Evaluations on reduction of the ITER TFC ripple generated by CN HCCB-TBM

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ABSTRACT

Reduced Activation Ferritic/Martensitic (RAFM) steel has been chosen as structural material for China Helium-Cooled Ceramic Breeder Test Blanket Module (CN HCCB-TBM). The magnetization of RAFM definitely increases the toroidal field perturbation (called TF ripple) in international thermonuclear experimental reactor (ITER). The TF ripple could cause ripple loss of high-energy particles and result in a large localized heat load on the first wall of TBMs. Thus some positive measures to reduce the TF ripple generated by TBMs have been evaluated by finite element models (FEM) in this paper. It has been shown that under the intervention of ferromagnetic inserts (FIs) the TF ripple could be reduced to the acceptable level of ITER (namely, TF ripple ∼0.7% at R = 8.2 m of plasma edge near the equatorial plane) while fully considering several actual combinations (mass-reduction and recess) of HCCB-TBM and introduction of correction coils.

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1. Introduction

The ITER major toroidal field (TF) is produced by 18 D-shape coils with equally toroidal angle (20°). Each TF coil carries a total current ITF ∼9.11 MA and the toroidal magnetic field at major radius R = 6.2 m of the machine is ∼5.3 T [1]. The discreteness of toroidal field coils (TFC) causes asymmetric perturbations of the toroidal magnetic field distribution, or the TF ripple (δTF), which definition is shown as [2]:

\[ \delta_{TF}(R, Z) = \frac{B_{\theta,\text{max}}(R, Z) - B_{\theta,\text{min}}(R, Z)}{B_{\theta,\text{max}}(R, Z) + B_{\theta,\text{min}}(R, Z)} \]

In tokamak device the TF ripple is utilized to control the plasma thermal stability and can potentially lead to losses of high-energy particles from plasma. These losses could result in a large localized heat load on plasma facing components (PFCs), which could make an unacceptable level of heat load damage in ITER machine [3]. Thus ferromagnetic inserts with appropriate SS430 steel in the space between the double walls of the ITER VV (Vacuum Vessel) are going to be used to reduce the value of the TF ripple [4,5]. However, the reduced activation ferritic/martensitic (RAFM) steel, one ferromagnetic material, has been selected as structural material for the six test blanket modules (TBMs) which will be installed and tested in ITER in three dedicated equatorial ports directly facing the plasma. Their presence in VV will further create perturbations of the main ITER magnetic field. In ITER the approach to lower TF ripple generated by TBMs is being investigated to ensure safety operation of plasma, which is one of the most important objectives in electromagnetic testing of TBMs. Although some analyses and assessments on reduction of TF ripple have been carried out with the intervention of FIs or optimized FIs and TBM, an accurate evaluation on reduction of TF ripple is still necessary and important to each TBM due to difference of structural design [2,6,7].

In this paper, based on optimization design of FIs in ITER and updated design of CN HCCB-TBM (China Helium Cooled Ceramic Breeder TBM), a detailed evaluation of TF ripple has been performed by establishing three-dimensional finite element model (FEM) of ANSYS code [8]. It has been shown that TF ripple could be reduced to the acceptable of ITER by synthetically considering the recess of TBM position in equatorial port and decrease of FM (ferritic material) mass in TBM. The role of correction coils has been analyzed to assess the reduction of TF ripple.

2. Updated CN HCCB-TBM design and analytical FEM

2.1. Updated design of CN HCCB-TBM

Preliminary design of the HCCB-TBM had been performed, based on the definition and the strategy of DEMO fusion reactor in China. Its main components included first wall, caps, grids and twelve sub-modules. Each sub-module was a relative independent breeding unit. RAFM steel (e.g., CLF-1 steel, a ferritic material being developed in Southwestern Institute of Physics) has been selected as structural material for the first wall and main components,