Effect of Resonant Magnetic Perturbations on Super Dense Core Plasma in LHD

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1. Introduction

In Large Helical System (LHD), the super dense core (SDC) plasma [1] develops when a series of pellets is injected into the neutral beam heated plasma in the outward shifted configuration where the stochastic layer surrounding the confinement region is very thick. The central density more than ~ 1×10^{21} m^{-3} and the central temperature about 0.3 keV are maintained by an internal diffusion barrier (IDB) formed in the core region, where the steep density gradient is seen. During the IDB-SDC discharge, the large Shafranov shift due to the high central plasma pressure takes place, which strongly ergodize the edge magnetic field structure. In the stochastic layer, it is expected to have different heat and particle transport properties from the region with perfectly nested flux surfaces. It is found that the diffusion coefficient in the stochastic region is larger than that in the core region. Furthermore, enhanced particle transport in the edge region is also observed when the resonant magnetic perturbation (RMP) is superimposed, which is similar to “density pump-out” observed in tokamak RMP experiments [2,3].

To clarity the effect of RMPs on edge energy and particle transport, RMPs are applied dynamically during the discharge. In this paper edge plasma behaviour with dynamically applied RMPs is mainly presented, together with the experimental results with static RMPs.

2. Experimental results

Experiments were performed in LHD which is the largest super conducting heliotron device with poloidal/toroidal period numbers, major/minor radii, and toroidal magnetic field strength of l/m = 2/10, R/a = 3.9 m / 0.6 m and B_t = 3 T, respectively. The SDC discharges are achieved by the central fuelling with pellet injection and high power (> 15 MW) neutral beams (NBs). Repetitive pellet injection enables the quasi steady-state SDC discharge more than several seconds, although NB power should be reduced due to the accumulated heat loads to the drift tubes of NBs and plasma facing components.

RMPs with poloidal/toroidal mode numbers *m*/*n* of 2/1 and 1/1 are applied with 10 pairs of small loop coils installed on top and bottom sides of the torus. The amplitude of the RMP can be varied up to ~ 0.12 % of B_t at 3 T. In the dynamic RMP experiment, RMPs were ramped up or down for about 5 seconds in the full range of its amplitude. The typical time trend of the discharge is shown in Fig. 1.

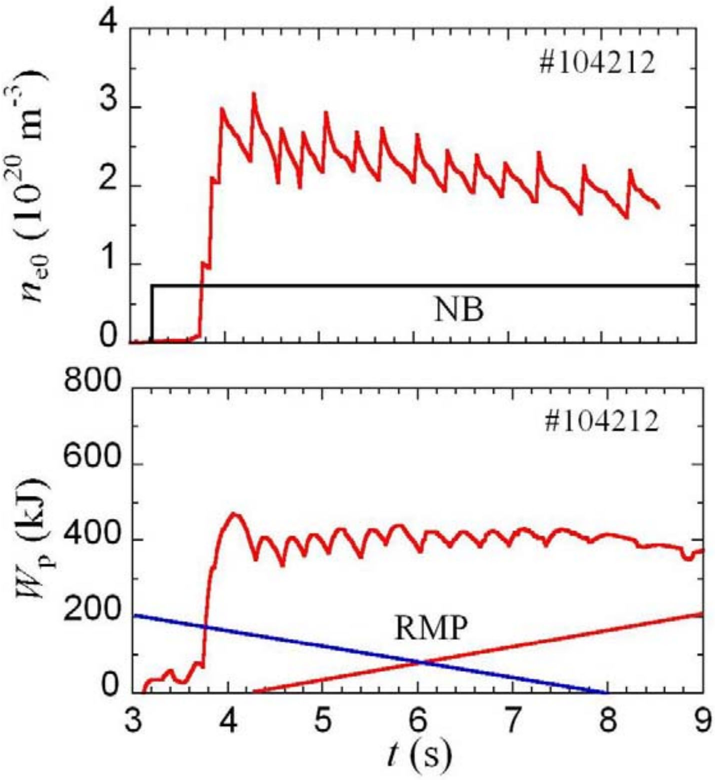

Fig. 1. Time evolution of central electron density n_{e0} and plasma stored energy W_p of typical dynamic RMP experiment. RMP is ramped up (red) or down (blue) for about 5 s, as shown in bottom figure. NB is injected although the discharge, as shown in top figure.

Several pellets were injected continuously within ~ 0.1 s to build up the SDC plasma. Subsequent injections at the frequency of several Hz were carried out with feedback control system, referring to n_e signal, to sustain the SDC plasma in steady-state. The RMP is ramped up or down during the discharge as shown in the bottom in Fig. 1. It is found that the SDC plasma with n_{e0} ~ 2 x 10^{20} m^{-3} is sustained for more than 5 s. Note that W_p signal has not been compensated for errors from time-varying RMPs.

In Fig. 2, electron density profiles measured with the Thomson scattering system are presented. These profiles were taken just before the RMPs ramp up (open circles) and down (closed circles), in other words, without (open) and with (closed) RMPs. Clear reduction of electron density (density pump-out), in the mantle region of R < 3.5 m and R > 4.2 m, i.e. outside the $\iota/2\pi = 0.5$ surface, is observed, although the density reduction in the edge or SOL (scrape-off layer) region is unclear.

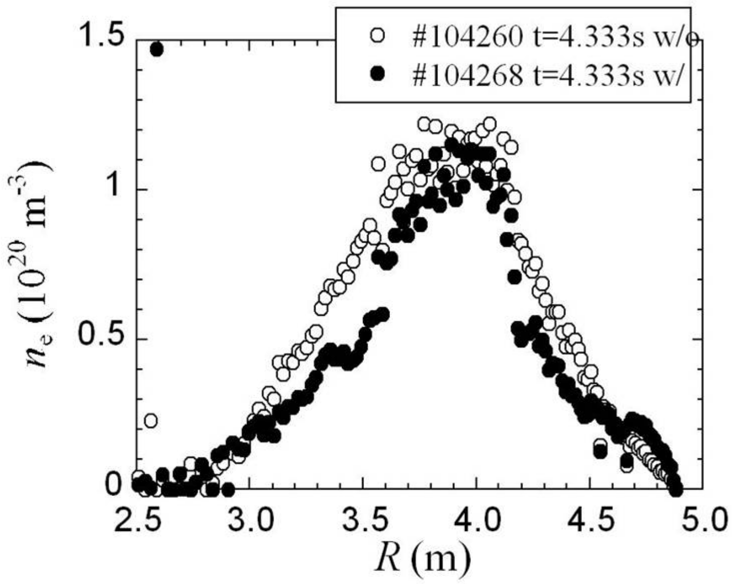

Fig. 2. Electron density profiles just before RMPs ramp up (open circles) and down (closed), in other words, without (open) and with (closed) RMPs.

In order to see the response of the mantle plasma to RMPs, plasma behaviour during the ramp up/down of the RMP was investigated. Time evolution of electron density measured with the Thomson scattering system was analysed. In Fig. 3 (a), mantle density as a function of the RMP amplitude is presented. Red and blue symbols represent data during ramp up and down of RMPs, respectively. Thus the state of mantle plasma evolves clockwise, as shown with arrows in the figure. Two different symbols correspond to two different positions, i.e. inboard and outboard sides of the torus, respectively. It can be seen from Fig. 3 (a) that the reduction of the density, i.e. density pump-out, is small during the ramp up of RMPs. On the other hand, the plasma responds according to the RMP amplitude in the ramp down phase. In other words, the response of the mantle plasma to RMPs is insensitive or slow especially in the ramp up phase of RMPs, which results in the hysteresis character in the n_e - RMP amplitude diagram. The mechanism to include the hysteresis in the relation between particle pump-out and the RMP amplitude has not been clarified yet. These experimental results suggest that the magnetic diffusion time is changed according to the initial magnetic topology in the mantle region.

To see the effect of edge modification, i.e. stochastization, with the RMP on particle transport, diffusion coefficient D at the mantle region (normalized minor radius r/a = 0.75) was calculated in the density decay phase after each pellet injection. In Fig. 3 (b), D as a function of the RMP amplitude, I_{RMP}, is presented. Similar dependences of edge n_e and D on the RMP amplitude can be seen. This result may provide important information to clarify the underlying physics between the self-organization of the magnetic topology and the particle transport.

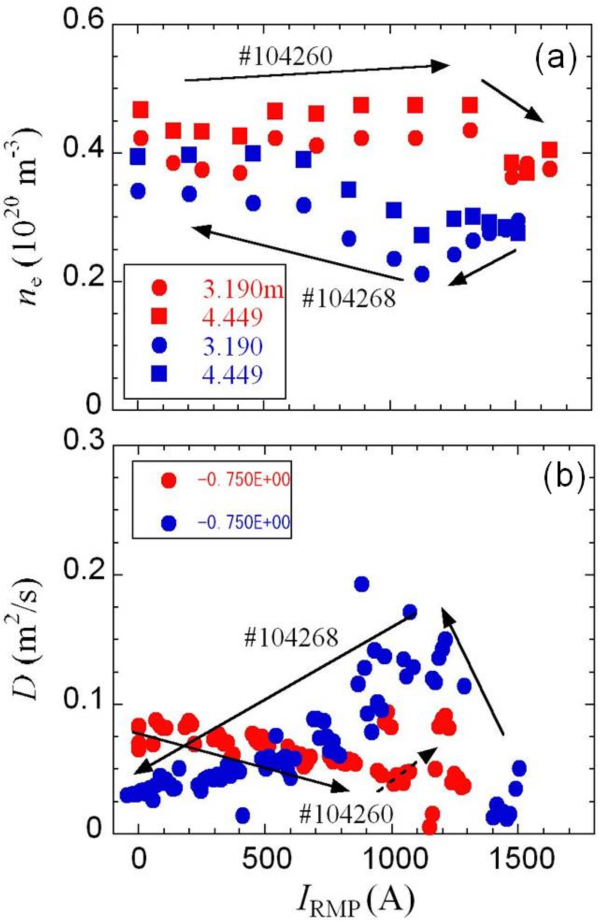

Fig. 3. Edge density and related diffusion coefficient as a function of the RMP amplitude.

References

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