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CFETR integration design platform: Development of space analysis module

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ABSTRACT

Space allocation is important in the design of a fusion reactor, where numerous components operate under complex conditions, including a strong magnetic field, high-energy neutron irradiation, and a wide temperature range (4.5 K at the magnet and ~300–500℃ at the blanket). To ensure the consistency of the China Fusion Engineering Test Reactor (CFETR) design, multi-component interference checks and distance measurements must be routinely performed. In this paper, a space analysis module is developed on the CFETR Integration Design Platform to provide the space analysis function for both rigid and deformed components (using the Representative-Triangles method). The example of the space allocation of a vacuum vessel (VV) and a thermal shield (TS) is demonstrated. The deformation due to heating under the bake-out condition is considered (during operation, heating and swelling due to radiation also cause deformation). With the input from the component design module, the space analysis can be well-performed for both rigid models and thermal deformation results (under the simplified boundary condition). Through iteration between the component design modules and the space analysis module, a preliminary designed clearance of 40 mm between the VV and TS is insufficient owing to the deformation during bake out, and the optimized clearance increases by a factor of two.

1. Introduction

The China Fusion Engineering Test Reactor (CFETR) is a superconducting reactor that aims to bridge the gaps between the fusion experimental reactor ITER and the demonstration reactor DEMO [1–3]. Owing to the intrinsic complexity of fusion device design [4] and the geographical distribution of the designers, an integration design platform is necessary to support the CFETR design effectively and consistently. The CFETR Integration Design Platform (CIDP) is currently under development to coordinate the design work, manage the large amount of data, and provide a centralized design environment for the CFETR [5,6].

The CIDP comprises a project management system (PMS), an engineering design system (EDS), and an integrated design framework (IDF), as shown in Fig. 1. The design data and documents are managed by the PMS, together with the design requirements and work breakdown structure. The design works are coordinated by the EDS, where detailed design tasks are assigned to the designers and the design data are collected and transferred to the PMS. The IDF provides a unified and centralized design environment based on a design cloud. Two sub-frameworks—an engineering design framework and a physics design framework—are built in the IDF. In the engineering design framework, various types of computer-aided design (CAD)/computer-aided engineering (CAE) software, such as CATIA, ANSYS, and FLUENT, can be easily combined to form a workflow using the OPTIMUS software. According to the specified design and analysis procedures, several engineering modules are developed for a toroidal field coil, poloidal field coil, vacuum vessel (VV), thermal shield (TS), etc., where pre-set workflows and necessary data-exchange interfaces are integrated. The situation is similar for the physics design framework, where various physics codes, such as EFIT, TGYRO, and ONETWO, can be combined in the One Modeling Framework for Integrated Tasks (OMFIT), and several modules are developed for the specified purpose of physics design. In this study, a space analysis module is developed in the engineering design framework, to provide the functions of interference checks and distance measurements between different components.

The design of the CFETR involves many complex components, such as the superconducting coils, breeding blankets, divertor, VV and TS. To achieve reasonable space allocation and ensure the consistency of the CFETR design, interference checks must be routinely performed to ensure that the case of an equal area captured by more than one component, i.e., a “clash” between different components, is avoided. Furthermore, because of the complex operational environment (strong magnetic field, fusion neutron irradiation, temperature range of 4.5 K to several hundreds of degrees centigrade, etc.), the deformation of components caused by physical effects, including thermal and structural

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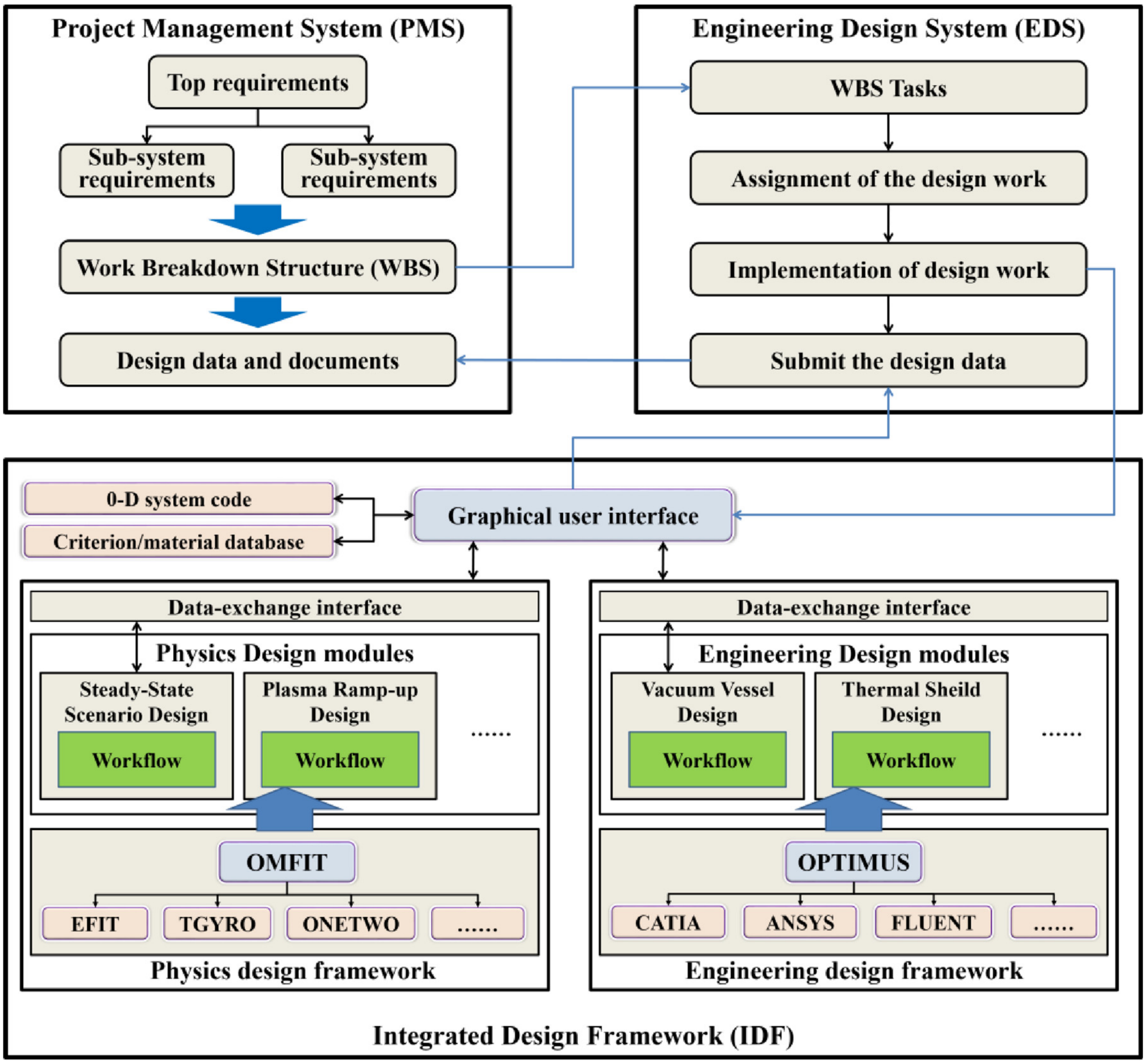

Fig. 1. Structure of the CIDP.

stress, should be examined carefully to avoid clashes and ensure safety under all conditions. Therefore, the space analysis function for both rigid CAD models and deformed models is realized in the module developed in this study.

The implementation of interference checks and distance measurements for rigid CAD models is straightforward in CATIA. However, it is more complex and difficult to detect clashes and to measure the minimum distance between deformable models. Generally, finite-element analysis (FEA) is performed to evaluate the deformation of components, and the result is stored in the meshes of the finite-element model (FEM). Many methods for processing these meshes and accelerating the calculation have been studied. An optimized method of interference checking for deformable triangle meshes was developed [7], and a fast method for detecting clashes by using Representative-Triangles (R-Triangles) was studied [8]. To perform space analysis on the deformed result in the platform, the R-Triangle method is applied in the workflow of the space analysis module. With conversion by EnSight, the result of the structural analysis can be triangulated to build an STL model made up of R-Triangles, and space analysis can be then performed using CATIA. Therefore, for both rigid and deformed models, assembly and further space analysis between components can be performed in the space analysis module.

The detailed workflow of the space analysis module, which can handle both the rigid CAD model and the deformed result of FEM, is presented in Section 2. The implementation of the space analysis module is demonstrated in Section 3 using an example of interference checking between the VV and TS for both the rigid model and deformed results during bake-out. The optimization of the designed clearance between the VV and TS is demonstrated to ensure that there are no clashes between VV and TS due to the thermal deformation during bake-out. The conclusions are presented in Section 4.

2. Workflow of space analysis module

A sketch of the workflow of the space analysis module is shown in Fig. 2. The engineering software involved in the module is listed as follows.

(1) CATIA: CAD software for building geometric models and performing space analysis.
(2) ANSYS: for performing FEA and outputting the analysis results.
(3) EnSight: post-processing software for reading the results of FEA and performing the conversion of the FEM.

Coupling interfaces are built inside the space analysis module. Design results from the engineering design modules can be transferred into the space analysis module through the interfaces. The interfaces are described as follows.

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