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Study of power load pattern on EAST divertor using PFCFlux code

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HIGHLIGHTS

- This paper demonstrates the modeling result of power load pattern on EAST graphite divertor by using the PFCFlux code.
- The grazing angle varies both poloidally and toroidally, changing by half a degree over the distance of 50 mm away from the strike point.
- The correlation between both grazing angle and flux expansion and the magnetic equilibrium parameters are found by using the linear regression method.
- The modeling result indicates that the edges of graphite tiles of EAST divertor are perfectly shadowed.

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ABSTRACT

The power load pattern on an EAST divertor component, spanning six tiles in the poloidal direction, has been studied with the PFCFlux code. A total of 49 different EAST plasma equilibria in lower single null configuration are used in the study. It is found that the incidence angle, or grazing angle, varies both toroidally and poloidally on the target, changing by approximately half a degree over a distance of 50 mm from the strike point. Strong correlations between the triangularity of the magnetic equilibrium and both the grazing angle and the flux expansion are found by using linear regression. A smaller value of triangularity gives wider plasma-wetted region on the target in lower-outer configuration, and a narrower plasma-wetted region in lower-inner configuration.

1. Introduction

The lifetime of plasma facing components (PFCs) in magnetic confinement fusion devices is a critical issue for future high performance steady-state operation, such as ITER (having design values: plasma current I_p = 15MA, toroidal magnetic field B_t = 5.3T, elongation κ = 1.7 and triangularity ε = 0.33) [1]. The patterns of power loading on divertors in current tokamaks are of great concern in terms of material failure and component damage [2]. The grazing angle, defined as the smaller, acute angle between the incident field line and the component surface, along with flux expansion, plays an important role in the determination of the power deposition onto PFCs. It is therefore of interest to investigate the correlation of both grazing angle and flux expansion with main plasma parameters, such as plasma current, toroidal field, triangularity and elongation, as these parameters are controllable during plasma operation.

The PFCFlux code [3] is used to predict heat fluxes onto the PFCs. This code, which includes shadowing effect and has a short calculation time, has proven useful for several design tasks [3,7,8]. In this paper, the PFCFlux modelling tool is employed to study the detailed characterisation of the power loading pattern on Experimental Advanced Superconducting Tokamak (EAST) divertor. A brief introduction to EAST divertor geometry and of the PFCFlux code is given in Section 2. Section 3 shows the results obtained of the power load study, followed by a summary in Section 4.

2. EAST divertor and PFCFlux code

2.1. EAST divertor

EAST, as a superconducting device aiming at long-pulse steady-state operation, started its first operation in 2006 [4] and achieved the record of longest pulse length (over 30 s) in high confine-

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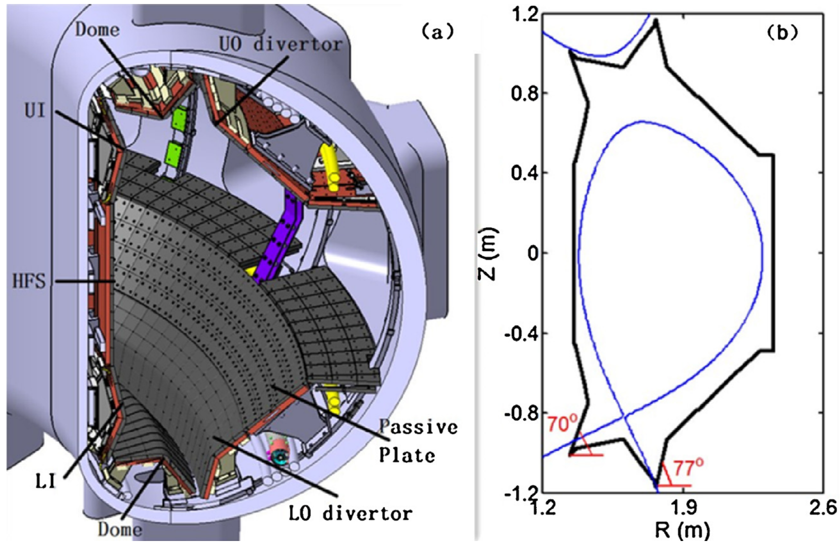

Fig. 1. (a) Picture of three-dimensional model of in-vessel components in EAST, including lower and upper divertor targets, dome structure, passive plates and high field side. (b) A typical lower single null magnetic equilibrium on EAST, where the blue solid line represents the last closed flux surface. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ment regime during the 2012 campaign [5]. The main machine parameters of EAST are: major radius $R = 1.7–1.9$ m, minor radius a = 0.4–0.45 m, toroidal field $B_t = 3.5$ T, plasma current $I_p = 1$MA, triangularity $\varepsilon = 0.4–0.7$ and elongation κ up to 1.9. Three different divertor configurations can be used: lower single null (LSN), upper single null (USN) and double null (DN), which gives EAST a broad operational space. A picture of the three-dimensional model of EAST PFCs is shown in Fig. 1(a), including upper outer (UO), upper inner (UI), lower outer (LO) and lower inner (LI) divertor targets, dome structure, passive plates and high field side (HFS). A typical LSN magnetic equilibrium is given in Fig. 1(b), with $I_p = 0.4$MA, $B_t = 1.8$T, $\varepsilon = 0.51$ and $\kappa = 1.6$. The last closed flux surface (LCFS), represented by the blue solid line, is obtained from the magnetic field reconstruction code EFIT, which provides the essential information relevant to magnetic equilibrium, e.g., triangularity, elongation and poloidal magnetic flux with a grid size of 129 × 129. The intersection points of the LCFS on divertor target plates, named strike points, are usually controlled near to the divertor corner in order to improve pumping efficiency.

EAST graphite divertor component consists of two vertical target plates and one dome structure, creating a 'W'-shape. Each target plate, e.g., LO, LI, UO and UI, has 16 sectors in the toroidal direction. There are 54 flat graphite tiles in a 9 × 6 array, bolted to CuCrZr heat sink with soft graphite interlayer [6], installed in one sector, as shown in Fig. 2. The angle between the tile surface of LO divertor target plates and the horizontal plane is 77°, while it is 70° for the LI divertor target plates. The power load limit for EAST actively water-cooled graphite divertor component is 2 MW/m^2 in steady-state operation [12]. In 2014, the upper graphite divertor was replaced by an ITER-like W-monoblock divertor, which is not indicated in Fig. 1(a).

2.2. PFCFlux code

The compatibility between high performance steady-state operation and safety of PFCs requires the development of a tool which could provide reliable power load prediction on these components. The Tokaflu code [3] was developed earlier to meet this requirement. In order to enhance its calculating capability, the PFCFlux code was completely redeveloped on a more modern platform, with the same physics models and algorithms. The powerful fea-

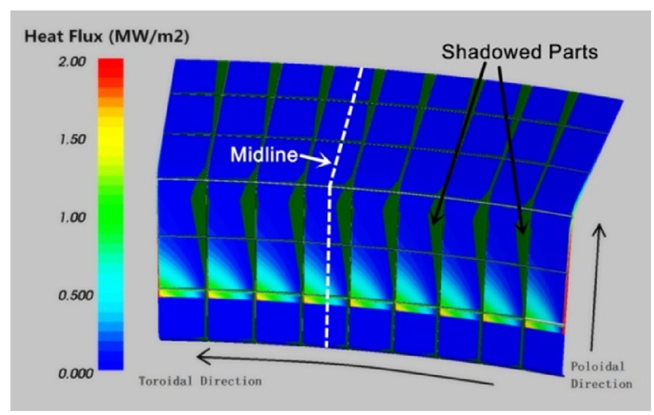

Fig. 2. Power load pattern on one sector of LO divertor targets as calculated by PFCFlux, for a standard LSN magnetic equilibrium with parameters of $I_p = 0.3$MA, $B_t = 1.85$T, $\varepsilon = 0.48$ and $\kappa = 1.6$. The input parameters are power loss $P_{sol} = 1$MW and power decay length $\lambda_q = 10$ mm.

ture of field line tracing enables the PFCFlux code to calculate heat fluxes onto PFCs within a short time period, taking into account the shadowing effect. The shadowing effect means that parts of target object are shielded by neighbouring surfaces when doing the field line tracing. The two essential inputs for the calculations are fine meshes of the 3D in-vessel components and a magnetic equilibrium file with standard format. In principle, the mesh size of 3D objects should not be larger than the power decay length λ_q. The magnetic equilibrium file, consisting of major radius R, vertical axis Z, poloidal magnetic flux ϕ, magnetic field in R and Z directions B_r/B_z, and toroidal magnetic field B_t is output by the aforementioned EFIT code. A classical exponential decay function, shown in Eq. (1), is introduced to describe the profile of parallel heat flux $q_{//}$at the outboard mid-plane (OMP) in the scrape-off layer (SOL). The equation reads

$$q_{//} = q_0 \exp(-(r - r_0)/\lambda_q), \quad (1)$$

where the r represents the major radius along the OMP, r_0 stands for the major radius of the LCFS at the OMP, q_0 accounts for the parallel heat flux at r_0. λ_q means the power decay length at the OMP. This definition comes from the empirical knowledge of power repartition in the SOL. In the PFCFlux code, the quantity λ_q is an