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Design of structural components for the helical reactor FFHR-d1A

H. Tamura*, T. Goto, T. Tanaka, S. Masuzaki, N. Yanagi, J. Miyazawa, A. Sagara

National Institute for Fusion Science, Toki, Gifu 509-5292, Japan

HIGHLIGHTS

- A design for the helical reactor FFHR-d1A is conducted. Stress analysis of the coil support structure is performed.
- Fundamental design for the vacuum vessel and access ports is presented.
- A concept of the gravity support is shown.

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ABSTRACT

FFHR-d1 is a conceptual design of the helical reactor being developed at the National Institute for Fusion Science. The maintenance of in-vessel components is very important for the fusion demo reactor. In addition, sufficient pathways are needed for the divertor exhaust. To implement these, the vacuum vessel, coil support structure, and cryostat require large apertures. However, the coil support structure has to be sufficiently rigid to remain within soundness and deformation limits. A design combining the structural components in the FFHR-d1A was developed from mechanical and thermal viewpoints. Consequently, components having a sufficiently large port area were provided. An investigation of the maintenance and exhaust schemes has been planned on the basis of this fundamental design.

1. Introduction

FFHR-d1 is a helical reactor based on research results from the large helical device (LHD) being developed at the National Institute for Fusion Science [1,2]. Because FFHR-d1 is a demonstration device for fusion power plants, a blanket system (i.e., a tritium-breeding blanket and a neutron radiation shield) and a divertor system will be installed in the device. These systems require maintenance and part exchange. To implement such a maintenance scheme, the vacuum vessel (VV), coil support structure, and cryostat require large apertures. The LHD-type coil configuration can provide a space between a pair of helical coils (HC), but the coil support structure is needed to sustain the HC against the electromagnetic (EM) force. Therefore, the structural design of the FFHR-d1 coil support structure must include large apertures to ensure a sufficient access port area. Stress analysis of the coil support structure was performed on the basis of the design, in which the structure was made of stainless steel (SS) 316 [3]. The maximum stress of 600 MPa appeared at the corner region of the outer aperture, and the stress level was within the permissible limit for the SS at cryogenic temperature.

In parallel with the design activities for FFHR-d1, modifications for the fundamental design parameters have been investigated, aimed at advancing the core plasma design, ignition and fueling scenario, engineering realization, etc. FFHR-d1A is a key three-dimensional design strategy that has modified the aspect ratio by changing the helical pitch parameter from 1.25 to 1.20 to improve high energy confinement [4]. The main difference between FFHR-d1 and d1A structural components is that the minor radius of the HC is changed from 3.9 to 3.744 m. The major radius (15.6 m) and geometrical position of the vertical field coils (VFCs) is the same. The HC has slightly decreased in size by changing the minor radius. It is expected that the EM force on the HC and VFC will decrease, so the volume of the coil support structure can be reduced.

The LHD-type fusion reactor has a very complicated shape, and its structure and stored magnetic energy are very large compared with those of experimental fusion devices. Precise geometrical dimensions are needed to design in/out-vessel components and to examine a maintenance scenario. Design optimization that considers the three-dimensional structure is important for realizing a fusion reactor. This article aims to clarify the feasibility of the LHD-type fusion reactor FFHR-d1A. Analyses to evaluate the EM

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* Corresponding author. Tel.: +81 572 58 2115; fax: +81 572 58 2616.
E-mail address: tamura@nifs.ac.jp (H. Tamura).

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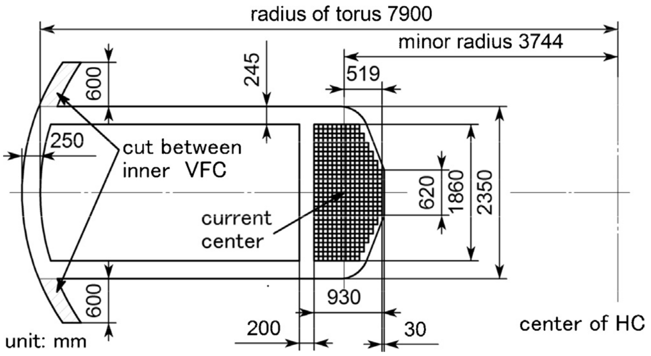


Fig. 1. Cross-section of HC perpendicular to the coil winding direction assumed in the magnetic/mechanical analysis.

force and stress distribution on the magnet system, the optimal design for the coil support structure with gravity support, the optimal access port size for maintenance, and general device assembly are presented in this paper.

2. Coil support structure

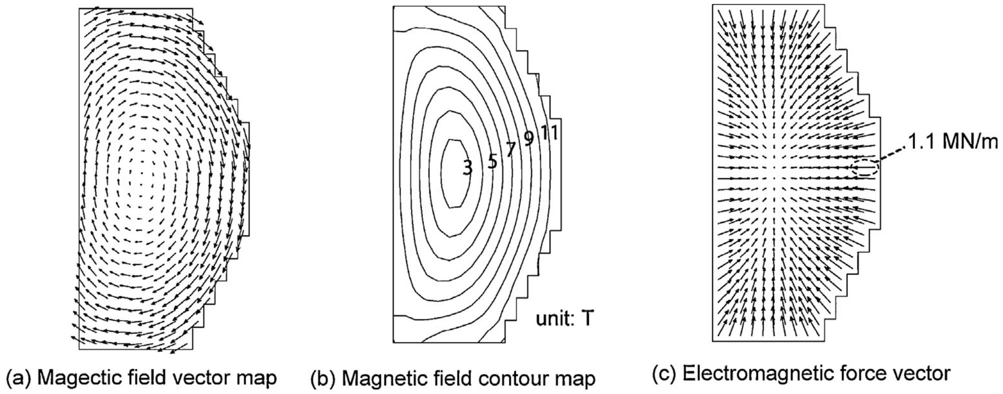
2.1. EM force

There are several candidates for the HC winding based on not only the type of superconductor but also the type of cooling method, such as low/high temperature superconductors, forced flow, and indirect cooling [5-7]. To estimate the magnetic field distribution in the coil, it is necessary to define the coil cross-sectional shape and the layout of conductors. Fig. 1 shows the cross-section of the HC assumed for the calculation of magnetic field distribution. The coil winding area consists of 390 turns of superconductor and insulating material. One superconductor and surrounding insulating material occupies a square shape with each side measuring 62 mm. A cooling path also exists in the winding area. The capacity of the superconductor is 94 kA of current flow, that is, the overall current density is 24.45 A/mm^2. The bottom of the coil is step-like to prevent interference with the VV. Two sets of VFCs are assumed to have rectangular cross-sections.

The magnetic field distributions induced by the coils were calculated with the finite element method program ANSYS. The coils and other surrounding components were presumably composed of nonmagnetic materials. Fig. 2 represents the result of the magnetic field and EM force distribution in the HC at the inboard side of the torus. Fig. 2(a) and (b) shows the magnetic field vector and intensity contour map, respectively. The magnetic field in the lateral direction induces the hoop force and that in the minor radius direction induces the overturning force on the coil. Fig. 2(c) shows the EM force vector distribution for the entire superconductor. The calculated maximum overall EM hoop force and the overturning force among each cross-section of the HC were 64 and ±8 MN/m, respectively. These results were slightly lower than those of the original FFHR-d1 [3], because the force depends on the shape of the HC cross-section and the distance between the HC and VFC.

2.2. Stress analysis

A design study of the original FFHR-d1 coil support structure was initiated on the basis of the following concepts: (1) the support was made of 300-mm-thick SS 316, (2) VFCs were connected to the support, (3) the support had a continuous structure throughout the circumference of the device, and (4) apertures were as large as possible. For FFHR-d1A, some modifications were made. First, the basic thickness was set to 250 mm to reduce the total weight. (ITER project research and development realized a maximum welding depth of 260 mm for SS [8].) Second, the round shape of the corner regions at which the high stress distribution appeared in FFHR-d1



(a) Magectic field vector map (b) Magnetic field contour map (c) Electromagnetic force vector

Fig. 2. Magnetic field distribution in HC at inboard side of the torus: (a) vector map, (b) contour map of intensity, and (c) EM force vector distribution.

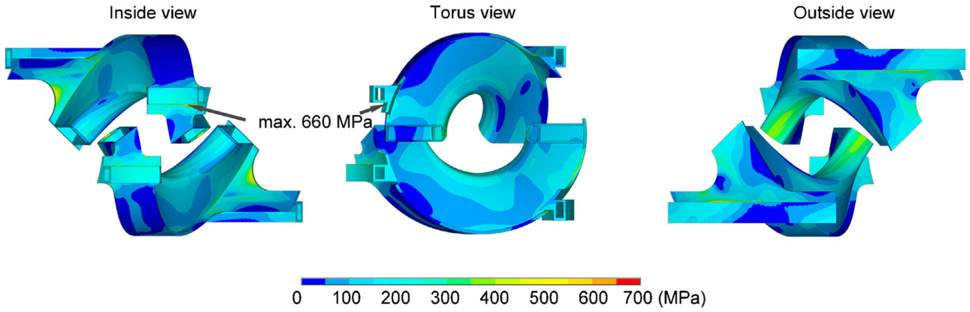


Fig. 3. Results of structural analysis: von Mises stress distribution in the coil support structure.