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Investigation on the magnetic field distortion by ferromagnetism of the blanket for the helical fusion reactor

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HIGHLIGHTS

- The effect of ferritic steel to the heliotron magnetic configuration is examined for the first time.
- ANSYS is used for the calculation of magnetic field.
- The magnetic field data obtained by ANSYS is fed to HSD code to make the field-line tracing.
- Expansion of magnetic surfaces are observed with $\mu_r > 1$.
- The rotational transform is reduced.

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ABSTRACT

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. However, since the ferritic/martensitic 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. 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. In order to include the distortion of magnetic field produced 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. Second, the magnetic field by assuming nonmagnetic materials in the blanket is calculated as a reference. In this phase, the magnetic field-line tracing code 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 ferritic materials and the new magnetic fields are calculated. Comparison of magnetic field properties by changing the permeability of the structural material is investigated.

1. Introduction

With the development of the research on the magnetic fusion, a large number of experiments and theory of plasma physics as well as fusion engineering have approved the scientific and technological feasibility of fusion energy to become a new energy source within this century for peaceful purposes. The conceptual design studies on the LHD-type helical fusion reactor (FFHR) are progressing at NIFS [1–3].

In the future fusion reactors, ferritic/martensitic steel is a realistic candidate to be used as a structural material of the breeding and shielding blanket, because of the low activation characteristics after neutron irradiation which can reduce the issue of radioactive waste disposal. However, since the ferritic steel is a ferromagnetic material, distortion of magnetic field produced by coils is a concern on the plasma confinement by having island formation and a partial change of magnetic surfaces and their characteristics. Though there have been many studies on this effect on tokamaks, very limited studies have been done for helical devices. They were done by

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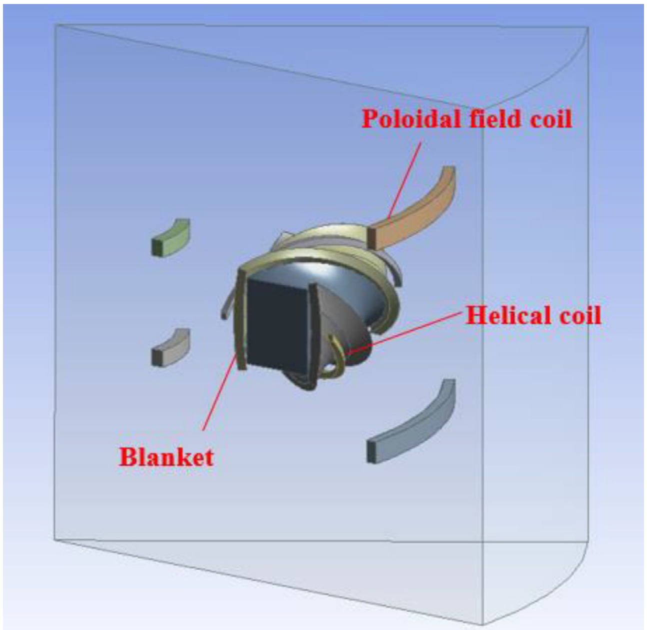

Fig. 1. 3D model of the magnet coils and blanket (Type-1) incorporated in the numerical calculation by ANSYS.

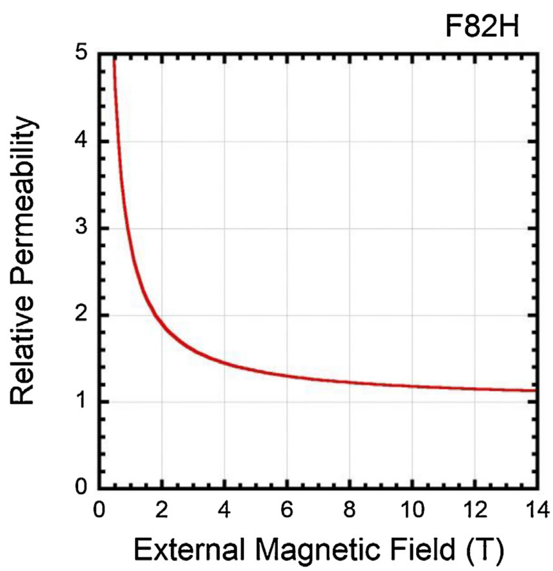

Fig. 2. Relative permeability of F82H ferritic steel as a function of external magnetic field. Reproduced from the data depicted in Ref. [5].

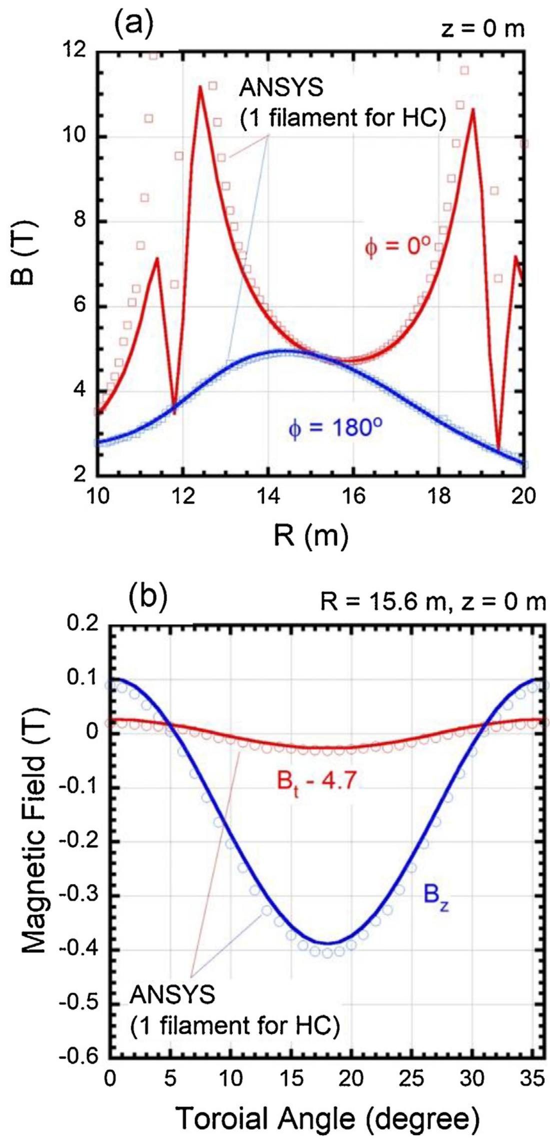

Fig. 3. Comparison of the magnetic field strength obtained by HSD and ANSYS for (a) the absolute value at the equatorial plane ($z = 0$ m) as a function of the major radius R (m), and the field components B_t and B_z at $R = 15.6$ m and $z = 0$ m as a function of the toroidal angle.

the group at IPP Max Planck for the Helias (stellarator) magnetic configuration equipped with modular coils [4]. The result shows that the magnetic surfaces are not significantly changed and the rotational transform is slightly lowered by as much as 5% in the worst case. There has been no study so far for the heliotron magnetic configuration employed for FFHR equipped with continuously wound helical coils. In this paper, this valuable analysis is carried out for the first time for heliotron so that the realization of FFHR could be more secured.

2. Calculation method

In order to include the distortion of magnetic field produced by the ferritic steels in the blanket, the numerical calculation code ANSYS based on the finite element method (FEM) is used. First, the precise structures of the magnet coils and blankets are input to establish the 3D modelling for the finite element calculation. Second, the magnetic field by assuming nonmagnetic materials in the blanket 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. Third, the nonmagnetic material is changed to ferritic materials and the new magnetic fields are calculated. Comparison of magnetic field properties by changing the permeability of the structural material is investigated.

In the numerical calculation using ANSYS, a 3D model is built for each component, as shown in Fig. 1. First, The element SOLID97 is used for the coils (a pair of helical coils and three pairs of poloidal coils), blanket, and the surrounding vacuum area. Second, the element INFIN111 is used for infinity. Third, the data of contact surfaces of two different materials are matched.

Some simplifications are incorporated in the present model. First, only the blanket near the helical coils (Blanket Type-1) is included by assuming that the cross-section has the same rectangular shape in the plane perpendicular to the helical trajectory

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