§3. Stability Analysis of RMP Assisted Detachment in LHD

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It has been found that the detachment can be stabilized by application of resonant magnetic perturbation (RMP) in LHD [1)]. The RMP (m/n=1/1) creates the remnant magnetic island in the edge stochastic layer and the radiation distribution is modified by the structural change as confirmed in the numerical simulations as well as in experiments [2,3)]. Without the RMP, otherwise, the enhanced radiation with increasing density can not be stabilized and leads to radiation collapse. As the similar stabilization effects have been observed in W7-AS [4,5)], where the large edge magnetic island with shorter magnetic field line connection length provides detachment stabilization. The responsible mechanism is considered to be the decoupling of the divertor recycling from the confinement region, which then avoids a positive feedback of density increase after detachment transition that is a cause for radiation collapse. The similar explanation can apply to the case of LHD, since also the spatial separation of the m/n=1/1 island and the confinement region is found to be important to realize the stable detachment in LHD, too. In the present analysis, however, we investigate the detachment stability in terms of the energy balance of the radiating edge plasma with island magnetic field structure using a perturbation method.

Figure 1 shows the edge T_e and n_e radial profiles (triangles) obtained by the Thomson scattering system and corresponding carbon radiation estimated from the T_e and n_e, using carbon cooling rate $L(T_e)$ with $n_e\tau = 10^{17}$ m^{-3} s. The radiation amount in this toroidal plane can be calculated as,

$$P_{rad} = \int C\, n^2\, L(T_e)\, dR\,, \qquad (1)$$

where $C = n_{carbon} / n_e$, fraction of carbon density. Here it is assumed that with a certain factor multiplied to P_{rad}, it can be representative for a total radiation through the torus. Based on the idea of perturbation method, here we apply small perturbation of T_e, dT_e (< 0) to the T_e profile, which is then reflected also on n_e by assuming that $T_e\, n_e$ = constant, as shown in Fig.1 with dashed lines. With dT_e (< 0), the radiation peaks move radially inward and we can also calculate P_{rad} for this perturbed profiles. When $\partial P_{rad}/\partial T_e > 0$, dT_e (< 0) leads to decrease of P_{rad}, and then the perturbed T_e comes back to the initial state, i.e., this is a stable branch. On the other hand, When $\partial P_{rad}/\partial T_e < 0$, dT_e (< 0) leads to further increase of P_{rad}, and thus T_e decreases further and the radiation peaks penetrate radially inwards. This corresponds to the radiation collapse, i.e. an unstable branch.

Figure 2 shows the P_{rad}, as a function of dT_e for the cases with and without RMP. In the case with RMP, there is clear stable branch ($\partial P_{rad}/\partial T_e > 0$) appearing at dT_e = -10~-5 eV. This branch appears as the radiation peaks penetrate beyond the m/n=1/1 island structure, i.e., flattening region of T_e. On the other hand, in the case without RMP, the entire profile of P_{rad} shows $\partial P_{rad}/\partial T_e < 0$, i.e., unstable, except for the small portion of $\partial P_{rad}/\partial T_e > 0$ around dT_e = -13 eV, which is due to T_e flattening caused by intrinsic small remnant island. This small stable branch, however, is considered to not be able to stop inward penetration of radiation because of the smallness. The analysis shows clear difference in the behavior of P_{rad} between the cases with and without RMP, and thus the flattening of T_e due to the structural change of magnetic field by RMP can affect the energy balance in the edge region, which can be responsible for the detachment stabilization.

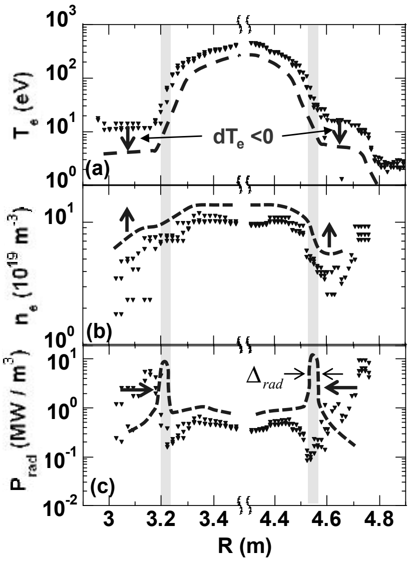

Fig. 1. Radial profiles of (a) T_e, (b) n_e obtained by Thomson scattering system, and (c) estimated P_{rad}. The dashed lines show perturbed profiles with dT_e < 0.

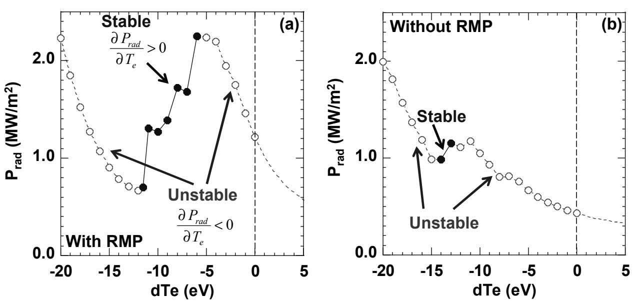

Fig. 2. P_{rad} as a function of temperature perturbation, dT_e. (a) with RMP, (b) without RMP.

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