Fusion Engineering and Design 89 (2014) 2691–2708

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Strategy for solving a coupled problem of the electromagnetic load analysis and design optimization for local conducting structures to support the ITER blanket development

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HIGHLIGHTS

- We present the way of modeling transient electro-magnetic loads on local conductive domains in the large magnetic system.
- Simplification is achieved by decomposing of the problem, multi-scale integral-differential modeling and use of integral parameters.
- The intrinsic scale of loads on a localized conductor with eddy is quantified through the load susceptibility tensor.
- Solution is searched as response of a simple equivalent dynamic simulator, using control theory methods.
- The concept is exemplified with multi-scenario assessment of EM eddy loads on ITER blanket modules.

ARTICLE INFO

Article history:
Received 16 October 2013
Received in revised form 27 May 2014
Accepted 10 July 2014
Available online 15 August 2014

Keywords:
Tokamak
ITER
Blanket
Electromagnetic transients
Eddy currents
Electromagnetic loads

ABSTRACT

The complexity of the electromagnetic (EM) response of the tokamak structures is one of the key and design-driving issues for the ITER. We consider the specifics of the assessment of ponderomotive forces, acting on local components of a large electro-physical device during electromagnetic transients. A strategy and approach is proposed for the operative EM loads modeling and analysis that enables design optimization at early phases of development. The paper describes a method of principal simplification of the mathematical model, based on the analysis and exploiting specific features and peculiarities of the relevant technical problem, determined by the design and operation of the device and system under consideration. The application of the method for predictive EM loads analysis and corresponding numerical calculations are exemplified for the localized ITER blanket components — shield modules. The example demonstrates the efficiency of EM load analysis in complex electromagnetic systems via a set of simplified models with different scope, contents and level of detail.

1. Introduction. The formulation of the problem of analytical supporting the ITER blanket development

A blanket in a large tokamak, such as the ITER machine [1], is subjected during operation to a combination of versatile loads. The electromagnetic (EM) ponderomotive forces due to the interaction of eddy currents, induced in conducting elements of the structure, with the magnetic field represent one of the most substantial and crucial types of loading. These forces are notably characterized by the complexity of their spatial and temporal distributions. The magnitude and configuration of the EM loads determine to a great extent the design and the adopted engineering solutions.

At the same time, the basic conceptual solutions, introduced in the design, define the set of engineering problems to be considered in performance analysis of subsystems and components.

For example, the modular design is chosen for the ITER blanket (Fig. 1): the nuclear shielding of the superconducting coils and the protection of the vacuum vessel from direct contact with the plasma is achieved through so called shield blanket modules. The total number of these individually supported and electrically isolated from each other elements, mounted on the vacuum vessel (VV), is 441, according to the reference scheme of segmentation. The shield modules are equipped with the removable protectors — first wall (FW) panels [2]. This layout determines the importance of calculations of the total net forces and torques,

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http://dx.doi.org/10.1016/j.fusengdes.2014.07.007
0920-3796/

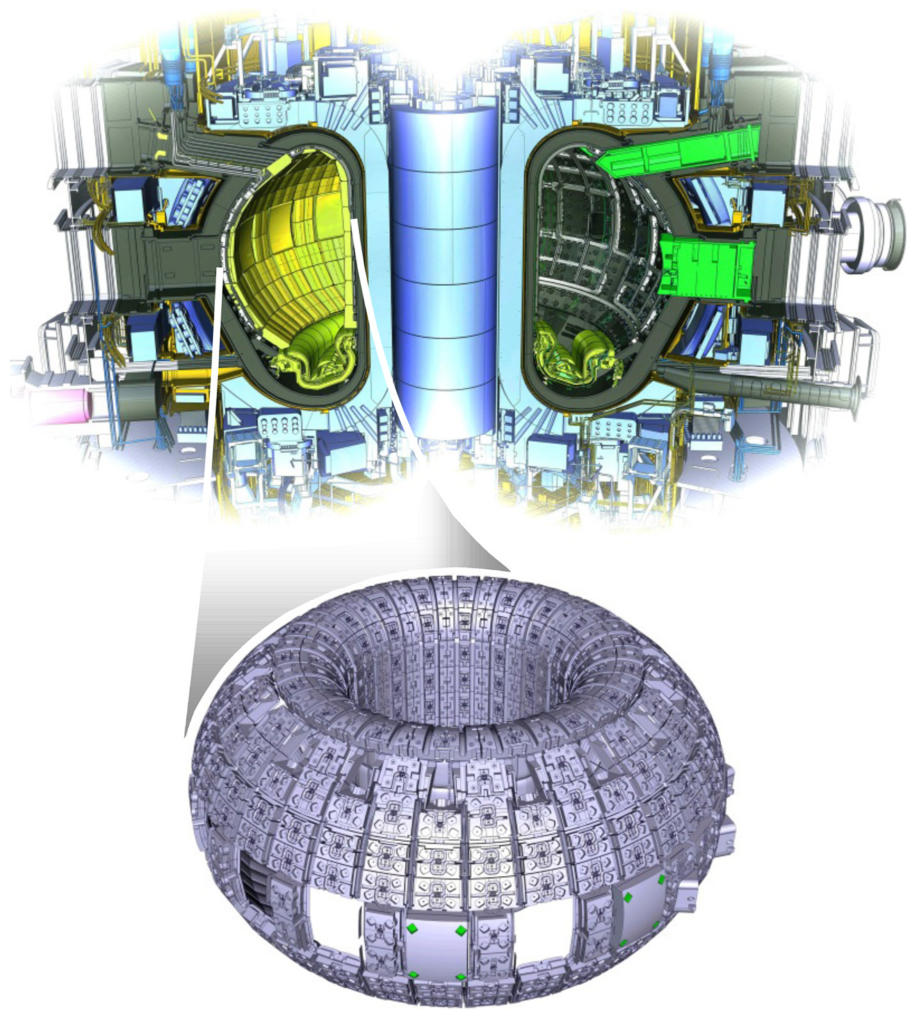

Fig. 1. The ITER blanket.

acting on separate modules during the fast EM transients, developed, for example, at plasma instabilities and disruptions [3] and of the assessment of loads on their attachments to the VV [4]. The peculiarity of the situation here originates from the connection between the mechanical and electromagnetic problems, with the necessity to solve in parallel (in fact — iteratively) the two conjugate engineering tasks: designing of the system and analysis of the acting loads, reciprocally depending on this design. Thus, the selection of the engineering solutions and the assessment of loads turn into the two linked parts of the common process of optimization.

2. Rationale for simplifications in operative assessments at early phases of blanket development and optimization

The numerical modeling of the transient processes in the magnetic system and passive conducting structures of electro-physical and electro-technical installations, extensively involves the computational technologies, based on finite-element (FE) methods. The joint solutions for the current density and the magnetic field distributions are found then, as a rule, simultaneously, which requires all main components of the magnetic system, both active and passive, to be accounted in the same model. This complicates the application of the FE methods for large devices, characterized by the presence of elements of very different scales, internal structure and geometrical shape. In certain cases the use of the full-scale universal all-purpose FE models is getting unreasonably difficult, impractical or technically impossible. In general, the selection of the modeling methods is substantially influenced by:

- the type and the details of the considered problem, the objectives, availability and reliability of the input data, maturity of the design, changing between the phases through the lifecycle of the project;
- the amount and the diversity of the loaded components and units;
- the available computational resources.

Practically all above mentioned aspects play a role in the development of the blanket of the ITER tokamak — a large-scale electro-physical installation with strong magnetic field. From the standpoint of the analytical support of the development of blanket components and analysis of the EM loads, expected at plasma disruptions, one of the main challenges is a wide range of types and size variants of modules, together with the variation of the magnetic field and its dynamics between the modules in different positions [5,6]. Another challenge in the development of blanket modules is a necessity to account for a wide spectrum of scenarios of transients in the magnetic system, associated with plasma instabilities and disruptions. The numerosity of the considered scenarios partially compensates the limited reliability of the data, determined by the novelty of the device of similar scale and by the lack of experimental data [7].