Fusion Engineering and Design xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

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

Electromagnetic and structure analysis for EAST vacuum vessel with plasma facing components during VDE

Liu Sumei [a,b,*], Sun Jinxin [a], Lu Mingxuan [b], Lei Mingzhun [b], Pei Kun [b]

[a] *School of Engineering, Anhui Agricultural University, Hefei, 230036, China*
[b] *Institute of Plasma Physics, Chinese Academy of Science, Hefei, 230031, China*

HIGHLIGHTS

- The DINA code was used for the safety evaluation of EAST structures firstly.
- The real time variation of plasma cross profile current is explored by means of Java based on outputs of DINA code during VDE.
- The more accurate loading on plasma cross profile models has led to the precise VDE than ever equivalent plasma section model.

ARTICLE INFO

Article history:
Received 2 October 2016
Received in revised form 26 January 2017
Accepted 8 February 2017
Available online xxx

Keywords:
EAST
Vacuum vessel
Plasma facing components
VDE
Electromagnetic analysis
Mechanical analysis

ABSTRACT

Experimental Advanced Superconducting Tokamak (EAST) is a superconducting magnet tokamak and its goal is to achieve the magnetic confinement fusion. The major plasma disruption (MD) or the vertical displacement event (VDE) all will produce toroidal eddy current in the vacuum vessel (VV) with plasma facing components (PFCs) and cause mechanical forces, which represent one of the most vital loads for tokamak. This paper is focused on calculational methods and results for the electromagnetic loads on the simplified but practical model of EAST VV with PFCs respect to VDE scenarios based on outputs from DINA, which are one of major sources of electromagnetic loads on VV and PFCs. Commercial finite element method software, ANSYS, was employed to evaluate the eddy current on the VV and PFCs modules with the 22.5° sector model for major conducting structure of the tokamak. As the results of calculating the eddy currents and electromagnetic forces, stress and deformation on EAST VV with PFCs can be obtained. According to the analysis results, some advices to more effectively protect EAST vacuum vessel and PFCs from being destroyed in VDE is given out.

1. Introduction

The Experimental Advanced Superconducting Tokamak (EAST) device is based on a superconducting magnet system built by Institute of Plasma Physics Chinese Academy of Sciences, which consists of 16 Toroidal Field (TF) coils and 14 Poloidal Field (PF) coils (the 6 Central Solenoidal (CS) assembled consists of 6 PF coils). A vacuum vessel (VV) with 16 rectangular horizontal ports and 32 bathtub-shaped vertical ports are welded from 16 sectors into a torus. The Plasma Facing Components (PFCs) and their supports are installed on the inner wall. The EAST device has a height of 10 m, a diameter of 7.6 m and a total weight of 360 t. The main parameters of the EAST device are listed in Table 1 [1]. The vacuum vessel is one of the key components for EAST device which can provide an ultra-high vacuum and clean environments for plasma operation, while eddy current will flow on the vacuum vessel torus which can produce electromagnetic force on VV and PFCs when plasma disruption (MD) event or vertical displacement event (VDE) happens [2,3].

2. Description of models and load specification

2.1. The finite element models of EAST

Considering the periodicity and the symmetry on EAST structure, 1/16 section (22.5°) of the whole complicated model has been set up. Besides VV and PFCs, the finite elements model (FEM) contains 2 halves toroidal coils (TF), 14 poloidal coils (PF) and the plasma, as shown in Fig. 1. The VV model also is included inner wall, outer wall, one horizontal window, one upper vertical window and one down vertical window. PFCs contain latitude circles, support structures, high field plates, inner plates, dome plates, outer

* Corresponding author at: School of Engineering, Anhui Agricultural University, Hefei, 230036, China.
E-mail addresses: smliu@ipp.ac.cn, liusm1117@163.com (L. Sumei).

http://dx.doi.org/10.1016/j.fusengdes.2017.02.036

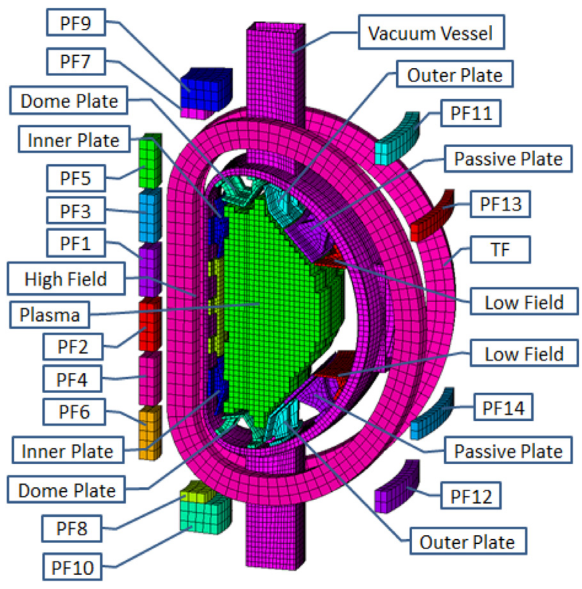

Fig. 1. Typical finite element model layout of EAST.

plates, passive plates and low field plates. PF coils have 14 big circles numbered from PF1 to PF14. TF coils have 16 D-shape coils for the whole model, one which is divided into two halves for each 1/16. According to the ANSYS electromagnetic analysis rules, the air area and the infinite field area should also be included in the model (they are remained under cover in Fig. 1). And element type solid62, solid97 and infin111 are used. Infin111 is for infinite field modeling; solid97 is for all the others, PF coils, TF coils, plasma current and air. Solid62 is electromagnetic-structure coupled element type, and it can be used for VV with PFCs considering structure effect in electromagnetic analysis [4–9].

2.2. Boundary conditions and load specification

The correct boundary conditions can be applied to the electromagnetic model. The first one is the cyclic symmetry boundary condition, which requires the concordant mesh on the two sides of the model. The second one is the flux parallel boundary condition, which is applied to the central axis in view of the direction of the magnetic field along the axis. The third one is the infinite field boundary condition, which has been simulated by applying infinite field flag to the external surfaces of the infinite field elements, and the infinite field elements can be generated by extending the external surfaces of the air. The size of the infinite field area is about the size of the air area to ensure the simulation accuracy. The last one is the terminal boundary condition. The low terminal of VV is fixed, and the top terminal of VV can be slide only vertical. The whole model is electrical connective in the toroidal direction, and the short circuit terminal boundary condition should be applied in order to constrain the volt degrees of freedom to zero on the symmetry surfaces [4–9].

The plasma current is moved vertical down along with time during VDE happens, the more accurate loading on plasma cross profile models has led to the worse VDE than ever equivalent plasma section model. Fig. 2 . The currents of PF coils and TF coils in steady-state are listed in Table 2shows the equivalent plasma current variation with time at number (8385) of plasma current points during VDE happens, and it can be seen that equivalent plasma current start to change at the time of 5.06 s, and end at 5.10 s. The more accurate real time loading is based on outputs of DINA code. The real time variation of plasma cross profile current is explored by means of Java based on outputs of DINA code [9,10], and it is also

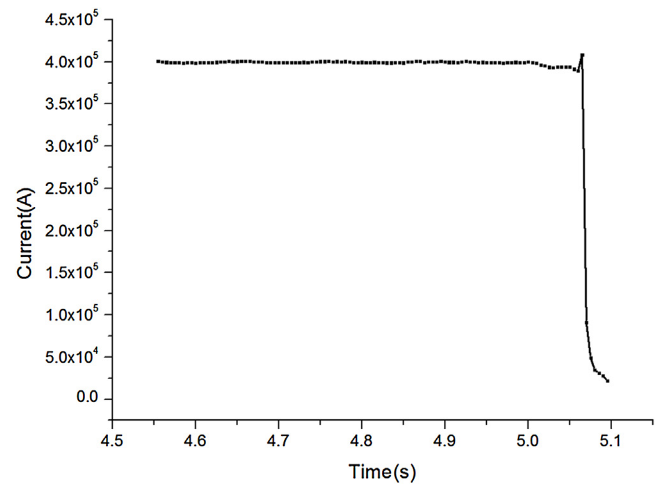

Fig. 2. Equivalent plasma current variation with time.

Table 1
Main parameters of EAST device.

Items	Parameters
Toroidal field, B_0 (T)	3.5
Plasma current, IP (MA)	1
Major radius, R_0 (m)	1.7
Minor radius, a (m)	0.4
Aspect ratio, R/a	4.25
Elongation, K_x	1.6–2.0
Triangularity, d_x	0.6–0.8

Table 2
Currents of PF coils and TF coils in steady-state.

Coil	Turns	Current per turn/A
PF1/PF2	140	240
PF3/PF4	140	1340
PF5/PF6	140	5020
PF7/PF8	44	12820
PF9/PF10	204	12820
PF11/PF12	60	−7590
PF13/PF14	60	−14040
TF	140	1430

from 4.50 s to 5.10 s. Fig. 3(a) shows the plasma cross profile current of number (8385) of plasma current points at 4.625 s, and Fig. 3(b) shows the plasma cross profile current of number (8385) of plasma current points at 5.095 s.

3. Results of analysis and discussion

The electromagnetic analysis was done firstly to acquire the eddy current and electromagnet force, and structure analysis was followed with applying electromagnetic force as load. And more accurate stresses and strains will be obtained by this way. Electromagnet force distribution and time history are concerned of all the results specially [4–9].

Fig. 4 is the time histories of electromagnet force on VV and PFCs of EAST from 4.80 s to 5.10 s at number (8385) of plasma current points during VDE happens. It can be shown that electromagnet forces keep smoothly at the beginning and reach the peak values at 5.08 s, and the high field plate is subjected to the maximum. So this moment (5.08 s) for VV and PFCs are the most dangerous. Fig. 5 shows the distribution of electromagnet fields at 5.08 s. The maximum of magnetic field is 5.3 T also in the high fields. Fig. 6(a) and (b) shows the distribution of structural Von mises stresses on VV and PFCs at 5.08s. The maximums of stress are 46.7 MPa and 38 Mpa