§45. Mitigation of Large Amplitude Edge-Localized-Modes by Resonant Magnetic Perturbations (RMPs) on LHD

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Suppression and mitigation of ELMs were demonstrated by application of RMPs in some tokamaks[1-3]. “Density pump-out” is induced by RMPs in DIII-D and JET [1, 2], but not in AUG [3]. The RMP effects on particle transport and ELM suppression or mitigation in tokamak plasmas are not fully understood so far. The study of the effects in helical plasmas is significant for the comprehensive understanding and long pulse sustainment of high performance plasmas.

On LHD, H-mode plasmas having repetitive large amplitude ELMs have been obtained by neutral beam injection (NBI) in an outward-shifted configuration, of which magnetic axis position in the vacuum field is R_{ax}=3.9m[4]. Here, 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. ELMs in LHD are thought to be induced by ideal/resistive interchange modes. An H-mode with large amplitude ELMs in the case without RMPs is shown in Fig.1, where up to 20 % of the stored energy (W_p) drops by each ELM pulse. The ELM repetition frequency is ~5 – 30 Hz. In the vacuum configuration of R_{ax}=3.9m, the m=1/n=1 RMPs would resonate partially with the $\iota/2\pi$=1 surface, because the surface locates in stochastic field region. On this condition, the RMPs enhance field stochasticity just inside the rational surface, having remnant magnetic islands. This effect is expected to tailor the pressure profile in the ETB region. The RMPs were applied stationary to the H-mode plasma with large amplitude ELMs. When the radial field strength of RMPs was increased up to ~5x10^{-4} T on the magnetic axis of the vacuum field at the toroidal magnetic field B_t=0.9T, the ELM amplitude was reduced by a factor of 2 - 3, and the repetition frequency was increased by a factor of 5 - 8. The energy loss rate by each ELM pulse is reduced down to ~2 % of W_p. We assume that the energy confinement in LHD plasmas follows the ISS04 scaling [5] which is gyro-Bohm type. The H-factor can be evaluated with the normalized stored energy $W_p/(<n_e>^{0.54}P_{tot}^{0.39})$ for two cases without and with RMPs, where $<n_e>$ and P_{tot} are the line averaged electron density and absorbed total NBI power, respectively. In the plasma without RMPs, the H-factor transiently reaches the maximum H=1.25 at t=4.2s, and the H-factor averaged over t=4.0 – 4.7s ELMing phase is ~1.18. On the other hand, the H-factor averaged over t=4.0 s to 4.7s decreases to ~1.12 by RMPs, but the H-mode character is maintained. Note that NBI power was stepped down to obtain favorable density rise and get H-mode easier, as shown in Fig.1. In both shots, the L-H transition takes place about 10 - 20 ms after the power step down. The vacuum field calculation shows about 10 % reduction of nested magnetic surface region by the above strength of RMPs because of enhanced field stochasticity in the edge. The ~17 % decrease of the RMP strength lead to no ELM mitigation. This ELM mitigation is realized by preferential reduction of edge electron density by RMPs, while electron and ion temperature profiles remain unchanged. The collisonality at the ETB top is appreciably high, i.e., plateau regime. The change of edge electron density profile leads to slight decrease of the pressure gradient at the $\iota/2\pi$=1 surface. In both cases without and with RMPs, m=2/n=2 edge MHD modes are excited just before each ELM event, having different magnitude, and are thought to trigger ELMs. The radial profile of the density drop by an ELM pulse suggests that the radial width of ELM impact shrinks into 2/3 of that in plasmas without RMPs.

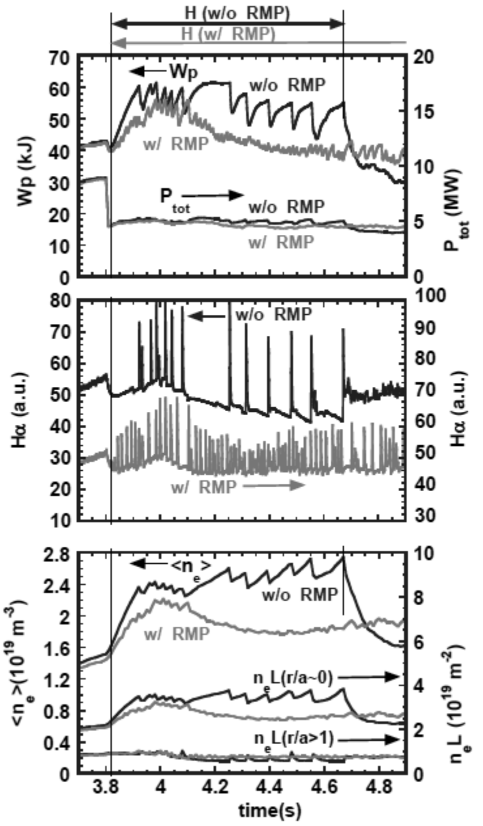

Fig.1 Time evolutions of W_p, absorbed total NBI power P_{tot}, $H\alpha$ emission, line averaged electron density $<n_e>$, and line electron densities at the plasma center and edge in the shots without and with RMPs.

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