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Design Window Analysis for the Helical DEMO Reactor FFHR-d1
ヘリカル原型炉FFHR-d1の設計領域解析

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A conceptual design for the LHD-type heliotron DEMO reactor FFHR-d1 has started from the last fiscal year under the Fusion Engineering Research Project in National Institute for Fusion Science. As the first step, design window analysis is carried out using the system design code HELIOSCOPE. Density and temperature profiles which directly extrapolated from the LHD experimental results are adopted in the analysis to enhance the reliability. One of the key issues is the radial-build design at the inboard side of the torus. Therefore, further detailed analysis for the optimization of blanket thickness and the cross-sectional shape of the helical coils are being carried out.

1. Introduction

According to the steady progress in the plasma experiments and related engineering R&Ds of the Large Helical Device (LHD)[1], conceptual design studies for an LHD-type heliotron fusion reactor FFHR[2] has been advanced from the 1990’s. The latest design FFHR-2m2 proposed a commercially-attractive design concept which enables a 30 full power years operation. Since the last fiscal year, a new conceptual design, named FFHR-d1, has started under the Fusion Engineering Research Project in National Institute for Fusion Science (NIFS). By utilizing design bases established so far on the conceptual designs of the FFHR series [2], this new conceptual design focuses on a demonstration of maintainability, tritium self-sufficiency, inherent safety and a net electric power generation as the next step DEMO reactor.

The conceptual design activity and related engineering R&Ds for FFHR-d1 has been conducted by 13 task groups in the Fusion Engineering Research Project. As the first step of the conceptual design, design window analysis is carried out using the system design code for heliotron reactors HELIOSCOPE [3]. In this presentation, the initial result of the design window analysis is shown and the direction of the design and the issues in the design which clarified through the analysis are discussed.

2. Prerequisite in the design

As described in the previous section, FFHR-d1 is a DEMO reactor, which will be constructed as the next device after LHD to demonstrate a steady-state control of a burning plasma. Therefore, high reliability in the core plasma design is required. Here we adopted a new approach to determine the core plasma profile named DPE (Direct Profile Extrapolation) method, which directly extrapolates the core plasma profile obtained in the experiment to a reactor condition [4]. This method eliminates uncertainties arose from the assumption in the plasma profile and the plasma volume. The existence of a stable equilibrium is also secured.

As shown in Fig. 1, the space for blankets of an LHD-type heliotron device is limited especially at the inboard side on vertically elongated poloidal cross-section. In the design study of FFHR-2m2, the design point with this minimum blanket space of >1.0m were considered to secure a sufficient tritium breeding ratio and suppression of fast neutron flux on the superconducting coil. Consequently, the major radius of R_c=17m is selected for FFHR-2m2. Such enlargement of reactor size leads to a reduction of thermal and neutron wall load and a flexibility in the design of maintenance ports. However, the magnetic field strength is restricted to suppress the stored magnetic energy W_{mag} below 160GJ, which is considered as the maximum allowable value to wind a large helical coil with the ITER-relevant technology. On the other hand, higher magnetic field strength is favorable from the standpoint of the core plasma design. Since a plant-scale electricity generation and a long-term operation are not necessary conditions of a DEMO reactor, the thickness of blanket could be reduced and the increase in the wall load is acceptable. Thus design window analysis including the region which has a blanket thickness of <1.0m are carried out. Since it is favorable to leave the possibility of a flexible selection in the magnetic configuration from the viewpoint of the design robustness, design window analysis are carried out with the configuration of helical pitch parameter γ_c=1.25 (corresponding to smaller plasma aspect ratio compared with the case of FFHR-2m2) and the inward-shifted magnetic axis with the ratio between the magnetic axis position and the major radius of R_{ax}/R_c=3.6/3.9, which shows a large plasma volume and good confinement property in the LHD experiment.

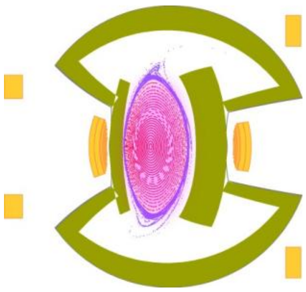

Fig.1. Cross-sectional view of the plasma, blankets, vacuum vessel and coils of an LHD-type heliotron reactor.

3. Design window analysis and design issues

Figure 2 shows the contours of several physics and engineering design parameters on the plane of the magnetic field strength (averaged toroidal field on the winding center of the helical coil $B_{t,c}$) and the major radius. All design points in Fig. 2 satisfy the self-ignition condition and have the electron density and temperature profiles determined by the DPE method with the confinement improvement factor γ_{DPE}=1.3, which is expected by an improvement in plasma heating profile (note this confinement improvement factor is relative to the experimental result used for the DPE).

Here we consider three design constraints. One is the stored magnetic energy, which is the same as in the design study of FFHR-2m2; W_{mag}≤160GJ. Second is the density limit at the plasma edge. The edge density n_{ea} should be lower than the Sudo density limit n_{Sudo} [5]. Third is the peak beta value β_0. Although the achievable maximum peak beta value needs to be carefully examined through theoretical and experimental analysis, here β_0=10%, which is the maximum value obtained in the past LHD experiment, is selected as a design limit (note that we didn't consider a loss of alpha particles and the existence of impurity ions). Consequently, the region with a wedge shape that is not shadowed in Fig. 2 is a possible design window for FFHR-d1. Since a larger blanket space is favorable, the design region around R_c=15-16m and $B_{t,c}$=4.5-5.0T can be a candidate for FFHR-d1. Since the space between the helical coil and the plasma is limited, a detailed optimization of the radial build design including blanket thickness and the cross-sectional shape of the helical coil is one of the key issues for to advance the design of FFHR-d1. Therefore, detailed analysis is being carried out by the related task groups (blanket, in-vessel components and superconducting magnets).

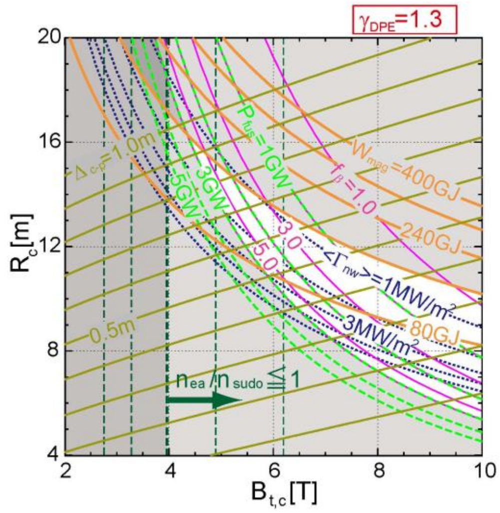

Fig.2. Example of design window analysis for FFHR-d1. Contours of the stored magnetic energy W_{mag}, the minimum gap width between the plasma and the helical coil Δ_{c-p}, enhancement factor of the beta value f_β, fusion power P_{fus} and average neutron wall load $<\Gamma_{nw}>$ are shown.

5. Summary

Design window analysis for the LHD-type heliotron DEMO reactor FFHR-d1 is carried out. According to the core plasma design based on the direct profile extrapolation from the LHD experiment, the design direction and the key issues in the design are clarified. Further detailed analysis including 3D structure of in-vessel components are needed to enhance the feasibility and reliability of the design.

Acknowledgments

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