits in the edge region where the n_e is relatively high. However, in this case, the NBH power can penetrate deep in the core plasma, which provides sufficient power deposition in the central region. The numerical calculation with FIT code also supports this scenario. It is considered that the central power deposition of NBH could be achieved by edge ergodization with RMP.

In the IDB-SDC discharge with RMP described above, fuelling was made only with pellet injection. No gas puff was utilized. In addition to the pressure rise in the central region, another interesting phenomenon was observed when a relatively strong gas puff was injected into SDC plasma with RMP. The divertor flux was suddenly decreased ~ 0.2 s after the gas puffing, as shown in Fig. 2. Little deterioration in the core parameter was seen. These results suggest the simultaneous achievement of SDC and the divertor detachment. It was also found that RMP is essential to obtain the divertor detachment during the SDC discharge.

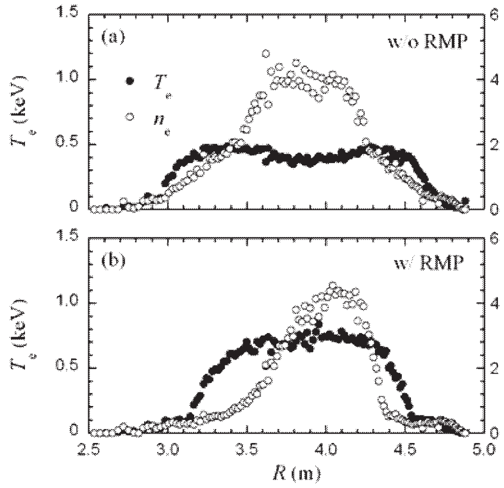

Fig. 1. Electron temperature T_e and density n_e profiles for (a) w/o RMP and (b) w/ RMP.

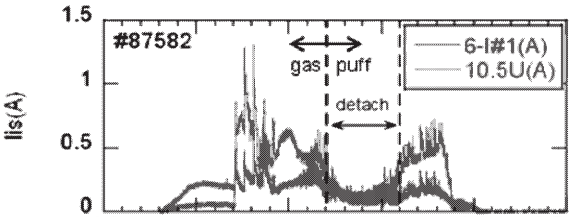

Fig. 2. Time evolution of divertor probe signals.

1) Evans, T., et al. : Nature Physics **2** (2006) 665.