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Thermo-mechanical and damage analyses of EAST carbon divertor under type-I ELMy H-mode operation

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HIGHLIGHTS

- Type-I ELMy H-mode is one of the most severe operating environment in tokamak.
- An actual time-history heat load has been used in thermo-mechanical analysis.
- The analysis results are time-dependent during the whole discharge process.
- The analysis could be very useful in evaluating the operational capability of the divertor.

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ABSTRACT

The lower carbon divertor has been used since 2008 in EAST, and many significant physical results, like the 410 s long pulse discharge and the 32 s H-mode operation, have been achieved. As the carbon divertor will still be used in the next few years while the injected auxiliary heating power would be increased gradually, it's necessary to evaluate the operational capability of the carbon divertor under the heat loads during future operation. In this paper, an actual time-history heat load during type-I ELMy H-mode from EAST experiment, as one of the most severe operating environment in tokamak, has been used in the calculation and analysis. The finite element (FE) thermal and mechanical calculations have been carried out to analysis the stress and deformation of the carbon divertor during the heat loads. According to the results, the main impact on the overall temperature comes from the relative stable phase before and after the type-I ELMs and local peak load, and the transient thermal load such as type-I ELMy only has a significant effect on the surface temperature of the graphite tiles. The carbon divertor would work with high stress near the screw bolts in the current operational conditions, because of high preload and conservative frictional coefficient between the bolts and heatsink. For the future operation, new plasma facing materials (PFM) and divertor technology should be developed.

1. Introduction

EAST is a full superconducting tokamak with a non-circle cross-section vacuum vessel (VV) and the active cooling plasma facing components (PFCs). Its scientific and engineering missions are to realize long pulse and high confinement steady-state operation plasma as well as to explore the solutions for power exhaust and particles control [1]. The EAST divertor is designed as up-down symmetry structure to provide large experimental flexibility. EAST can operate with a single null or double nulls mode [2].

The carbon divertor is composed of graphite tiles, CuCrZr heatsink and stainless steel (SS) support. It has been used in EAST for the first time from 2008. Since then, a series of significant physical results, like the 410 s long pulse discharge with 0.28 MA and the 32 s H-mode operation, had been achieved [3]. Although the upper divertor was upgraded to tungsten divertor in 2014 which is based on cassette and monoblock technology [4,5], the plasma facing materials of the lower divertor remains carbon and will still be used in the next few years. To guarantee the operational reliability, it is necessary to evaluate the thermo-mechanical characteristics of the carbon divertor under the higher anticipated heat loads in the coming years.

In this paper, an actual time-history heat loads, including type-I ELMs, was used for the finite element thermo-mechanical analysis. And then, the referential parameters, such as time dependent

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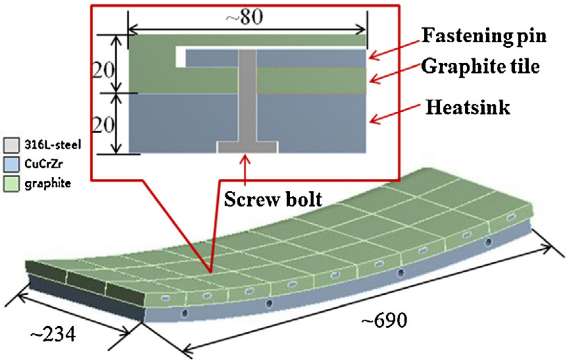

Fig. 1. The lower outer carbon divertor assembly (mm).

temperature, stress and strain, were calculated to evaluate the performance of carbon divertor. A beneficial attempt has made to estimate the fatigue damage of materials under the time-history heat loads.

2. Structure

The EAST lower carbon divertor is divided into 16 divertor modules along toroidal direction. Each module occupied 22.5°, and comprised inner target, dome and outer target. The poloidal cross section is W-shaped. Since the inner and outer targets touch the last closed flux surface (LCFS), most energy from plasma deposits on these two targets. In this paper, the outer target was chosen for the finite element (FE) calculations, see Fig. 1. In the target, the graphite tiles are bolted to CuCrZr heatsink in 3 × 9 arrays with M6 screw bolts and fastening pins. The CuCrZr heatsink is bolted to the SS support, which is not shown in the figure, with M8 screw bolts. In order to improve the thermal contact between the graphite tiles and heatsink, a 0.38 mm thick layer of flexible graphite is placed between them.

3. Numerical calculation

3.1. Heat load

EAST #42556 shot, a typical type-I ELMy H-mode discharge, was selected to simulate the time-history heat loads on the lower outer divertor target. Fig. 2(a) shows the time distribution data of incident heat flux from experiment. The type-I ELMs phase duration is about 1.7 s. And it can be clearly seen that the frequency and average peak heat flux is about 10 Hz and 7 MW/m^2, respectively. Besides the type-I ELMs, a remarkable bulge up to 5 MW/m^2 appears at 6.8 s. Its is due to the bad coupling between the lower hybrid waves, and the energy was losing in the divertor area instead of going back to the plasma. It is a low possibility but still possible event for EAST in the future. More information about EAST #42556 shot can be found in [6]. In order to make it suitable for FE calculation using ANSYS WORKBENCH, the discrete data were simplified and fitted in curves, see Fig. 2(b). The whole process was divided into 8 stages according to the discharge sequence: current climbing stage (0–1.5 s), L-mode (1.5–1.9 s), L-H transition (1.9–1.98 s), ELM-free H-mode (1.98–2.6 s), instability growth (2.6–3.7 s), type-I ELMy H-mode (3.7–5.4 s), local peak induced by lower hybrid wave (5.4–8.25 s) and H-L back transition (8.25–9.0 s). It should be pointed out that in the initial 0.9 s, the heat loads on the divertor target is almost zero, so the start point of the calculation in this paper is 0.9 s.

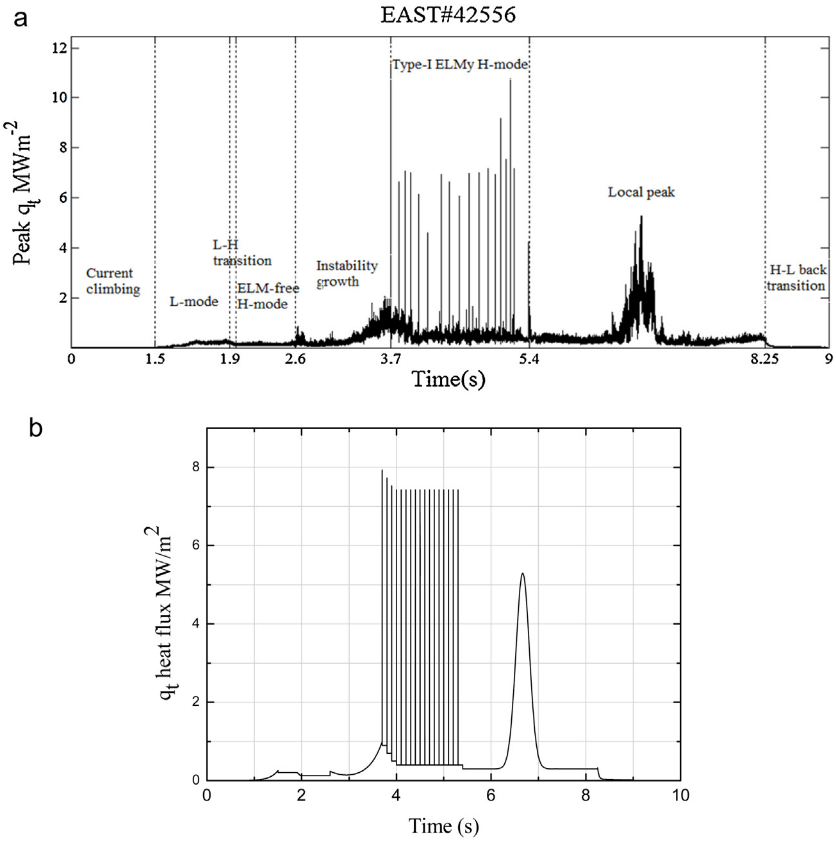

Fig. 2. (a) Temporal evolution of heat flux on lower outer divertor measured by Langmuir probes during #42556 shot. (b) The fitted curves according to the heat flux of EAST#42556 shot.