Recent progress in understanding of the outer divertor heat flux increase during RMP-ELM suppressed regimes in KSTAR

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For reactor-scale fusion devices such as ITER, control of the divertor target power loading, both in steady state and during ELMs, is particularly challenging with regard to tungsten target lifetime. It has been demonstrated on several tokamaks that resonant magnetic perturbations (RMP) can be an effective method to achieve ELM control or suppression. In addition, it is expected that along with the role of RMPs in suppressing ELMs, the broadening of divertor target power loading, and hence a reduction in the peak heat flux density, in the presence of the 3D fields may be an additional benefit of the application of RMPs.

In KSTAR, striation of the outer target heat load has been clearly observed during RMP-ELM suppression regimes using an infra-red (IR) thermography system. The data has been obtained in KSTAR H-mode discharges with I_p = 500 ~ 600 kA, q_{95} = 4.5 ~ 5.5, B_T = 1.8 ~ 3.0 T and P_{NBI} = 2.8 ~ 4.0 MW and a full carbon wall with the outer strike point located on the central divertor target, which can be considered geometrically as a quasi-horizontal target. Recent improvement in the controllability of the RMP configuration has made it possible to investigate the divertor heat flux response to changes in the configuration during a single plasma discharge while maintaining ELM suppression. Experiments in which the RMP phase is rotated during a single discharge strongly indicate that the non-axisymmetric outer divertor target heat flux pattern is mainly determined by the toroidal mode number and phase of the perturbation. Interestingly, in KSTAR, it has been observed that the outer target peak heat flux is usually much higher during the ELM-suppressed regime than that without RMPs, regardless of the toroidal location (Here, it is assumed that the measurement of the outer divertor heat flux for all toroidal locations can be performed by rotating the phase of RMP in the full toroidal angle across the fixed IR camera field of view.) In addition, recent observations have shown that the plasma radiation loss in the divertor regimes decreases when RMPs are applied, implying that the reduction in radiation losses plays a role in increasing the outer divertor heat flux.

Previous EMC3-Eirene modeling of the perturbed 3-D scrape-off layer and boundary without plasma response (vacuum approximation) cannot explain the observed divertor peak heat flux increase in KSTAR when RMPs are applied. Since the plasma response to the magnetic perturbation can significantly impact the divertor heat loads, this paper compares recent measurements of target heat loading during ELM suppression experiments with new EMC3-Eirene simulations invoking different response models (e.g. the vacuum and ideal plasma response approximations). For the ideal plasma response, IPEC code results are embedded in EMC3-Eirene. By comparing the outer heat flux profiles by EMC3-Eirene at various toroidal angles corresponding to the experimental RMP phase with the measured profiles, the impact of the magnetic perturbations and plasma response on the heat flux profiles will be examined in this paper.