§6. Heat Flux Reduction by Helical Divertor Coils in the Heliotron Fusion Energy Reactor

Yanagi, N., Sagara, A., Goto, T.

Based on the progress of high-density and high-temperature plasma experiments in the Large Helical Device (LHD), conceptual design studies on the heliotron-type fusion energy reactor FFHR are being conducted on both physics and engineering issues [1]. In order to best utilize the built-in helical divertors in FFHR, we propose a new divertor sweeping scheme which could effectively reduce the divertor heat flux and mitigate the erosion of divertor plates. The concept employs a small set of helical coils, which we call "helical divertor coils". Alternating the currents in these coils within a few percent of amplitude of that in the main helical coils effectively sweeps the strike points on the divertor plates in the poloidal direction.

Figure 1 shows the vacuum magnetic surfaces of FFHR-2m2 and the field changes provided by the helical divertor coils. Here, the major and minor radii of the main helical coils are 17.0 m and 4.08 m, respectively. The magnetic axis is shifted inward in order to obtain good particle confinement like as with the standard configuration of LHD. One of the remarkable features of the heliotron configuration is that clear divertor legs appear out of the confining region and their structures are not seriously affected by plasma beta or toroidal plasma current. In Fig. 1, we find that the divertor legs can be moved effectively by modulating the amplitude of the current in the helical divertor coils by ±1 % of the amplitude in the main helical coils. Inclining the divertor plates against divertor legs enlarges the width of strike points to ~800 mm. Since the total length of four divertor legs is ~900 m along the torus, the wetted area would then be ~700 m^2. If a fast sweeping is realized, the effective heat flux would thus be lower than 1 MW/m2 on time average having the total power flow of ~600 MW to the divertor regions with a 3 GW fusion power. Erosion of divertor plates would also be mitigated even with slow sweeping and the replacement cycle could be significantly prolonged. It should be emphasized that despite the movement of divertor legs, the magnetic surfaces show almost no change with this scheme, which is different from the two other divertor sweeping schemes which have been previously proposed for LHD [2, 3].

In the present design of FFHR-2m2, the total current in the main helical coil is 39.95 MA, and ±2% amplitude gives the current in the helical divertor coils of ~±800 kA. If we assume 0.4 m thickness for the nuclear shielding structure in the vicinity of the helical divertor coils and employ 0.5 Hz frequency of sweeping, the skin effect reduces the magnetic field to be half with a resistivity of stainless-steel. In this respect, the magnetic surfaces are calculated with ±1 % amplitude in Fig. 1. The total current of 800 kA would be supplied by 25 turns of 32 kA conductors. If we employ quasi steady-state sweeping only for the purpose of mitigating the erosion of divertor plates, the required current could be half.

Regarding the engineering design of the helical divertor coils, we consider that they could be situated in the supporting structures of the main helical coils as shown in Fig. 1. We propose that these coils be fabricated using high-temperature superconductors (HTS), represented by YBCO. It is noted that we have initiated conceptual design studies on applying HTS also to the main helical coils [4], and short sample tests of 10 kA-class conductors proved highly stable. The helical divertor coils could be constructed with prefabricated segments, and jointed on site [4]. The losses in the coils generated at joints and by AC operations are of no serious concern with an elevated temperature at 60 K or higher.

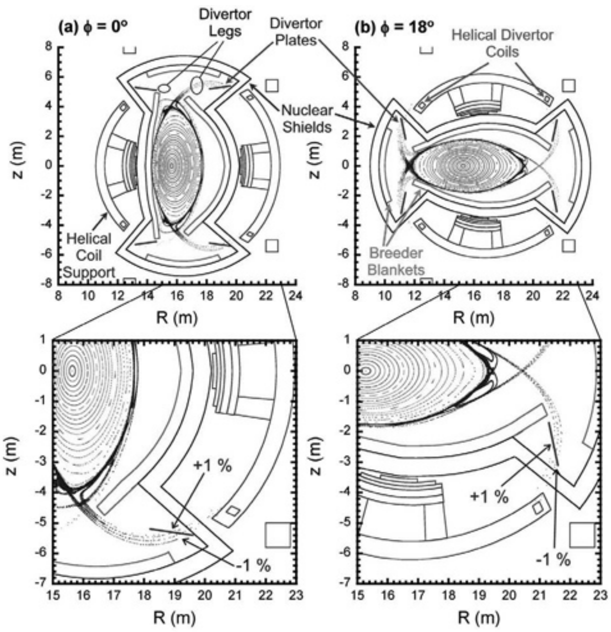

Fig. 1 Vacuum magnetic surfaces and divertor legs of FFHR-2m2 at two toroidal cross-sections of (a) ϕ = 0° and (b) ϕ = 18°, including the field changes provided by the helical divertor coils.

1) Sagara, A. et al., Fusion Eng. Des. 83 (2008) 1690.
2) Nakamura, Y. et al., Nuclear Fusion 46 (2006) 714.
3) Yanagi, N. et al., Plasma Fusion Res. SERIES l (2000) 52l.
4) Yanagi, N. et al., Plasma Fusion Res. 5 (2010) S1026.