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Engineering Optimization of Heliotron Magnetic Configuration for the Helical Fusion Reactor Design FFHR-d1C

ヘリカル炉FFHR-d1C設計におけるヘリオトロン磁場配位の工学的最適化

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Optimization of the heliotron magnetic configuration is being explored for the LHD-type helical fusion reactor FFHR-d1 with its multi-path strategy. The following items are the present targets to be examined from the engineering point of view: (1) reduction of magnetic stored energy, (2) increase of blanket space at the inboard side of the torus, (3) mitigation of divertor peak heat flux. Two ideas are proposed in this paper to meet these requirements.

1. Introduction

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 introduced. Within this strategy, “d1A” is the base option for promoting the 3D engineering design. The Aspect 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 by reducing the Shafranov shift. Figure 1 shows the magnetic surfaces of FFHR-d1A. 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 optimization to minimize the magnetic stored energy and mechanical stresses. Slight modifications of the helical coils and vertical field coils could provide many engineering benefits.

2. Engineering optimization of the heliotron magnetic configuration for FFHR-d1C

For the design of 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 the torus
(3) Mitigation of divertor peak heat flux

Here, (1) is the motivation for initiating the present study. Regarding (2), the relatively short blanket space between the helical coil and plasma at the inboard side of the torus is an inherent problem. Securing a larger space for a thicker shield would lower the neutron flux so that the lifetime of the helical coils is prolonged and the nuclear heating is reduced. In terms of (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 [2]. Complete detachment is inevitable to reduce the heat flux, but the other option is to seek for a configuration with a flattened toroidal distribution of strike points.

3. Possible configurations for FFHR-d1C

In this paper, two configurations are examined to meet the above engineering demands.

3.1 *FFHR-d1C-BE*

As was found in the former study for FFHR-2m [3], it is confirmed that having smaller Outer Vertical (OV) 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 (IV) field coils. Winding the helical coils around a vertically elongated (by 5%) ellipse enlarges the magnetic surfaces (by 10%) without using IV coils. Figure 2 shows the magnetic surfaces of this configuration, named FFHR-d1C-BE (“Big Eye”).

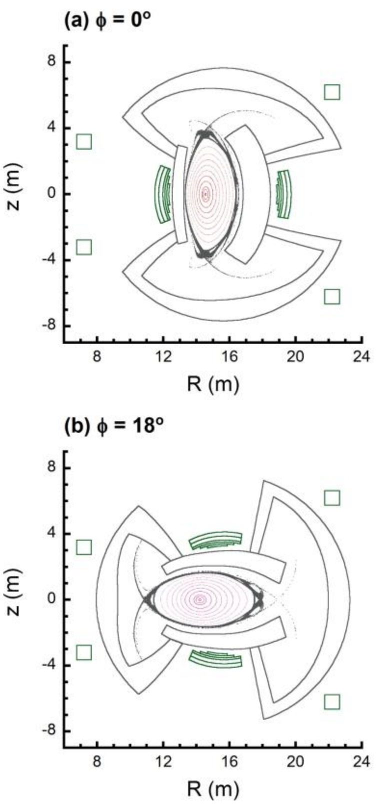

Fig.1. Vacuum magnetic surfaces of FFHR-d1A at toroidal angles (a) ϕ = 0° and (b) 18°.

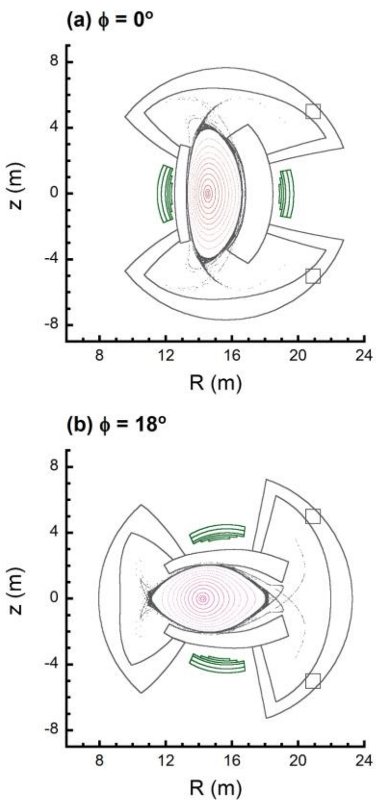

Fig.2. Vacuum magnetic surfaces of FFHR-d1C-BE at toroidal angles (a) ϕ = 0° and (b) 18°.

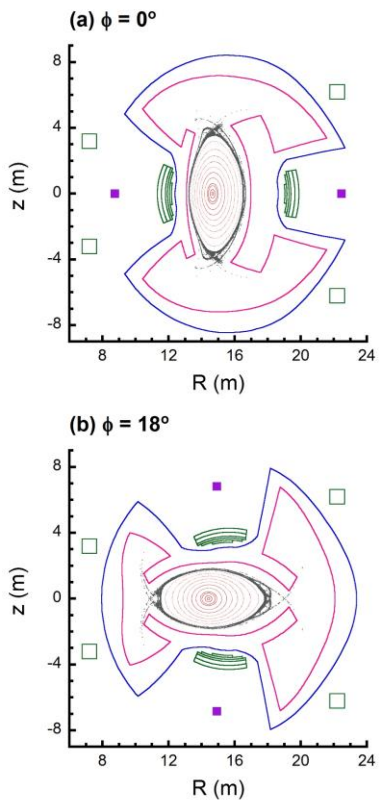

Fig.3. Vacuum magnetic surfaces of FFHR-d1C-TW at toroidal angles (a) ϕ = 0° and (b) 18°.

With this configuration, the divertor strike points show more flattened profiles as a function of the toroidal angle, and the peak heat flux could be mitigated to ~1/3 of that of d1A. In this case, having 75% reduction by radiation dispersion would realize a peak heat flux of ~10 MW/m^2.

3.2 *FFHR-d1C-TW*

It is well known that the blanket space at the inboard side of the torus could be enlarged by selecting a small γ_c value [4]. 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 having this configuration, named FFHR-d1C-TW ("Torus-gap Widened"), is shown in Fig. 3. In this case, the effective γ_c is 1.20 by having sub helical coils with -5% current outside the main helical coils (γ_c =1.25). The gap at the inboard side of the torus is enlarged by 100 mm.

4. Discussion and summary

In parallel with engineering optimization, physics optimization for plasma confinement and stability is an important task. By adjusting the essential Fourier modes that define the outermost magnetic surface, a new configuration having favorable features of both inward and outward shifted configurations has been proposed [5]. This configuration also employs a modified winding law of the helical coils; with trajectories around a horizontally elongated ellipse.

Optimization of the magnetic configuration is being explored from the engineering viewpoint for the LHD-type helical fusion reactor FFHR-d1 with its multi-path design strategy. Two configurations have been examined; the magnetic stored energy could be reduced by <25% and the blanket space at the inboard side of the torus could be enlarged by >100 mm. Toroidal asymmetry of divertor strike points could also be mitigated. Further optimization will be pursued so that the best configuration for FFHR-d1C will be selected.

References

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