Study of divertor heat load control in the HL-3 tokamak

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One of the unsolved problems for a next step fusion device (such as ITER) is the handing of the power fluxes into the divertor, in particular with respect to short plasma events, such as edge localized modes (ELMs) [1]. Maintaining acceptable power load on the divertor target plates will require the dispersal of a large fraction of the plasma heat efflux through radiative processes in the core and divertor plasma. However, the standard radiative divertor may be insufficient to keep heat fluxes within the technological limit and control material erosion by reducing divertor plasma temperature simultaneously for the future devices, such as DEMO. Recently advanced divertors have been proposed as a promising method to handle the peak heat fluxes onto target surfaces [2-3]. An essential element of the advanced divertor is the flux expansion, allowing to spread the heat load over a much broader area than that in the case of a standard divertor.

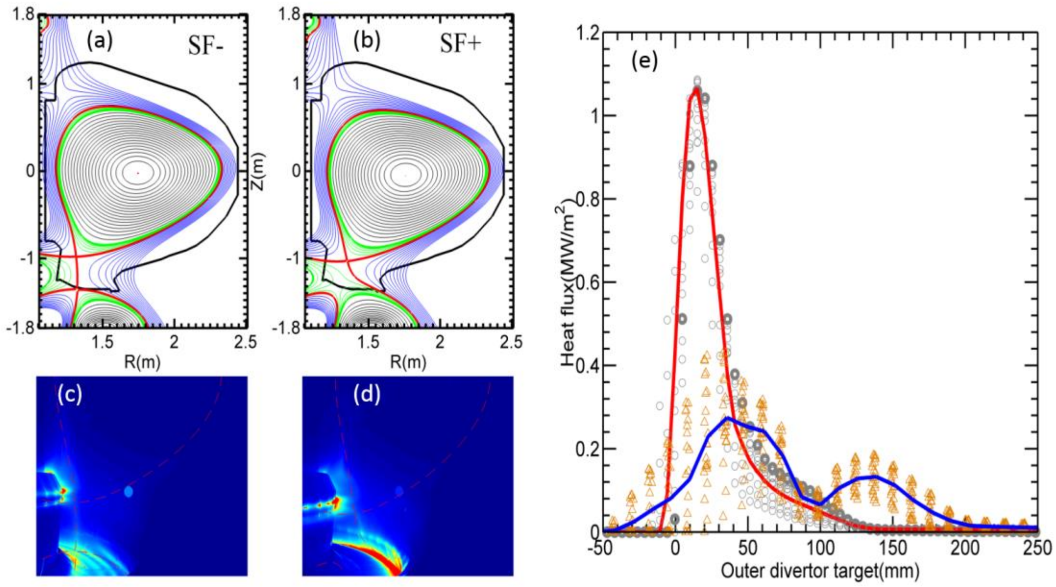

Figure 1. The divertor configurations reconstructed by EFIT (a,b), the corresponding visible images (c,d), and comparison of divertor heat flux of standard configuration (red line, #1737) and snowflake one (blue line, #1797). The heat flux profiles are given within a time window of 50ms.

The HL-3 device is a medium-sized copper-conductor tokamak, and one of the primary goals of the HL-3 project is to achieve a variety of advanced divertor configurations, in order to solve the power handing problems. The advanced divertor configurations (such as SF-, SF+) are carried out in HL-3 recently and observed by an infrared/visible imaging system and divertor flush probes, as shown in figure 1. An imaging system is developed for the lower divertor working in both visible and infrared wavelengths for in-vessel inspection. The visible images show the advanced divertor configurations clearly. The characteristics of higher flux expansion in the null-point region are indicated by the larger regions of plasma emission in the outer strike point compared with a conventional single-null configuration. According to the HL-3 divertor geometry, the flux expansion width on the targets are estimated of about 20cm in SF- and 15cm in SF+. It is also confirmed by the ion saturation current density. The heat flux deposited onto the divertor targets are measured by the infrared thermography system with spatial and temporal resolutions of about 7mm and 5ms, respectively. The peak heat flux is much lower in the snowflake divertor configuration than that in the standard one, because snow flake plasmas feature a longer SOL connection length and higher flux expansion in the null-point region. The plasma parameters of two shots (#1737 and #1797) are similar and the deposited power loads on the outer divertor targets are almost considerable, but the wetted area in the snow flake configuration (#1797) is $A = \frac{\int q(s)ds}{q_{peak}} \sim 1m^2$, which is about 4 time of that in the standard one.

Divertor detachment experiments are also carried out with standard and advanced divertor conigurations. In the high-recycling regime, the divertor region predominantly undergoes excitation reactions, primarily concentrated near the LCFS. Only in regions distant from the LCFS do we observe a minor transition from excitation reactions to recombination and recombination reactions. But at the onset of plasma detachment, recombination reactions dominated at the strike point. The experimental results show that, plasma detachments are obtained with lower electron density with advanced divertor configurations. The effects of plasma $\vec{E} \times \vec{B}$ drift on the asymmetries in detachment onset between the inboard and outboard divertor are clearly observed under standard divertor configurations. But for the advanced divertor configurations the detachments are occurred at the outer divertor targets. These maybe are benefit of the flux expansion, which results into a lower plasma temperature in the divertor. Enhanced plasma radiation belts are formed around X-point during plasma detachments, but the stability of the radiation location is better for the the standard configuration.

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