§19. Investigation on the Magnetic Field Distortion by Ferromagnetism of the Blanket for the Helical Fusion Reactor

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The conceptual design studies on the LHD-type helical fusion reactor (FFHR) are progressing at National Institute for Fusion Science (NIFS) by employing the heliotron magnetic configuration with continuous helical coils [1]. The major radius of the helical coils is 15.6 m. This is four times larger than that of the currently working Large Helical Device (LHD). In the future fusion reactors, ferritic steel is a realistic candidate to be used as a structural material of the blanket, because of the low activation characteristics after neutron irradiation which can reduce the issue of radioactive waste disposal. And thus, it is considered to be applied also to FFHR-d1. However, since the ferritic steel is a ferromagnetic material, distortion of magnetic field produced by the magnet coils is a concern on the plasma confinement due to island formation and partial changes of magnetic surfaces [2].

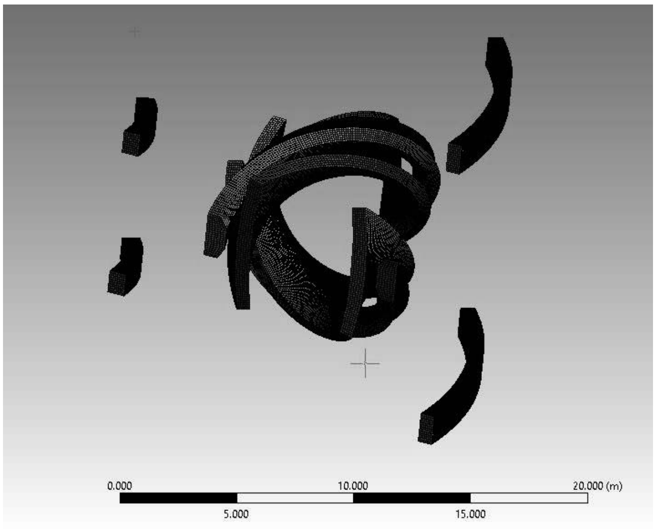

Fig.1 The finite element model of the coils and blankets of FFHR-d1A. The element model "SOLID 97" is used for the coils, blanket, and air. The element model "INFIN111" is used for infinity.

In order to include the distortion of magnetic field by the ferritic steels in the blanket, the numerical calculation code ANSYS based on the finite element method (FEM) is incorporated. First, the precise structure of the magnet coils, vacuum vessel, and blanket is input to establish the 3D modelling for the finite element calculation as Fig.1. The element SOLID 97 is used for coils, blanket, and air. The element INFIN111 is used for infinity. The current in the helical coils is +36.66 MA. The currents in the Outer Vertical Coils and the Inner Vertical Coils are -20.14 MA and +21.61MA, respectively. Second, the magnetic field by assuming a nonmagnetic material in the blanket (vacuum) is calculated as a reference. In this phase, the magnetic field-line tracing code "HSD" is combined to obtain the magnetic surfaces and their associated parameters, such as the rotational transform and magnetic well. Third, the nonmagnetic material is changed to a ferritic material (F82H) and the new magnetic fields are calculated. Comparison of the magnetic field properties by changing the permeability of the structural material is investigated.

The obtained vacuum magnetic surfaces of FFHR-d1A are shown in Fig.2 as a function of the relative magnetic permeability μ_r. Slight expansion of magnetic surfaces is seen for $\mu_r > 1$. In the latest design of FFHR, a pair of sub-helical coils, named "NITA coils" with opposite-directed currents and located at the outer region of the main helical coils, are used to enlarge the blanket space [3]. We propose that the NITA coils be used to control the magnetic surfaces in case the expansion by the ferromagnetic effect is too large.

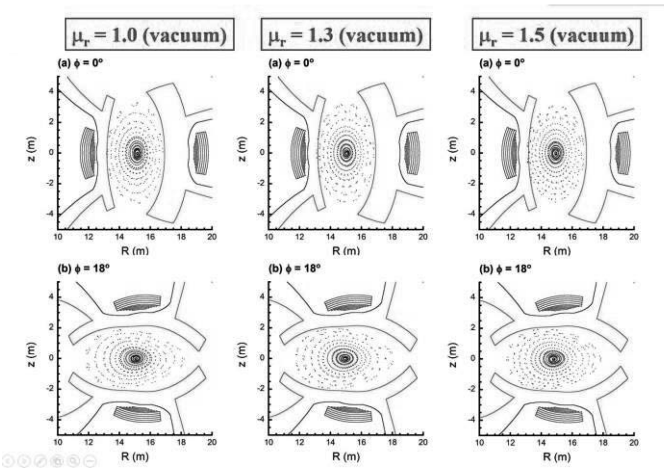

Fig.2 Changes of vacuum magnetic surfaces of FFHR-d1A with the relative magnetic permeability μ_r of 1.0, 1.3, and 1.5. The magnetic axis is shifted slightly outward in the present calculation compared to the standard case of FFHR-d1A.

1) Sagara, A. et al.: Fusion Eng. Des. **89** (2014) 2114.
2) E. Harmeyer et al.:IPP-Report: IPP **III/241** (1999)
3) Yanagi, N. et al.: Plasma Fusion Res. **11** (2016) 2405034.