24C01

Operations of divertor heat load mitigation on LHD
LHDにおける受熱板熱負荷軽減運転

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Experiments on divertor heat load mitigation are conducted on LHD. Ne seeding can increase the radiation intensity by a factor of two and decrease the n_e and T_e on divertor plates by half without deterioration of core confinement. The resonant magnetic perturbation field of the m/n=1/1 mode can also induce the detachment and stabilize the position of the radiation region at the island. These schemes can be combined and increase the radiation further.

1. Introduction

In magnetically confined fusion reactors, divertor plates will be exposed to the extremely high energy flux more than 10 MW/m^2 from a plasma, which is beyond the present engineering limit of the divertor structure. Although great efforts have been paid to development of divertor materials and their structures so far, it is crucial to reduce the divertor flux. It is one of the key issues to realize fusion reactors because its economic merit depends on the maintenance and replacement of the divertor plates.

The power dispersal via energy loss such as radiation by impurity species is, at the moment, a possible scheme to reduce the divertor power load lower than the engineering limit. The operation of this scheme is called “divertor detachment”. Impurity seeding experiments for optimization of edge parameters and impurity species have been conducted in tokamaks.

On the other hand, several experiments to mitigate the heat and particle loads have started on the Large Helical Device (LHD). LHD has a different peripheral magnetic structure, such as the existence of the stochastic layer, and edge n_e and T_e profiles from those in tokamaks. Investigation of operations for heat and particle loads mitigation on LHD is not only useful for helical reactors but also for toroidal plasmas.

2. Impurity Gas Puffing

In present medium/large fusion devices, a plasma facing material is carbon, and it works as a dominant radiator to reduce the edge T_e. However, carbon will not be utilized in fusion reactors to reduce tritium retention in the vacuum vessel and to avoid severe erosion of plasma facing components. Instead, metallic materials such as tungsten will be used for plasma facing materials. Therefore, it is considered that impurities such as Ne seeding are necessary to enhance the radiation loss in the edge region.

Figure 1 shows time evolutions of plasma parameters of a Ne seeding discharge with a line average density ($n_{e,bar}$) of 5×10^{19} m^{-3}. The Ne gas is puffed from t = 4 s for 120 ms. The Ne gas flux is ~ 1.6 Pa·m^3/s, and it is about 10 % of H_2 gas flux at t = 4 s. Total radiation power (P_{rad}) rises from 2 MW (~0.15×P_{NBI}) to 4 MW (~0.3×P_{NBI}) during the Ne

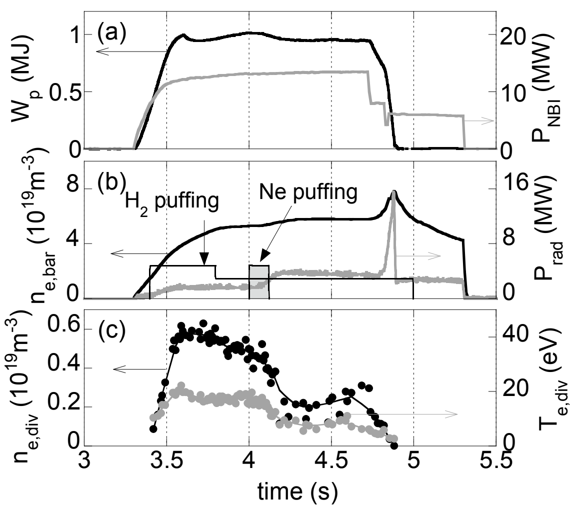

Fig. 1. Typical time evolutions of (a) plasma stored energy (W_p) and NBI power (P_{NBI}), (b) line averaged density ($n_{e,bar}$), radiation power (P_{rad}) and gas-puffing, (c) electron density ($n_{e,div}$) and temperature ($T_{e,div}$) in the divertor (torus inboard-side).

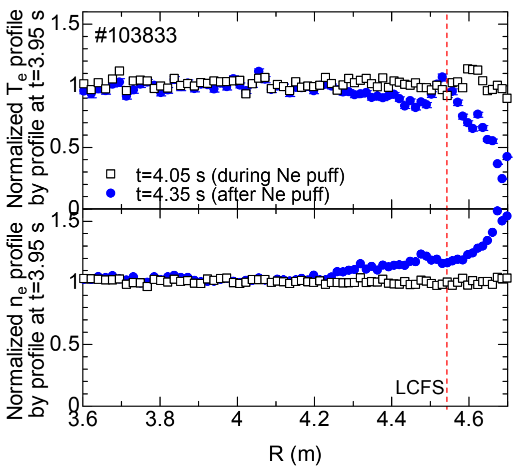

Fig. 2. Normalized radial profiles of n_e and T_e profiles by those at t=3.95s (before Ne seeding) in the same discharge as Fig. 1.

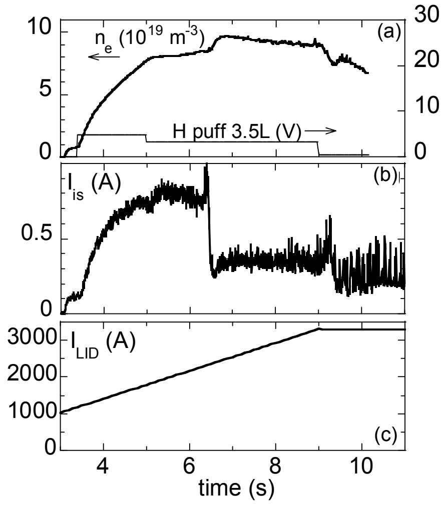

Fig. 3. Time traces of (a) line averaged density and gas puff wave form, (b) the divertor particle flux, (c) RMP coil current.

puffing. It is clearly shown that both divertor n_e ($n_{e,div}$) and T_e ($T_{e,div}$) decreased with the Ne seeding. This means that particle and heat loads to the divertor are reduced. The Ne seeding does not strongly affect global parameters such as the plasma stored energy, W_p, and $n_{e,bar}$.

Figure 2 shows radial profiles of n_e and T_e normalized by those before the Ne seeding (t=3.95 s). While n_e and T_e change in the stochastic region and near the LCFS in the core plasma, the central n_e and T_e around R~3.6 m do not change. They are preferable features of the Ne seeding.

3. Inducing Detachment and Stabilization of Radiation Region with RMP

Thermally unstable plasmas after the detachment from the divertor plates are observed in various devices. These instabilities lead to difficulty of control of the radiation level and location, the X-point MARFE with deterioration of core plasma performance.

In LHD, it is found that the resonant magnetic perturbation (RMP) field of the n/m=1/1 mode has a stabilizing effect on the strongly radiating plasma, where the detachment operation is successfully sustained without deterioration of the core plasma performance up to the end of the discharge[2). Without the RMP, otherwise, the plasma leads to radiative collapse. From the measurements of bolometer and AXUVD, the strong radiation layer is considered to be stabilized around X-point of the island.

Figure 3 shows time traces of $n_{e,bar}$, the divertor particle flux and the ramp-up perturbation coil current for the m/n=1/1 RMP field. After the initiation of the discharge at t=3 s, $n_{e,bar}$ is gradually increased by gas puffing and it reaches the flat top ~8×10^{19} m^{-3}, while the perturbation field continues to increase during the discharge as shown in the coil current. By keeping the density constant after t=5 s, only the perturbation field increases and the plasma goes to the detached state at t=6.3 s as shown in the divertor particle flux reduction. The detachment is sustained up to the end of the gas puffing at t=9 sec. The detachment transition occurs at the coil current of slightly above 2000A. The timing of the coil current ramp up is shifted back and forth in time while keeping almost the same density flat top to confirm the effect of the RMP field. It is found that the detachment onset is accordingly shifted back and forth in time. These results demonstrate that the RMP field is a new control knob of the divertor detachment.

The compatibility of the island induced detachment with the impurity gas seeding has also been confirmed. The additional Ne seeding to the island detached plasma increases the radiation intensity by a factor of 1.4, while keeping the stable detachment.

4. Summary

On LHD, the impurity gas seeding successfully mitigates heat and particle loads to the divertor plates. The RMP field can induce the detachment. It is possible to combine these two schemes and further radiation can be obtained.

References

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