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Dynamic ELM and divertor control using mixed toroidal harmonic resonant magnetic perturbations in DIII-D and EAST

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Mixed toroidal harmonic Resonant Magnetic Perturbations (RMPs) have been used on both EAST and DIII-D to reduce the threshold for Edge Localized Modes (ELMs) suppression and to spread the divertor heat flux. Experiments using mixed toroidal harmonic RMPs have validated predictions that divertor heat and particle flux can be dynamically controlled while maintaining ELM suppression in DIII-D. Theoretical modeling has reproduced the linear and non-linear response observed on magnetic sensors during ELM mitigation and suppression. Mixed n=2 and 3 toroidal harmonic RMP significantly lower the threshold current for ELM suppression compared to the single n=3 RMP. Rotating RMP has been demonstrated recently in EAST as a promising method in controlling the steady state particle and heat flux on the divertor, when the transient power loads induced by ELMs have been eliminated by RMPs. It is observed that the particle flux patterns on the divertor targets change synchronously with rotating RMP fields as predicted by the modeled magnetic footprint patterns by TOP2D. ELM suppression over one full cycle of a rotating n=2 RMP that was mixed with a static n=3 RMP field has been achieved in DIII-D. Strong changes in the three-dimensional heat and particle flux footprint in the divertor were observed during the application of the mixed toroidal harmonic RMPs, which also agrees well with modeling. Plasma response during ELM suppression using mixed toroidal harmonic RMPs shows that small n = 2 field help to penetrate n = 3 mode which eventually leading to ELM suppression. Plasma response measured by magnetic sensors shows linear relation in the mitigation stage in DIII-D, while a non-linear jump of plasma response is observed during the transition from mitigation to suppression of ELM in DIII-D. MHD simulation with the MARS-F code shows good agreement during ELM mitigation in both mode structure and phase, while it has a phase shift to the observed response during ELM suppression in DIII-D, which is similar to that in EAST. These results expand physics understanding and potential effectiveness of the technique for reliably controlling ELMs and divertor power/particle loading distributions in future burning plasma devices such as ITER.
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