EXPLORATION OF MAGNETIC PERTURBATION EFFECTS ON PLASMA EDGE TRANSPORT FOR ADVANCED DIVERTOR CONFIGURATIONS IN HL-3

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In the high confinement mode (H-mode) operating scenario of a future fusion device, such as ITER, the local heat deposition on divertor targets is quite high compared to the tolerance of the current materials, particularly during the edge-localized mode (ELM) crash which is kind of a magneto-hydrodynamic instability due to quasi-periodic relaxation of the edge transport barrier. The control and mitigation of transient high heat loads induced by large Type-I edge localized modes(ELMs) is an important task for current tokamaks, as well as future fusion reactors. Recently, applications of the three-dimensional (3D) magnetic topology for controlling the edge plasma transport luxes are compared with experimental data, and possible sources of discrepancy are discussed. As an effective measurement, resonant magnetic perturbations(RMPs) created by external magnetic coils have been dememonstrated for causing the strike line splitting on divertor targets in many tokamaks [1-2]. They could also be used to ELM control through affecting the plasma pressure gradient and an associated current density in the edge plasma due to the changes of the magnetic topology. Suppression or mitigation of ELMs has been successfully demonstrated in many present day tokamak experiments by application of RMPs [3], which are now an integral part of the ELM control scheme for ITER.

In this paper, we report the first observation of ELMs mitigation by n=1 RMP in HL-3 tokamak and the comparion with the simulation of the EMC3-EIRENE code. HL-3 is a tokamak device with a major radius of 1.78m and a minor radius of 0.65m. The RMP system on HL-3 features 16 in-vessel coils arranged in a toroidal × poloidal configuration of 8 × 2. This arrangement allows for a more flexible magnetic field and spectrum shape. In the last compagin in 2024, the RMP coils system was successfully commissioned for the first time, configuring in an even connection setup with a dominant n = 1 component, which was instrumental in achieving ELM mitigation on the HL-3 tokamak. Figure 1 shows time traces of HL-3 discharge #6552 as a generic example. The toroidal magnetic field (Bt) at the magnetic axis was 1.52–1.53 T. The plasma current (Ip) is around 500 kA. The line-average density (ne) increases during that phase from from 1.9 to 3.5 × 10^{19} m^{-3} and the safety factor at 95% of the equilibrium poloidal flux (q95) ranging from 4.13 to 5.05. Upon increasing the auxiliary heating power to 2 MW, the transition to H-mode occurred at 1.35 seconds, marked by a significant rise in stored energy and density. The introduction of the RMP signal at 1.8 seconds resulted in a decrease in the amplitude of the Dα signal by 30% and an approximate threefold increase in frequency from 1.82 to 1.92 s.

In order to perform modelling of discharge 6552, the 3D edge transport code EMC3-EIRENE has been applied for the first time to the HL-3 tokamak, specifically utilizing a snowflake divertor configuration. The modeling results are presented for both an axisymmetric case and a case where a 3D magnetic field is applied in an n=1 configuration as shown in Fig.2. In the vacuum approximation, the perturbed field consists of a wide region of destroyed flux surfaces and helical lobes, which are a mixture of long and short connection length field lines formed by the separatrix manifolds. The helical lobes extending inside the unperturbed separatrix are filled with hot plasma from the core. The intersection of these lobes with the divertor results in a striated flux footprint pattern on the target plates. Profiles of divertor heat and particle flux shown partially as Fig. 3 are compared with experimental data. The modeling results reveal a significant reduction in peak heat fluxes and a more uniform distribution of particle fluxes on the divertor targets when the n=1 RMP is applied. To further investigate the divertor recycling behavior with RMP fields in comparison with the axisymmetric situation, a divertor recycling flux scan was performed from a sheath limited divertor regime to high recycling divertor regime. It demonstrates that significant effects on the spatial distribution of particle and heat fluxes are expected to occur for the high density/high radiation divertor conditions with which HL-3 must operate for the control of divertor heat loads. Possible sources of discrepancy, such as differences in plasma turbulence and edge plasma conditions, are discussed to further refine the understanding of magnetic perturbation effects on divertor configurations.

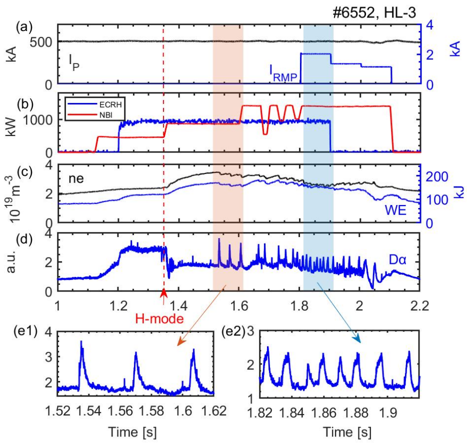

Fig.1. Time traces of plasma parameters and mitigation of ELMs by RMP on HL-3 discharge #6552. (a) plasma current Ip (black solid) and RMP coil current I_{RMP} (blue solid), (b) Auxiliary heating: NBI (red solid) and ECRH (blue solid), (c) electron density n_e (black solid) and stored energy W_E(blue solid), (d) divertor Dα light emission, (e1) the detailel veiw of ELMs in the absence of RMP, and (e2) the detailed view of ELMs with RMP application.

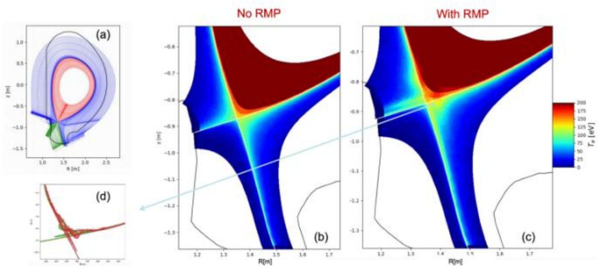

Fig.2. (1) Single null grid configuration for HL-3 discharge #6552 at ϕ=0° . Electron temperature at ϕ=0° for (b)axisymmetric case and (c) RMP case . (d)Magnetic field structue around X-point with RMP application.

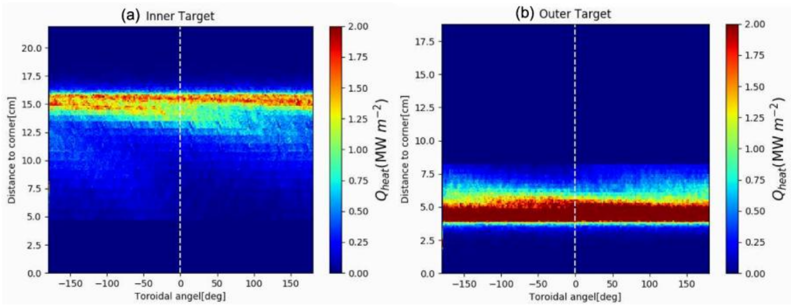

Fig.3. (1) 2D target heat flux patterns for #6552 at 1.83s for (a) inner target and (b) outer target.

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