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Mitigation Effects of Fishtail Divertor on ELM Thermal Shock

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The divertor peak heat load during an ELM is one of the most critical problems of future fusion reactors, the heat flux width of plasma boundary is about 1-2mm, and the heat flux is about 100MW. Under the standard magnetic configuration of diverter, the deposition width of the heat flux on the target plate expands about 10 times, and the heat flux intensity is about 100MW/m^2. When ELM is generated, the heat flux intensity on the diverter target plate increases a lot, which cannot meet the requirements of the future fusion reactor in terms of the materials and technologies currently available.

In order to control and reduce the heat flux intensity on the diverter target plate, many tokamaks have carried out relevant experimental research at present, and some new concepts of diverter technology have been proposed, such as the Snowflake divertor (SFD), Super-X divertor (SXD), and Double Null divertor, etc. The methods are to reduce the heat flux intensity on the diverter target plate by broadening the magnetic surface and multi heat flux branches. The experimental research on the new technology concept of divertor is limited to SFD, and the mitigation effect of SFD on elm has not been studied in detail. RMP coils and some physical methods with influence on plasma boundary are used to reduce the ELM amplitude and thermal shock.

A new divertor concept has been developed, on the EAST, the fishtail divertor (FTD), which can move the strike point like the swing of fishtail with the help of the alternating magnetic field. The heat flux can be widened by the fast swing of the strike point in a certain range of the divertor target area, which is achieved by setting up a coil located in the backside of the divertor target near the strike point and applying fast AC currents on the coil (FTD coil). The experimental results on EAST show that FTD has the function of striking point swing. The FTD is more effective for future narrow and high heat flux, and the same swing distance expands more for narrow heat deposition area.

The simulation results show that the strike point swing of FTD can effectively reduce the maximum temperature rise of the diverter target plate in the case of ELM. For hundreds of microseconds of ELM, at least a few kHz swing frequency is needed to alleviate the thermal deposition produced by ELM. Through the simulation, it is found that the temperature of the divertor target plate can be greatly reduced, even if the swing frequency of the strike point is only 100Hz.

In the simulation calculation, it is assumed that the pulse heat flux of 100MW/m^2 is superposed on the basis of 50MW/m^2 constant heat flux, with the heat flux width of 5mm and Gaussian distribution. The thermal pulse length of ELM is 300 microseconds, and 1000 ELMs are randomly generated in one second.

In the calculation, the heat transfer performance of the diverter target plate refers to ITER W mono-block, and all temperatures given are diverter target surface temperatures. When the strike point does not swing, the diverter target plate temperature of the heat flux deposition position can reach 2100℃ (Fig.1). While when the strike point swing distance is 10cm and swing frequency is 100Hz, 200Hz, 1 kHz, 2 kHz and 3 kHz respectively, the maximum surface temperature of divertor target plate fluctuates with the thermal shock of ELM, and the maximum temperature is about 400℃ (Fig.2a), 360℃, 300℃ (Fig.2b), 280℃, and 270℃ (Fig.2c).

The simulation results show that in order to reduce the thermal shock of ELM to the diverter target plate, as long as the FTD swing frequency is at 100 Hz, it can meet the operation requirements of the future fusion reactor under elm conditions. There is no need to make the period of FTD swing equal to the duration of ELM. Due to the swing of strike point and the cooling of diverter, the thermal pulse brought by ELM will be deposited in different positions on the diverter target plate, so the temperature of diverter target plate will be reduced more.

FTD can realize the swing of the strike point, expand the deposition area of heat flux on the diverter target plate, make full use of the cooling capacity of the diverter target plate, and at the same time, it has a significant mitigation effect on the thermal shock brought by ELM in the swing of 100 Hz.

In the future, the combination of FTD and long leg divertor is beneficial to the placement of FTD coil and neutron shielding. It can also gassing in the long leg divertor chamber, and further reduce the heat flux and particle energy through energy radiation.

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