Snowflake divertor simulation for HL-2M conception design

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1. Introduction

Handling the power and particle exhaust in fusion reactors based on conventional divertor technologies is a challenging problem. In the DEMO design study, the fusion power will be over 2500MW, the power flows into SOL/divertor regions may be over 500MW. In order to handle such large amounts of heat, a high fraction of the heating power has to be radiated. It is unclear if impurity seeding of the plasma edge with conventional standard X-point divetor configuration can achieve such high radiation fractions without significantly degrading core energy confinement[1]. Snowflake (SF) divertor[2] considerably enhances the divertor thermal capacity through a flaring of the field lines only near the divertor target plates, which may be a potential way to overcome these problems.

The scientific mission of HL-2M (with major radius R = 1.78m and minor radius a = 0.68m) is to explore the reactor relevant regimes with high core plasma parameters and to develop and verify solutions for power exhaust and particle control. So SF divertor configuration as one of the advanced divertor configuration has been successful explored on HL-2M by adjusting the current of the poloidal field magnetic coils. This paper presents the main result by edge plasma transport codes B2.5-Eirene[3].

2. SF configuration and divertor design

A standard down single null configuration has been designed and optimized for HL-2M at SWIP through EFIT, TSC and SWIPEQ. In the same time, a SF configuration also been explored but the target plates were be install in the upper space of vacuum vessel. Then HL-2M can operate two different kinds of divertor configuration with almost the same equilibrium parameters (such as elongation, minor radius and so on). By adjusting the current of the

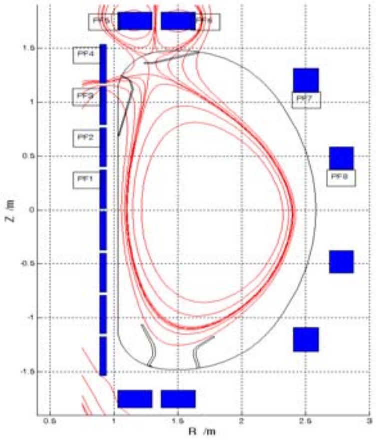

Figure 1. SF equilibrium configuration.

poloidal field magnetic coils, SF equilibrium configuration is calculated by EFIT and shown in Figure 1. In the standard divertor configuration, PF5 and PF6 magnetic coils are the divertor current coils. But in the SF divertor configuration, PF4 and PF6 magnetic coils are treated as divertor current coils to generate two X points, and the current of PF5 magnetic coil is reversed to adjust the position of the two X point. The current of the poloidal field in turns and main equilibrium parameters are shown in Tabel 1.

Tabel 1. The current of the poloidal coil and mian equilibrium parameters

	PF1	PF2	PF3	PF4	PF5	PF6	PF7	PF8
UPPER	6000A	-5600A	-3080A	2350A	-3290A	3800A	-8250A	-6900A
DOWN	6000A	-5600A	-4080A	-810A	-820A	250A	-5150A	-6900A
	R	a	elongation	utriang	ltriang	I_P	Bata p	B_t
	174.7	64.79	1.813	0.736	0.237	2.0MA	0.69	2.2

As the two X points of SF configuration is close to the vacuum vessel, two simple target plates are designed close the vacuum vessel, especially the outer divertor target. But the outer divertor magnetic flux expansion closes to the separatrix exceed that of the standard divertor configuration more than a factor of 4, which will help to decrease parallel heat flux from core plasma.

3. Main results of SF divertor

The SF divertor is invested by B2.5-Eirene. With respect to cross-field transport, there still exist relatively large uncertainties, the cross-field diffusion coefficient D = $0.4m^2/s$, and the constant cross-field ion and electron heat diffusivities $\chi_e = \chi_i = 1.0m^2/s$ are used. At the Core-SOL interface, the electron density is prescribed as the edge density with a common value as input parameters. The total power across the Core-SOL boundary to the computational region is equally split between the electron and ion heat channels. The neutral deuterium density at the Core-SOL boundary interface is set to zero. The recycling coefficient for deuterium is set to 100% at the divertor target plates and the main chamber wall. The pumping port is supposed at the private flux region[4,5].

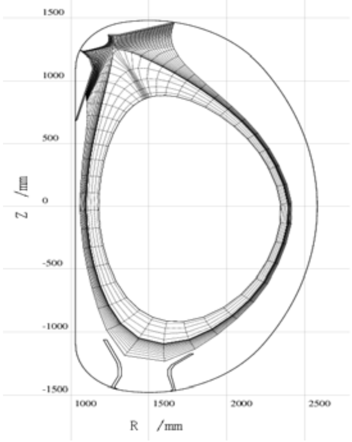

Figure 2. the SF divertor grid.

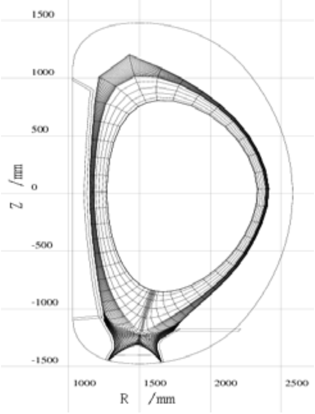

Figure 3. the standard X-point divertor grid.

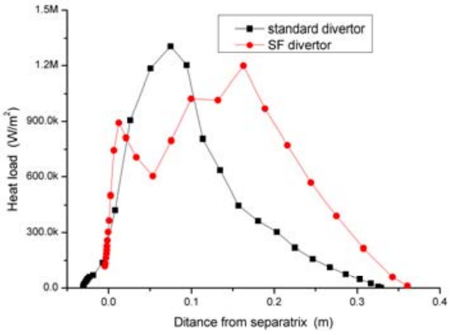

Figure 4. heat load profile at inner target.

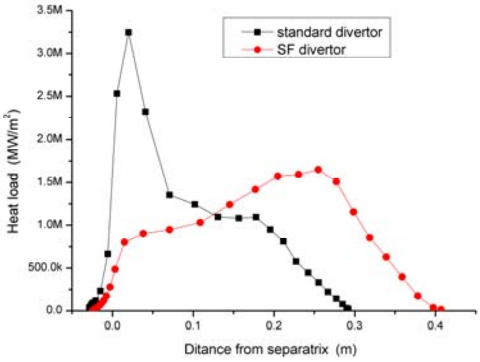

Figure 5. heat load profile at outer target.

The standard divertor are optimized and adopted in the HL-2M with standard down single null divertor[6]. Figure 2 and Figure 3 show SF divertor grid and the standard divertor grid. With heating power P = 10MW flows into SOL/divertor regions, when the density at separatrix $n_e = 2.0\times10^{19}/m^3$, the heat load profiles at inner and outer divertor targets are invested for the standard divertor and SF divertor. The heat load profiles are shown in Figure 4 and Figure 5. From the figures, it shows the peak load for the standard divertor locates at a small area near the separatrix. Because of the magnetic flux expand close to the separatrix for the SF divertor, the peak heat load reduces and the profile becomes more flat of the SF divertor compare to the standard divertor, especially for the outer divertor. For inner target, with the same target surface area, the peak heat load is respectively $1.20MW/m^2$ and $1.31MW/m^2$ for standard divertor and SF divertor. For outer target, owing to a big the magnetic flux expands near the separatrix to increase the target surface area for SF divertor, the peak heat load has a significant decline, it is 1.64MW/m^2, but for standard divertor, it is 3.2MW/m^2.

Figure 6 shows the peak heat load at outer target with different power flows into SOL/divertor regions. The peak heat load at outer target for standard divertor grows faster than that of SF divertor with the increase of the P. When P = 10MW and P = 20MW, the peak heat load are respectively 1.64MW/m^2 and 2.82MW/m^2 for SF divertor, but for standard divertor, the peak heat load is 3.2MW/m^2 and 7.9 MW/m^2.

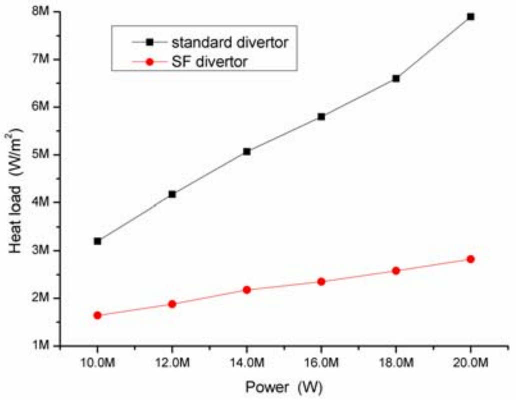

Figure 6 shows the peak heat load at outer target with different P.

4. Summary

The simulation results show that the SF divertor design for HL-2M can reduce the peak heat load by flattening the heat load profile at targets with magnetic flux expansion closes to the separatrix. When $n_e = 2.0\times10^{19}/m^3$, the peak heat load at outer target for SF divertor is about 50% and 36% of that for the standard divertor with P = 10MW and P = 20MW. So SF divertor will be helpful to mitigate heat load at divertor targets with high heating power operation for HL-2M.

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