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Distortion of magnetic field lines caused by radial displacements of ITER toroidal field coils

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ABSTRACT

An assessment of distortions of ideal (circle) field lines caused by random radial displacements of the TF coils by $|\Delta R| \leq 5$ mm has been performed from the statistical analysis assuming a uniform probability density function for displacements.

1. Introduction

Were the Toroidal Field (TF) of ITER tokamak [1] to coincide with an “ideal toroidal solenoid” (i.e. the number of TF coils $N_{TFC} \to \infty$), the magnetic field lines should be horizontal circles with the centers located on the vertical axis Z (see curve 1 in Fig. 1). The finite number $N_{TFC} = 18$ of the TF coils in their nominal positions produces non-axisymmetric periodic deviations of field lines (i.e. TF ripple) with the toroidal main mode number $n = 18$ (see curve 2 in Fig. 1). This will cause perturbation of the plasma boundary and peaking of heat loads on the first wall due to an increase in the angle χ between the first wall and the field line striking the wall (Fig. 1). The TF ripple may be partially decreased by the Ferromagnetic Inserts (FIs) [2,3].

Non-axisymmetric (random) shifts of the TF coils from their nominal positions destroy the periodical character of the TF ripple and can locally (at some toroidal angles φ) increase the angle χ and, correspondingly, the heat loads.

The paper is devoted to assessment of distortions of ideal (circular) field lines caused by random radial displacements of the TF coils on the first wall for the blanket modules (BMs) within the expected range of installation tolerances.

In the general case, the field line equation has a form $dx/B_x = dy/B_y = dz/B_z$, while the line location is determined by means of integration. The study presented is focused on a simplified technique [3], due to low field distortions typical for TF coils. Displacements of the TF coils are found in terms of deviations from an ideal (circular) field line.

The results of such study will be quantitatively assessed in terms of (i) a deviation of the perturbed field lines in the direction normal to the first wall plasma facing surface, (ii) an angle between the perturbed field lines and the first wall plasma facing surface, and (iii) a horizontal shift of the “magnetic axis” of the field produced by the TF coils.

2. Statement of the problem

In the study the first wall of each Blanket Module (BM) is defined as a ring given by the edges with the following coordinates: (R_1, Z_1) for the lower edge and (R_2, Z_2) for the upper edge. The coordinates of eighteen blanket modules edges in the Tokamak General Coordinate System (TGCS) are given in Table 1 and indicated in Fig. 2.

The coordinates of a unit poloidal vector (C_r, C_z) normal to each indicated line 1–2 can be found as

$$C_r = \frac{-(Z_2 - Z_1)}{\left((R_2 - R_1)^2 + (Z_2 - Z_1)^2\right)^{1/2}}, C_z = \frac{R_2 - R_1}{\left((R_2 - R_1)^2 + (Z_2 - Z_1)^2\right)^{1/2}}. \quad (1)$$

Let us consider an ideal toroidal field line (circle (l) below) passing through a point with the coordinates (R, Z). The field $B_0(R)$ and the current I_{TF} in every TF coil are related to each other by Ampere’s law:

$$\frac{1}{\mu_0} \oint_{(l)} B_\varphi dl = \frac{2\pi R}{\mu_0} B_0(R) = 18 \cdot I_{TF}. \quad (2)$$

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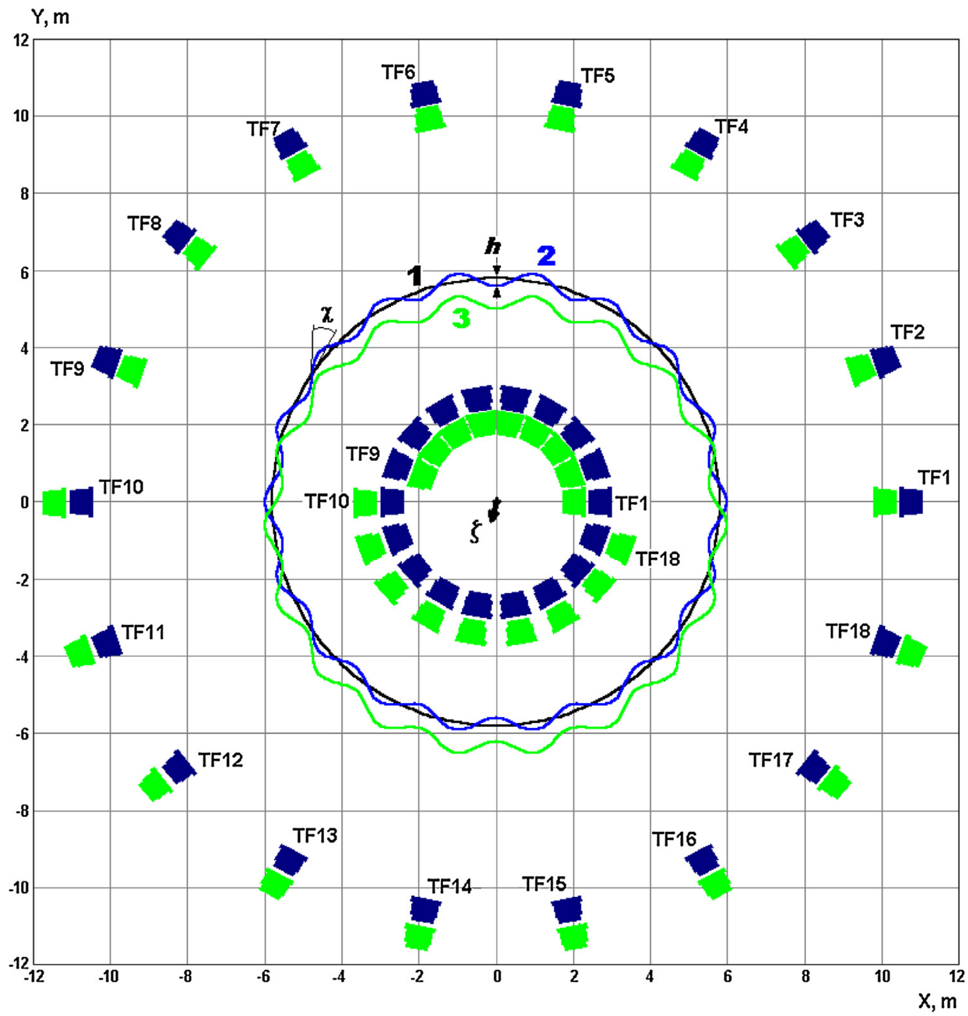

Fig. 1. Horisontal cross-section of ITER TF coils. 1–ideal circular line, 2 – non-axisymmetric periodic (N_{TFC} = 18) field line for nonshifted TF coils, 3–field line for the radially shifted TF coils (variant corresponding to *Case 3*). *h*, χ, and ζ are also indicated.

Table 1
Coordinates of BM edges (R_1,Z_1), (R_2,Z_2), and middle points (r_i, z_i).

Blanket module	i	R_1, m	Z_1, m	R_2, m	Z_2, m	r_i, m	z_i, m
BM1	1	4.1053	−2.5037	4.1053	−1.4914	4.10530	−1.99755
BM2	2	4.1053	−1.4914	4.1053	−0.4761	4.10530	−0.98375
BM3	3	4.1053	−0.4761	4.1053	0.5402	4.10530	−0.03205
BM4	4	4.1053	0.5402	4.1053	1.5566	4.10530	1.04840
BM5	5	4.1053	1.5566	4.1053	2.5719	4.10530	2.06425
BM6	6	4.1053	2.5719	4.1253	3.5852	4.12030	3.07855
BM7	7	4.1253	3.5852	4.3246	4.3371	4.22495	3.96115
BM8	8	4.3246	4.3371	4.9354	4.7196	4.63000	4.52835
BM9	9	4.9354	4.7196	5.7534	4.5344	5.34440	4.62700
BM10	10	5.7534	4.5344	6.5524	3.9256	6.15290	4.23000
BM11	11	6.5524	3.9256	7.4015	3.1796	6.97695	3.55260
BM12	12	7.4015	3.1796	7.9062	2.4647	7.65385	2.82215
BM13	13	7.9062	2.4647	8.2697	1.6847	8.08795	2.07470
BM14	14	8.2697	1.6847	8.3938	0.6354	8.33175	1.16005
BM15	15	8.3938	0.6354	8.3057	−0.4200	8.34975	0.10770
BM16	16	8.3057	−0.4200	7.9002	−1.3372	8.10295	−0.87860
BM17	17	7.9002	−1.3372	7.2824	−2.2544	7.59130	−1.79580
BM18	18	7.2824	−2.2544	6.2661	−3.0434	6.77425	−2.64890

For the nominal current $I_{TF} = -9.128$ MAt the field $B_0(R)$ is equal to

$$B_0 = \frac{-32.8608}{R[\mathrm{m}]}[\mathrm{T}]. \quad (3)$$

The corresponding toroidal field B_0 at the radius $R = 6.2$ m is −5.3 T. Here the negative sign corresponds to the clockwise direction of the toroidal field if viewed from above.

Deviation $h(\varphi)$ of the perturbed field line relative to the ideal field line passing through the point with the coordinates (R, Z, φ_0)