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Current status of He-cooled divertor development for DEMO

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ABSTRACT

A He-cooled divertor concept for DEMO is being investigated at the Forschungszentrum Karlsruhe within the framework of the EU power plant conceptual study. The design goal is to resist a heat flux of 10 MW/m^2 at least. The major R&D areas are design, analyses, fabrication technology, and experimental design verification. A modular design is preferred for thermal stress reduction. The HEMJ (He-cooled modular divertor with multiple-jet cooling) was chosen as reference concept. It employs small tiles made of tungsten, which are brazed to a thimble made of tungsten alloy W-1%La_2O_3. The W finger units are connected to the main structure of ODS Eurofer steel by means of a copper casting with mechanical interlock. The divertor modules are cooled by helium jets (10 MPa, 600 °C) impinging onto the heated inner surface of the thimble.

In cooperation with the Efremov Institute a combined helium loop & electron beam facility (60 kW, 27 keV) was built in St. Petersburg, Russia, for experimental verification of the design. It enables mock-up testing at a nominal helium inlet temperature of 600 °C, an internal pressure of 10 MPa, and a pressure difference in the mock-up of up to 0.5 MPa. Technological studies were performed on manufacturing of the W finger mock-ups. Several high heat flux tests were successfully performed till now. Post-examination and characterisation of the mock-ups subjected to the high heat flux tests were performed in collaboration with Forschungszentrum Jülich. Altogether, the test results confirm the divertor performance required. The helium-cooled divertor concept was demonstrated to be feasible. The knowledge gained from these experiments and some aspects on the design improvement are discussed in this contribution.

1. Introduction

Since several years FZK has been developing a helium-cooled divertor [1] able to withstand an extremely high heat flux (HHF) of at least 10 MW/m^2 [2] expected in DEMO. The reference jet concept uses small W finger modules favorable for stress reduction. It relies on impingement cooling with high-pressure helium jets (10 MPa, 600 °C). Subsequent R&D activites towards DEMO comprise, among others, development and tests of 1-finger and 9-finger cooling finger modules (Fig. 1) which build up bigger parts, e.g. target plates. For experimental verification of the design, a combined helium loop & electron beam facility (60 kW, 27 keV) (Fig. 2) [3] suitable for HHF tests was built at the Efremov Institute, St. Petersburg, Russia. Technological studies on manufacturing of the W finger mock-ups (MUs) [4] were performed.

Two experiment series for 1-finger modules were successfully performed in 2006 [1,5] and 2007 [6]. The results of HHF tests till now confirmed the divertor design performance. Nevertheless, based on the knowledge gained from experiments, still iterative improvement on manufacturing and design is being done in order to ensure the reliable and faultless function of the divertor cooling fingers. In the following, manufacturing and HHF tests of third 1-finger test series as well as manufacturing and thermohydraulic tests of a 9-finger module shall be reported.

2. The reference design HEMJ

The HEMJ design (Fig. 1) employs small tiles made of tungsten, which are brazed to a thimble made of tungsten alloy W-1%La_2O_3. The W finger units are connected to the main structure of ODS Eurofer steel by means of a copper casting with mechanical interlock. The divertor modules are cooled by helium jets (10 MPa, 600 °C) impinging onto the heated surface of the thimble. The design and preparation of HHF experiments including technological study on mock-up fabrication (Fig. 3) are described in detail in [1].

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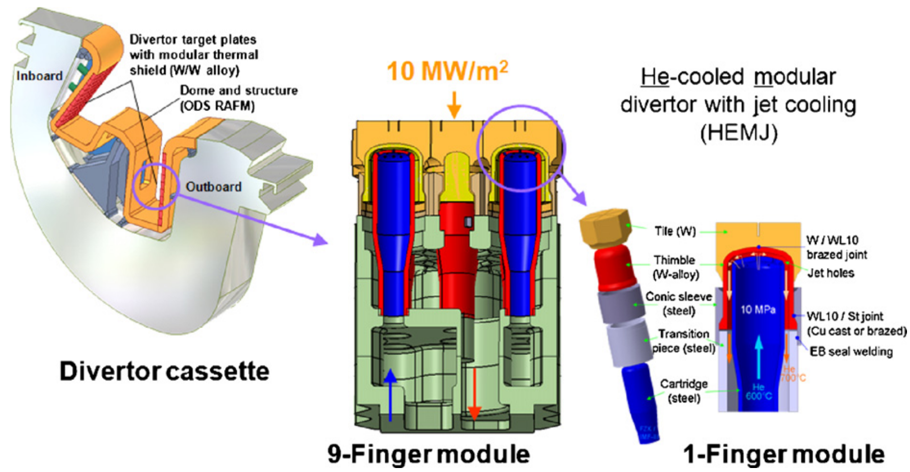


Fig. 1. The He-cooled modular divertor design HEMJ.

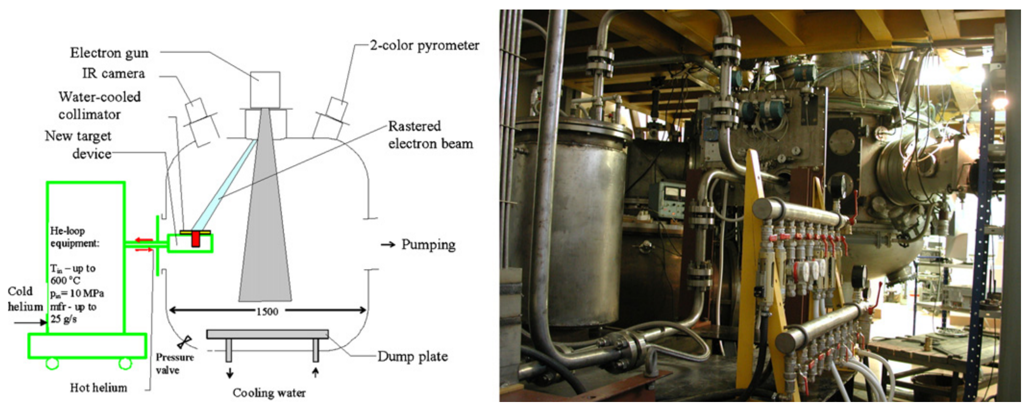
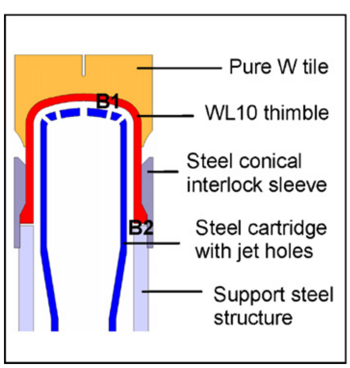


Fig. 2. The combined helium loop and TSEFEY testing facility at Efremov.



Materials	
W tile	▪ Plansee W grade (MUs #21-22) ▪ Russian W grade (remaining MUs)
W thimble	Plansee WL10 (W–1%La_2O_3)
Support structure	Eurofer
Joining methods	
W/W (B1)	Brazing with - nickel-based filler metal STEMET 1311®, T_{br} = 1050°C - CuNi44, T_{br} = 1300°C
W/Steel (B2)	Conical lock brazed with cobalt-based filler metal 71KHCP; T_{br} = 1050°C

Fig. 3. Definition of the tungsten modules fabrication for HHF tests.

3. Retrospect of the first and second high heat flux experiment series (2006–2007)

The first HHF test series [1,5] performed in 2006 contained six mock-ups (five of HEMJ and one of Slot types). Four additional HEMJ mock-ups were fabricated but they were not testable because cracking occurred in the tiles of all four mock-ups during the brazing of the W tiles with the thimbles. The temperature cyclic loading was simulated by means of switching periodically the beam on and off (variations 30 s/60 s, 30 s/30 s, and 60 s/60 s). The mock-ups were tested within a HHF range of 5–13 MW/m^2. The helium cooling parameters are 10 MPa inlet pressure, ~500–600 °C inlet temperature and the mass flow rate (mfr) varied in a range of ~5–15 g/s.

Already in this first test series the results confirmed that the required divertor performance of 10 MW/m^2 can be achieved by helium jet cooling. However, the results of destructive post-examinations also revealed some critical points relating to high thermal stresses and manufacturing quality. In detail, W parts of these mock-ups and the thimble contain pre-existing defect, presumably micro-cracks [7] initiated during the fabrication processes. Nevertheless, sudden destruction and/or completely broken mock-ups, i.e. no brittle failure were not observed. No recrystallisation of W thimble was observed in any mock-up. The measured pressure