Magnetostatic force analysis on ITER Fixators using a Semi-Analytical method

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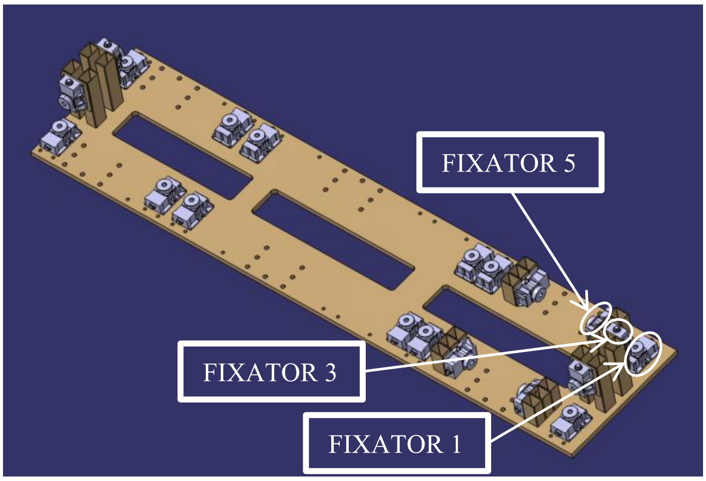
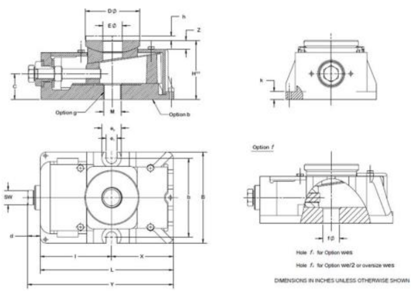
A semi-analytical approach is developed to compute ferromagnetic forces acting on ITER diagnostic support structures (EU-11 fixators), subject to intense static magnetic fields [1]. These fixators play a critical role in maintaining the structural stability of the Export Radial Neutron Camera diagnostic system. The methodology approximates each fixator as a uniformly magnetized hexahedron and applies self-consistent iterations to evaluate field-dependent nonlinear magnetization. Validation against CARIDDI [2] and ANSYS Maxwell [3] shows good accuracy and substantial reduction in computational time. The ITER Tokamak environment is characterized by extremely high magnetic fields (up to 11 T), which induce strong ferromagnetic forces in nearby steel components. These forces must be accurately assessed to guarantee the mechanical integrity of structural components, especially where magnetic steels such as AISI430 [4] are employed.

Traditional methods for computing magnetostatic forces rely on full 3D numerical simulations, involving fine meshing and nonlinear B-H curve modeling, which result in high computational costs and generally require specialized expertise. This work proposes a semi-analytical alternative, offering a balance between accuracy and computational efficiency for preliminary design and safety assessments. Each fixator component is approximated as a hexahedral block characterized by Centroid position and dimensions.
The geometric data used in the model were derived from engineering CAD drawings (Figure 1) and the centroids of each Fixator has been summarized in Table 1.





(a) (b)

Figure 1 - Geometry of the Fixators: (a) All Fixators used to Fix the base of the Export-RNC - in red the used Fixators; (b) Orthogonal projection of the geometry of a single fixator.

Table 1 - Centroids of each considered Fixator.

FIXATOR	(x,y,z) Centroids [mm]
1	(12861, -191, -354.5)
3	(12868, -81.5, -145)
5	(13112.5, -181, -317)

The detailed results of the semi-analytical method were validated using the CARIDDI code and confirmed through benchmarking with ANSYS Maxwell. This comparison made it possible to assess the accuracy and effectiveness of the new approximate method, confirming its ability to provide reliable estimates in significantly reduced computation times. The proposed method showed good agreement with CARIDDI and ANSYS Maxwell results.

Table 2 - Results comparison (Semi Analytical Method vs CARIDDI vs Maxwell)

	Fx SA Method	Fx CARIDDI	Fx Maxwell	Fy SA Method	Fy CARIDDI	Fy Maxwell	Fz SA Method	Fz CARIDDI	Fz Maxwell
Fix 1	20.71	23.74	22.89	-38.63	-42.88	-41.89	-52.38	-82.26	-82.96
Fix 3	-7.66	11.41	11.42	11.91	27.36	28.67	28.60	62.01	60.08
Fix 5	-60.50	-77.64	77.05	13.95	15.21	14.54	9.96	19.95	20.21

The semi-analytical method developed here allows fast reliable estimation of magnetostatic forces on ITER components using simplified hexahedral discretization and self-consistent magnetization modeling. While not intended to replace full nonlinear FEM simulations, it provides a valuable tool for early design validation or for use by non-specialist engineers, helping to estimate the order of magnitude of the forces involved, as shown in the results in Table 1.

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