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Progress in the initial design activities for the European DEMO divertor: Subproject “Cassette”

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HIGHLIGHTS

- A brief overview on the European DEMO divertor cassette design studies is presented.
- Comprehensive computational assessment of multi-physical loads is reported.
- Constraints, impact and implications of predicted loading are explained.
- System performance and rationales of further design optimization are discussed.

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ABSTRACT

Since 2014 preconceptual design activities for European DEMO divertor have been conducted as an integrated, interdisciplinary R&D effort in the framework of EUROfusion Consortium. Consisting of two subproject areas, ‘Cassette’ and ‘Target’, this divertor project has the objective to deliver a holistic preconceptual design concept together with the key technological solutions to materialize the design. In this paper, a brief overview on the recent results from the subproject ‘Cassette’ is presented. In this subproject, the overall cassette system is engineered based on the load analysis and specification. The preliminary studies covered multi-physical analyses of neutronic, thermal, hydraulic, electromagnetic and structural loads. In this paper, focus is put on the neutronics, thermohydraulics and electromagnetic analysis.

1. Introduction

Since 2014 preconceptual design activities for developing the divertor of European DEMO reactor have been conducted in the framework of EUROfusion Consortium. The aim of the divertor project (WPDIV) is to deliver a holistic design concept together with the key technologies required for materializing the concept preparing the conceptual design phase. WPDIV is an integrated, interdisciplinary R&D effort where 6 research institutes and 3 university groups are involved.

WPDIV consists of two subproject areas: ‘Cassette design and integration’ (hereafter ‘Cassette’) and ‘Target development’ (‘Target’). In the subproject ‘Cassette’, the overall system of cassette body is engineered whereas in the subproject ‘Target’ advanced design concepts and key technologies for the plasma-facing components (PFCs) of the targets are developed [1,2].

This design study is based on the baseline CAD configuration model of the European DEMO plant issued in 2015 [3]. The envisaged fusion power is 2037 MW (net electric power: 500 MW). In

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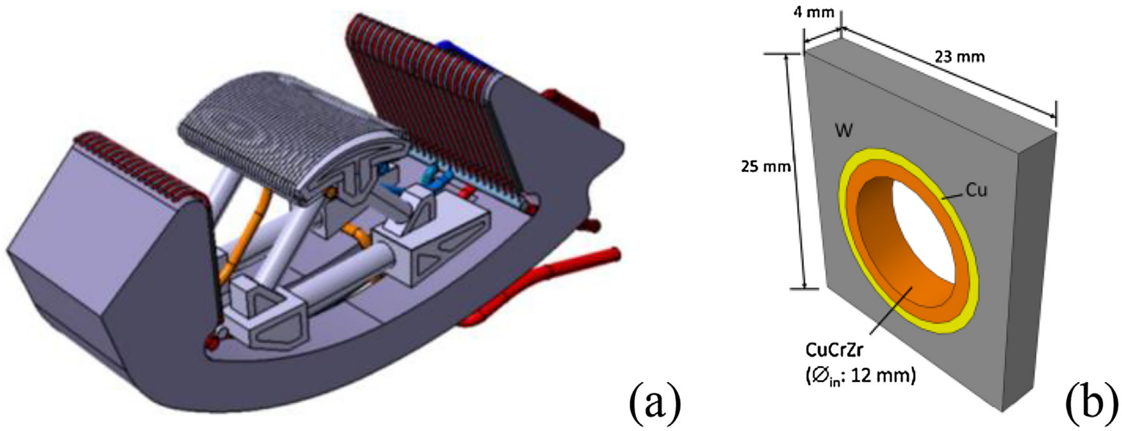

Fig. 1. (a) CAD model of the DEMO divertor cassette and (b) a target PFC mock-up with a schematic of the cross section [1].

this paper, recent results from the WPDIV activities are presented focusing on the subproject 'Cassette' (Fig. 1 [1]).

2. General technical information

In the European DEMO plant design, the divertor consists of 54 separable cassettes. For each set of three cassettes, a lower port is assigned for remote maintenance operation. The DEMO divertor has a reduced size compared to the ITER divertor [4].

In Fig. 2 the sectional geometry of the current cassette model (revised in 2016) is illustrated together with the dimensions. The cassette body has a poloidal extension of 3.02 m, height of 1.97 m and toroidal outer width of 1.04 m. The nominal gap size between two adjacent cassettes will be between 20 and 30 mm. The main body of cassette is made of Eurofer97, reduced activation ferritic martensitic steel. It is divided into chambers separated by stiffening ribs.

The in- and outboard vertical targets are protected by actively cooled PFCs covering the surface. The PFCs and main cassette body are cooled by separate cooling circuits to hold different coolant temperature for each. The primary option for coolant is water for the whole divertor whereas the feasibility of helium cooling is also explored as a low-priority option. The baseline design option for water-cooled PFCs is the ITER-type tungsten monoblock (with a reduced size) with CuCrZr cooling tube [4,5]. In addition, novel PFC design concepts are developed [2].

It is noted that the dome is still regarded as optional and its necessity is currently under extensive assessment.

3. Neutronic analysis

Based on the DEMO plant CAD model of 2015 (with helium-cooled pebble bed blanket), 3D neutronics analysis was carried out using the MCNP5 code and JEFF 3.2 nuclear data [6]. The calculations were normalized to the gross fusion power of 2037 MW which would correspond to a neutron production rate of 7.232×10^{20} n/s.

As the final decision is still open as to whether the dome shall be deployed or not, it was assumed that the entire surface of the cassette body to the plasma was covered with PFCs of the same kind to shield the whole cassette from particles and radiation. It is noted that this is a temporary option to avoid any unrealistic neutronic assessment in the absence of a dome. A consolidated shielding concept is currently devised which shall be employed in case dome is not adopted.

For the neutronics modelling of PFCs, it was assumed that the section of the PFC consisted of 3 homogenized layers where the outermost layers were tungsten and the middle layer was a mixture of tungsten (W: 34 vol.%), water (33 vol.%), CuCrZr (18 vol.%) and copper (Cu: 15 vol.%) representing the actual volume fraction of constituent materials in the PFC.

For the cassette body, water as well as helium was assumed as coolant, for which 3 different cases of materials mixture were considered as follows (volume percent):

1) H_2O-cooled: Eurofer (54%), H_2O (46%)
2) He-cooled: Eurofer (50%), He (50%)
3) He-cooled: Eurofer (30%), He (50%), B_4C (20%)

In the case 3, B_4C cladding was assumed for neutron shielding.

The chemical composition of Eurofer97 steel is given in Table 1. Only the major alloying elements and the impurities of high radiological impact are listed [7].

3.1. Neutron wall loading

The neutron wall load in the divertor exhibits high spatial variability due to the complex geometry. The maximum value amounts to 0.53 MW/m^2 at the upper surface of the cassette which is roughly one half of the maximum neutron wall load at the outboard equatorial first wall (1.33 MW/m^2).

3.2. Nuclear heating

Fig. 3 shows the spatial distributions of nuclear heating power density in Eurofer for the water-cooled (left) and the helium-cooled (right) cases, respectively. It shows that nuclear heating in Eurofer was concentrated near the surface of the cassette and decreased rapidly in the outward radial direction (nota bene: the color code scale is logarithmic). The volumetric heating power density ranged between 0.1 and 6 MW/m^3 for the water-cooled cassette body whereas it varied from 0.2 to 4 MW/m^3 for the helium-cooled case (0.1-3.5 MW/m^3 with B_4C shield).

Table 1
Chemical composition of Eurofer97 steel (wt.%) [7].

Fe	Cr	W	Mn	V	Ta	C	Ni	Mo	Ti	Nb	Al	B	Co
base	9	1.1	0.4	0.2	0.12	0.11	0.01	0.005	0.02	0.005	0.01	0.002	0.01

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