§7. Effects of Non-Axisymmetric Magnetic Perturbations on Edge Localized Modes in LHD

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Suppression or mitigation of ELMs is an important issue toward burning plasma experiments in ITER. In tokamaks and spherical tori, type I ELMs were successfully mitigated or suppressed by non-axisymmetric magnetic perturbations [1-5]. In LHD experimental campaign in 2011, large amplitude ELMs were mitigation by stationary applied resonant magnetic perturbations (RMPs) [6]. In the mitigation experiment, H-modes with large amplitude ELMs were produced in the so-called outward-shifted configuration of R_{ax}=3.9m, where the low-order rational surface $\iota/2\pi$=1 locates just outside the last closed flux surface (LCFS) and in stochastic field region intrinsically existing in the vacuum field. In the ELM mitigation, global energy confinement of the ELM mitigated H-mode plasmas was slightly reduced. In LHD, resistive interchange modes (RICs) are thought to be responsible for ELMs [7, 8]. The pressure gradient at the $\iota/2\pi$=1 rational surface where ELMs are excited is slightly reduced by the RMPs. Nevertheless, ELM frequency is considerably enhanced, having reduced ELM amplitude. This suggests that RMPs degrade MHD stability in the edge transport barrier (ETB) region. Following two causes are thought to be plausible candidates:(1) expansion of bad curvature region, and (2) decrease of the effective magnetic shear, because they would enhance the linear growth rate of RICs**.**

In 2012 experimental campaign, the experiment was conducted to study the following two targets (1) threshold of RMPs for ELM mitigation using a ramp-up waveform of RMP, and (2) effect of RMPs and non-resonant ones (non-RMPs) on ELM mitigation. Figure 1 shows the effects of a ramp-up RMP on ELM characteristics. In this experiment, the RMP coil current is ramped up with 380A/s ramp-up rate and reaches a flat-top of 760 A in 2 s after the turn on of the power supply. The current waveform is proportional to the flux loop signal ϕ_4 shown in Fig.1. The RMP strength at the plasma center in the vacuum corresponds to ~6 x 10^{-4} T at the flat-top. In Fig.1(a) where the RMP pulse is turned on at t=3.0 s, the RMP has no impact on ELMs in H-phase before the H-L back transition takes place. When the RMP is turned on at t=2.0s, the ELM mitigation is clearly realized just before the flat-top of RMP pulse, as shown in Fig.1(b). The threshold for ELM mitigation agrees well with that obtained in the stationary RMP experiment. This indicates that the RMP penetrates into ETB region without noticeable delay because of relatively low electron temperature in the ETB ($T_e \le$ 100 eV) and slow plasma rotation of the angular frequency ($\omega \le$ 10 krad/s). It is thought that the RMPs penetrate into ETB region without noticeable shielding effect by plasma response. The other research target in the 2012 campaign is which resonant and non-resonant magnetic perturbations for the $\iota/2\pi$=1 rational surface contribute to ELM mitigation in H-modes obtained in the R_{ax}=3.9m configuration. In Fig.2, ELM characteristics are compared for three cases: (1) RMPs dominated by m=1/n=1 Fourier components, (2) non-RMPs dominated by m=2/n=1 Fourier components, and (3) without both RMPs and non-RMPs. The RMPs clearly mitigate ELMs which are induced by RICs excited at the $\iota/2\pi$=1 surface, as shown in Fig.2 (#114435). The shot #114436 where non-RMPs are applied does not exhibit ELM mitigation, and is very similar to the shot without any magnetic perturbations. In conclusion, RMPs are essential for ELM mitigation in LHD H-modes.

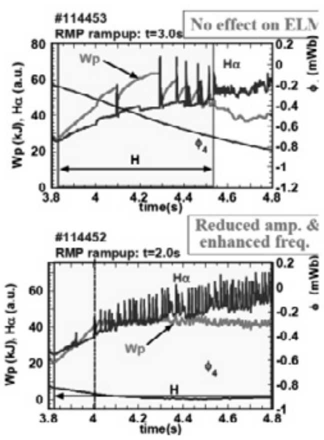

Fig.1 (a: upper traces) the case of late turn-on (t=3.0 s)of the RMP pulse, (b: lower traces) the case of early turn-on (t=2.0s) of RMP pulse.

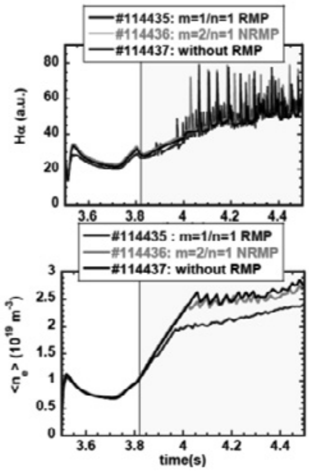

Fig.2 Comparison of three shots: #114435 with m=1/n=1 RMPs, #114436 with m=2/n=1 non-RMPs, and #114437 without both RMPs and non-RMPs.

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