§7. Strike Point Sweeping for the Heliotron Fusion Energy Reactor Using Helical Divertor Coils

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To best utilize the built-in helical divertors in the heliotron-type fusion energy reactor FFHR, we have proposed a new strike point sweeping scheme that reduces both the divertor heat flux and erosion of divertor tiles. [1),2)] This scheme employs a small set of helical coils, which we term *helical divertor coils*. Figure 1 shows the vacuum magnetic surfaces of the FFHR-2m2 design (major radius: 16.74 m, minor radius: 4.02 m) including the changes of the divertor legs by modulating the amplitude of the current in the helical divertor coils by ±2% of the current amplitude in the main helical coils. The strike point width is increased to ~800 mm and rapid sweeping reduces the time-averaged heat flux to <1 MW/m^2 with a total power flow of ~600 MW to the divertor regions for a fusion power of 3 GW. Despite the movement of the divertor legs, this scheme changes the magnetic surfaces and hence the fusion power very little.

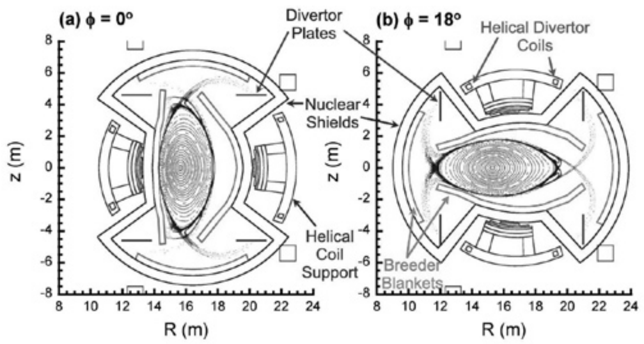

Fig. 1 Vacuum magnetic surfaces and divertor legs of FFHR-2m2 at two toroidal cross-sections including the field changes provided by the helical divertor coils.

For examining this strike point sweeping scheme, the temperature change of the divertor tile has been analyzed. We solve the one-dimensional heat diffusion equation analytically assuming that the divertor tile of 8 mm thickness is made of tungsten and a heat flux of 10 MW/m^2 is applied to the surface during the irradiation time. For a sweeping frequency of 0.5 Hz, the irradiation time and the repetition time can be approximated by 0.1 s and 2 s, respectively, considering the sweeping length of 800 mm and the expected width of the divertor leg of 80 mm. In this case, the temperature distributions within the tile thickness are plotted in Fig. 2(a) for t = 0.1 and 2 s. The temporal evolution of the temperature rise at the irradiated surface (z = 0 mm) is plotted in Fig. 2(b); it peaks at ~200 K at the end of the heating pulse at t = 0.1 s. After the irradiation ceases, or the heating zone moves away from the region of interest, the temperature begins to decrease almost down to the initial temperature before it receives the next heat pulse. Thus, there is a thermal cycle with a temperature change of ~200 K. However, since almost no temperature gradient is observed at the other end of the tile (z = 8 mm) throughout the process, the thermal fatigue may not be a serious problem at the interface between the tile and cooling pipe.

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. We propose that these coils be fabricated using YBCO high-temperature superconductors (HTS) and constructed with prefabricated segments which are joined on site. As the helical divertor coils are operated in AC modes, we roughly estimate the AC (hysteresis) losses, which could be ~30 kW/m^3 for a ±3 T field change at the sweeping frequency of 0.5 Hz. This heat should be removed by conduction to the surrounding cooling panels, and the maximum temperature rise is estimated to be ~10 K, which is still acceptable for HTS.

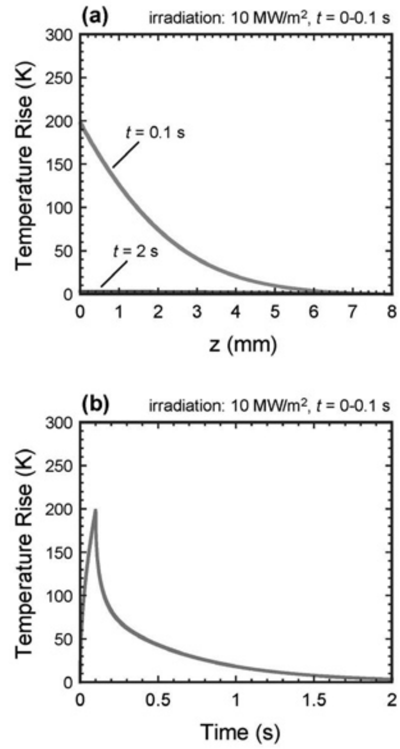

Fig. 2 (a) Temperature distribution in a tungsten slab at times of t = 0.1 and 2 s with a heat flux of 10 MW/m^2 applied to the z = 0 mm surface during t = 0-0.1 s. (b) Temperature rise as a function of time at z = 0 mm.

1) Yanagi, N. et al., Annual Report of NIFS April 2009 - March 2010.
2) Yanagi, N. et al., to be published in Nuclear Fusion.