§14. Compatibility of RMP Assisted Radiative Divertor Operation with Main Plasma Confinement and Operation Space in Magnetic Field Configuration in LHD

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It is found that resonant magnetic perturbation (RMP) fields have a stabilizing effect on the radiating edge plasma, realizing stable sustainment of radiative divertor (RD) operation in the Large Helical Device (LHD). Without RMP, thermal instability leads to radiative collapse [1]. Divertor power load is reduced by a factor of 3~10 during the RMP assisted RD phase.

It should be also noted that during RMP assisted RD phase, relatively good core plasma confinement, with confinement enhancement factor [2] $\tau_E^{\exp} / f_{ren}\, \tau_E^{ISS04} \sim 0.96$, has been achieved. Fig. 1 summarizes global energy confinement ISS04 scaling ($f_{ren}\, \tau_E^{ISS04}$) as a function of $\bar{n}_e$ normalized by the Sudo density limit [3] ($\bar{n}_c^{Sudo}$). In the case without an RMP, maximum confinement appears around $\bar{n}_e / n_c^{Sudo}$ = 0.4, and further increase in density monotonically leads to confinement degradation towards radiative collapse around the density limit. The attached case with an RMP shows a similar tendency, where degradation occurs at $\bar{n}_e / n_c^{Sudo}$ > 0.4, but with reduced values of the enhancement factor because of the large edge magnetic island mentioned above. After the transition to the RD operation, however, the energy confinement suddenly recovers even beyond those without an RMP around the density limit. The results show that an RMP introduces a new branch of radiating plasma equilibria, which is accessed above a certain density threshold, for example n_c^{RD} / n_c^{Sudo} ~ 0.6 at this perturbation strength. The underlying mechanism is under investigation in terms of change of confinement mode [4].

It is found that realization of a stable RMP assisted RD depends on the magnetic configuration. Fig.2 shows the dependence of controllability of RMP assisted RD on the radial location of the island X-point with respect to the last closed flux surface (LCFS), $r_{X\,point} - r_{LCFS}$, and on RMP strength, $\tilde{b}_r^{coil} / B_0$, where $r_{X\,point}$ and r_{LCFS} are the minor radii of the X-point of m/n=1/1 island and LCFS, respectively. The radial location of X-point has been changed by controlling coil current of helical and poloidal field coils in LHD. During the X-point scan the RMP strength has been fixed at $\tilde{b}_r^{coil} / B_0 \sim 1.0\times10^{-3}$. It is found that a stable RD is realized when $r_{X\,point} - r_{LCFS} \geq 0.05$ m. If the X-point is closer to the confinement region than this value, T_e at the island is relatively high, > 100 eV, where impurity radiation is small. Increase of density can reduce T_e at the island down to ~ 10 eV. But then discharge immediately terminates due to inward penetration of the radiation layer. The results suggest the importance of the separation of the radiation layer from the confinement region for a stable RD.

As $\tilde{b}_r^{coil} / B_0$ is reduced, the transition density to RD, n_c^{RD}, gradually increases. And finally around $\tilde{b}_r^{coil} / B_0 \sim 5\times10^{-4}$, it merges to the density limit $\sim n_c^{Sudo}$, i.e. there is no operation space for stable RD. Therefore, as soon as the plasma detaches from the divertor plate, the operation reaches a density limit and thus the discharge goes to a radiative collapse. The threshold RMP strength, $\tilde{b}_r^{coil} / B_0 \sim 5\times10^{-4}$, corresponds to an island width $w_{vac} / a \approx 0.23$ ($w_{vac} \approx 0.19$ m) at the outboard midplane. It is also found, that in this low $\tilde{b}_r^{coil} / B_0$ range, despite the still substantial size of w_{vac}, almost no T_e flattening is observed, indicating plasma healing of island. Thus radiation enhancement with the island structure is not available. The results suggest that RD controllability depends not only on energy transport with radiation enhancement, but also on the MHD plasma response to an RMP.

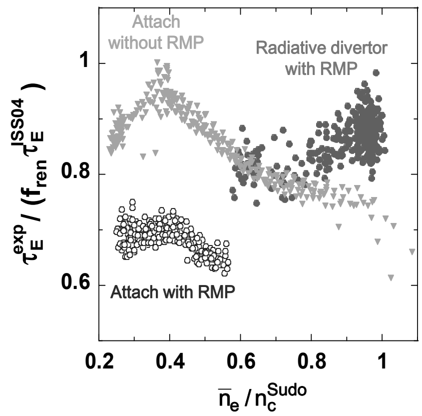

Fig.1 $\tau_E^{\exp} / f_{ren}\, \tau_E^{ISS04}$ as a function of $\bar{n}_e / n_c^{Sudo}$. Triangles, open circles and closed circles denote attached without RMP, attached with RMP and RD with RMP, respectively

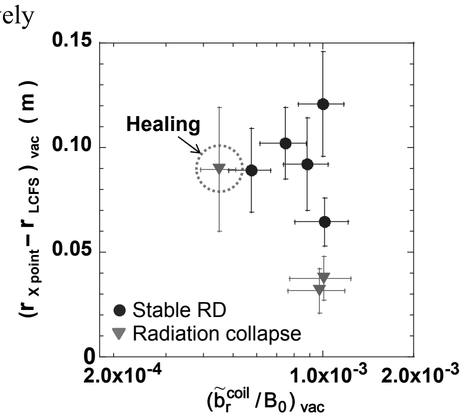

Fig.2 Dependence of RMP assisted RD controllability on magnetic field configuration, $r_{X\,point} - r_{LCFS}$ and $\tilde{b}_r^{coil} / B_0$. ▼: radiation collapse, ●: stable RD.

1) Kobayashi, M. et al.: Phys. Plasmas **17** (2010) 056111.
2) Yamada, H. et al.: Nucl. Fusion **45** (2005) 1684.
3) Sudo, S. et al.: Nucl. Fusion **30** (1990) 11.
4) Itoh, S.-I. et al: J. Nucl. Mater. **220-222** (1995) 117.