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Thermal and mechanical analysis of the EAST plasma facing components

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Abstract

The Experimental Advanced Superconducting Tokamak (EAST) is an advanced steady-state plasma physics experimental device, which has a long pulse (60–1000 s) capability, a flexible poloidal field system, auxiliary heating and current drive systems. Consequently, it will be able to accommodate divertor heat loads that make it an attractive test for the development of advanced tokamak operating modes. Now, the engineering designs for the EAST plasma facing component (PFC) are in progress. All the PFCs are made of copper alloy (CuCrZr) on which graphite tiles are mechanically attached. A layer of flexible graphite is placed between graphite tiles and copper alloy plate to ensure the better thermal transfer. The copper alloy are actively cooled by water flowing the cooling channel drilled by a special technology. This paper will introduce the thermal analysis including the mechanical behavior analysis for the plasma facing component using finite element method. Some candidate joint structure among the graphite tile, flexible graphite sheet and copper alloy are discussed in this paper.

Keywords: Tokamak design; Plasma facing component; Finite element analysis

1. Introduction

The Experimental Advanced Superconducting Tokamak (EAST) is an advanced steady-state plasma physics experimental device to be built in PR China. The plasma facing components (PFCs) are designed to protect the vacuum vessel, injection power system and diagnostic components from the plasma particles and heat loads. Thus, it must be designed to cope with particles and heat loads, in which the peak heat flux is 3.6 MW/m^2 in first phase of double null plasma operation. Now, all of the engineering designs for the EAST PFCs are in progress.

As shown in Fig. 1, the EAST PFCs consist of divertors, baffles, passive stabilizers and limiters. Each part has a plasma facing surface, which is affixed to a cooled support plate. One kind of multi-element doped graphite materials are chosen as materials for the tiles. Graphite tiles are bolted to the copper alloy (CuCrZr) cooling plate and retrained through the spring washers that allow limited deformation during thermal expansion. This mechanically restrained structure is used for all PFC system [1,2].

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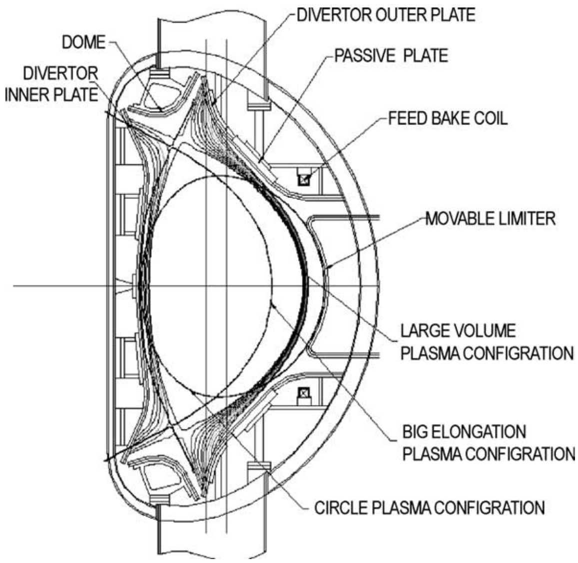

Fig. 1. Elevation view of EAST PFCs.

2. Working conditions for PFCs

The divertor was designed to provide the particle exhaust into the divertor cryo-pump, provide recycling control and impurity control. The baffle plates of the divertor will endure the maximum peak heat flux. Due to this reason all of the calculation including thermal and stress analysis were done for the divertor baffle plate system. EAST is designed to operate with shaped plasma cross-sections and in the double null (DN) or single null (SN) divertor configurations. Based on the physics design and experiment plan program EAST tokamak will operate in two phases: the first phase with a total injection power of 10 MW and the second phase with 20 MW. Tables 1 and 2 show the main parameters of EAST configuration and maximum peak heat fluxes on the divertor plate by numerical simulation [3].

Table 1
Major parameters of the EAST DN configuration

Major radius, R (m)	1.94
Minor radius, a (m)	0.47
Elongation at separatrix, κ_x	1.76
Upper triangularity at separatrix, δ_{ux}	0.56
Lower triangularity at separatrix, δ_{lx}	0.56
Plasma volume, V_P (m^3)	∼12.5
Connection length, L (m)	∼31

Table 2
Main results of the calculations for assessment of the operational flexibility

Divertor	P_{in} (MW)	$n_{e,sep}$ ($\times 10^{19}\,m^{-3}$)	$T_{e,div}$ (eV)	q_{div} (MW/m^2)
DN	1.5	0.31	85	1.0
	2.5	0.55	40	1.1
	5.0	0.98	22	2.0
	10.0	1.65	20	3.6
SN	1.5	0.37	100	2.0
	2.5	0.67	40	1.8
	5.0	1.16	26	3.0
	10.0	1.88	27	7.0

3. Design of PFCs structure

3.1. Design criteria

A number of criteria for the design of EAST plasma facing components must be respected [4].

(1) The PFCs must be designed in modules, which are easy to assemble and remove from the mid-plane port into the vacuum vessel. The modules should have enough flexibility to align the components with respect to the magnetic fields.
(2) The PFCs must be designed to withstand the peak heat flux 3.6 MW/m^2 due to the double null divertor plasma operation without any significant erosion or loss of integrity.
(3) Based on the research outlay, the chosen material of the plasma facing surfaces is the multi-element doped graphite by bolts and spring washers. However, the PFC design provides the flexibility to change the graphite tiles to other materials, such as beryllium or tungsten in the future according to the requirement of the plasma operation. During the first operation phase, the maximum temperature on the graphite tiles is to be kept lower than 850 °C during steady state plasma operation to reduce the physical sputtering, which is limited by the graphite material properties.
(4) The thermal stresses on the PFC are tentatively assessed as secondary stress in accordance with section III of American Society of Mechanical Engineers (ASME) code for the boiler and pressure vessel.