§5. Engineering Optimization of Magnetic Configuration for the Helical Fusion Reactor Design FFHR-d1C

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Conceptual design studies of the LHD-type helical fusion reactor FFHR-d1 are progressing steadfastly.[1] In order to secure the foundation of the design, a multi-path strategy of FFHR-d1 is being pursued. Within this strategy, "d1A" is the base option for promoting the 3D engineering design. The aspect (A) ratio or the helical pitch parameter γ_c was changed from the previous value of 1.25 (for "d1") to 1.20 to improve confinement characteristics associated with a reduction of the Shafranov shift. An increase of toroidal magnetic field (B) by 20% is proposed as "d1B" to secure the self-ignition capability at 3 GW fusion power. The increase of magnetic field, however, makes the mechanical stresses larger along with the increase of magnetic stored energy (by 40%), which makes the structural design and material selection more difficult. To accommodate this situation, "d1C" is a flexible design with configuration (C) optimization to minimize the magnetic stored energy and mechanical stresses. Slight modifications of the positions and/or winding laws of helical coils and vertical field coils could provide many engineering benefits.

For FFHR-d1C, the following three items are examined from the viewpoint of "Engineering Optimization" for the heliotron magnetic configuration:
(1) Reduction of magnetic stored energy
(2) Increase of blanket space at the inboard side of torus
(3) Mitigation of divertor peak heat flux

Here, (1) is the motivation for initiating the present study. For (2), the relatively short blanket space between the helical coil and the plasma (ergodic layer) at the inboard side of torus is an inherent problem. Securing a larger space for accommodating a thicker shield would lower the neutron flux so that the lifetime of the helical coils is prolonged and the nuclear heating is reduced. Regarding (3), the divertor heat flux shows a strong asymmetry around the torus and the peak heat flux would be seriously high for the FFHR-d1 configuration. A configuration with a flattened toroidal distribution of strike points should be pursued in addition to the realization of complete detachment.

As was found in the former study for FFHR-2m,[2] it is confirmed that having smaller outer vertical field coils (radius by 5% and height by 20%) is effective in reducing the magnetic stored energy (by 25%) It is also found that the quadrupole field could be adjusted by modifying the winding law of the helical coils instead of changing the position and current of inner vertical field coils. Winding the helical coils around a vertically elongated (by 5%) ellipse enlarges the magnetic surfaces (by 10%) without using IV coils. Figure 1 shows the magnetic surfaces of this configuration, named FFHR-d1C-BE ("Big Eye").

It has been well known that the blanket space at the inboard side of torus could be enlarged by selecting a small γ_c value.[3] It was recently proposed (by T. Watanabe) that γ_c could be flexibly adjusted by employing a pair of sub helical coils located outside the main helical coils. An example of having this configuration, named FFHR-d1C-TW ("Torus-gap Widened"), is shown in Fig. 2. In this case, the effective γ_c is 1.20 by having sub helical coils with -5% current (in the opposite direction) outside the main helical coils. The gap at the inboard side of torus is enlarged more than 200 mm, as shown in Fig. 3.

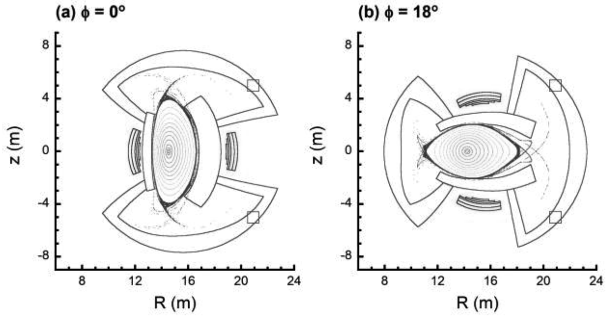

Fig. 1. Vacuum magnetic surfaces of FFHR-d1C-BE at toroidal angles (a) $\phi = 0°$ and (b) 18°.

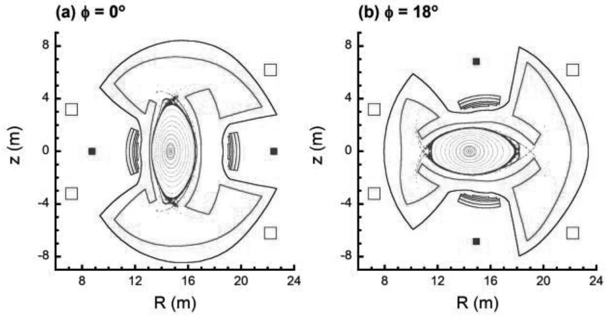

Fig. 2. Vacuum magnetic surfaces of FFHR-d1C-TW at toroidal angles (a) $\phi = 0°$ and (b) 18°.

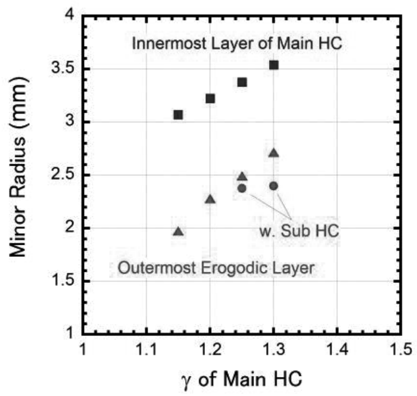

Fig. 3. Minor radial positions of the innermost layer of the main helical coils and the outermost ergodic layer. For the FFHR-d1C-TW configuration using sub helical coils, the distance between the two minor radial positions is enlarged.

1) Sagara, A. et al.: Fusion Eng. Des. **89** (2014) 2114.
2) S. Imagawa et al.: Nucl. Fusion **49** (2009) 75017.
3) A. Sagara, et al.: Fusion Eng. Des. **81** (2006) 2703.