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Control of radiative/detached divertor operation with m/n=1/1 RMP applied to the stochastic layer of LHD

LHDにおける共鳴摂動磁場によるデタッチメント制御実験

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Effects of resonant magnetic perturbation (RMP) field on the radiative/detached divertor plasma are investigated by applying m/n=1/1 RMP to the edge stochastic layer of the Large Helical Device (LHD). The remnant island in the stochastic layer created by the RMP changes the density dependence of radiation intensity compared to the non RMP case. There appears density window where radiation becomes insensitive to density. In this window, the radiative divertor plasma is stably sustained with concomitant divertor power/particle flux reduction observed at several probe arrays, while the toroidal uniformity of the detachment is not guaranteed yet. It has been demonstrated that the detachment onset can be controlled with ramp up of RMP current and that the RMP induced detachment is compatible with further enhanced radiation with extrinsic impurity gas puff.

1. Introduction

In magnetically confined fusion reactors, the energy flux to the divertor plate caused by the direct contact of plasma with the plate surface is expected to be several tens MW/m^2, which is far beyond the engineering limit of the divertor structure [1]. The power dispersal via volumetric energy loss such as line radiation by impurity species is, at the moment, only possible scheme to bring the divertor power load below the engineering limit. The reduction of the power load has been demonstrated in many devices by increasing the radiated power fraction up to 80 ~ 90 %. At the same time, however, it is found that once the plasma detaches from the divertor plates, the plasma tends to be thermally unstable and the control of the radiation level/location becomes very difficult. The loss of control of the detachment plasma leads to the X-point MARFE with deterioration of core plasma performance [2].

2. Effects of RMP on the radiation intensity

In LHD, effects of the resonant magnetic perturbation (RMP) field on the edge radiation are investigated by applying n/m=1/1 RMP to the stochastic layer. The RMP creates remnant island in the stochastic layer. The radiation intensity measured by resistive bolometer is plotted in Fig.1 as a function of line averaged density. The RMP coil current is changed from 0 to 3.4kA, where 3.4kA corresponds to $\tilde{b}/B_T$ ~ 0.11%. Application of RMP leads to rapid increase of radiation above $\bar{n}_e$ ~ 4x10^{19} m^{-3}, and enters the certain range where the intensity becomes insensitive to $\bar{n}_e$. In this range the increased radiation is easily sustained for several seconds until the end of discharge [3]. The two Langmuir probe arrays at top and inboard divertor plates show reduction of heat and particle load during this phase, although the divertor leg interferometer installed at the different location than the probes shows no reduction of the density. The

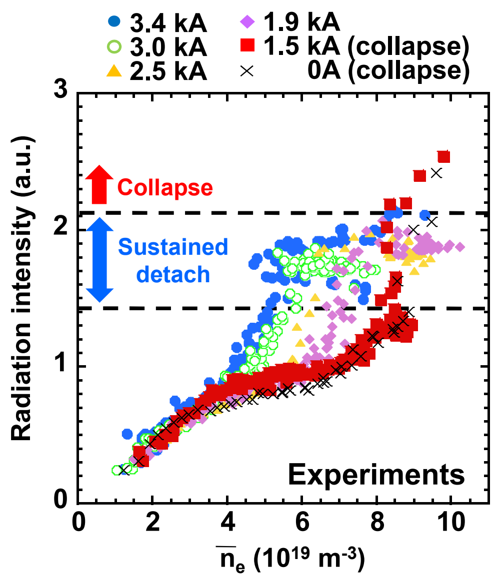

Fig.1 Radiation intensity as a function of line averaged density for different RMP coil current.

ratio of H_γ/H_β measured by visible spectrometer increased throughout the torus. The measurements indicate divertor detachment, but with a certain toroidal modulation probably related to the mode structure of the RMP. The distribution of the detached divertor plasma in toroidal/poloidal direction is under investigation.

In the case without RMP, the radiation increases rather slowly against density, and around $8.5\times10^{19}m^{-3}$ it increases quickly beyond the density limit resulting in radiative collapse. The change of RMP coil current from 3.4 to 0kA gradually shifts the curves towards non RMP case. There is a threshold value for the sustained detachment around 1.9kA.

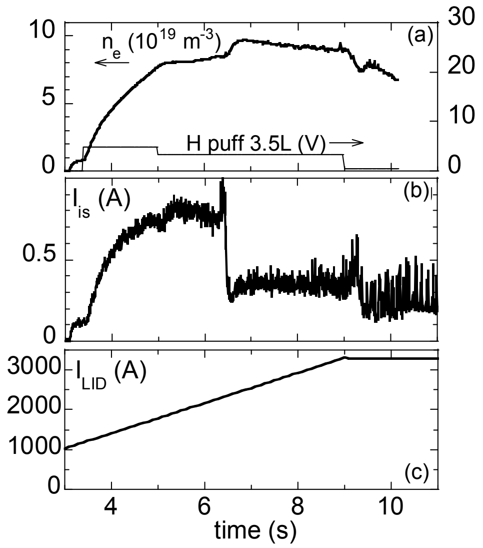

Fig. 2. Time traces of (a) line averaged density and gas puff wave form, (b) the divertor particle flux, (c) RMP coil current.

2. Control of detachment onset with RMP current

In the 14th experimental campaign (fiscal year 2010) of LHD, the possibility of detachment onset control with RMP has been demonstrated. Fig.2 shows the time trace of line averaged density, divertor particle flux and the perturbation coil current for n/m=1/1 RMP. After the initiation of the discharge at t=3 sec, the plasma density is gradually increased by gas puff and it reaches the flat top ~8×10^{19} m^{-3}, while the perturbation field is also increased during the discharge as shown in the coil current. By keeping the density constant after t=5 sec, only the perturbation field increases and the plasma goes to detachment at t=6.3 sec as shown in the divertor particle flux reduction. The detachment is sustained up to the end of discharge at t=9 sec. It is seen that the detachment transition occurs at the coil current of slightly above 2kA. The timing of coil current ramp up is shifted back and forth in time while keeping the almost same density flat top to confirm the effect of RMP. It is found that the detachment onset is accordingly shifted back and forth in time. The results demonstrate the availability of the new control knob on the divertor detachment.

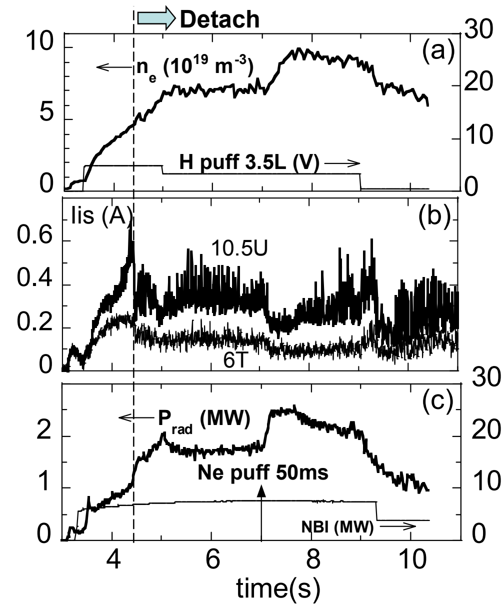

Fig. 3. Time evolution of (a) line averaged density and gas puff wave form, (b) divertor particle flux, (c) radiation intensity, NBI input power and Ne puff timing of 50 ms pulse (arrow).

3. Compatibility of the RMP induced detachment with extrinsic gas puff

The compatibility of the island induced detachment with the extrinsic gas injection, which is often effective to increase the radiation fraction, has been tested. Fig.3 shows the time evolution of the line averaged density, divertor particle flux and the radiation intensity. In this case, the full RMP current is applied from the beginning of the discharge, and the island detachment occurs at t=4.5 sec. The density is still increased even after the detachment onset up to 7×10^{19} m^{-3} and keeps constant afterwards. The neon is puffed at t=7 sec with 50 ms pulse as indicated with the arrows in the figure. The radiation intensity increases by a factor of 1.4, while keeping the stable detachment.

References

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