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FUSION-8401; No. of Pages 5
ARTICLE IN PRESS
Fusion Engineering and Design xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
Fusion Engineering and Design
journal homepage: www.elsevier.com/locate/fusengdes

Conceptual design of a First Wall mock-up experiment in preparation for the qualification of breeding blanket technologies in the Helium Loop Karlsruhe (HELOKA) facility

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HIGHLIGHTS

- Experiment in preparation for the qualification of Breeding Blanket technologies in HELOKA facility is proposed.
- Experimental capabilities, instrumentation of the mock-up and experimental program are presented.
- Design and manufacturing of the mock-up is described.
- Design of modular attachment system to obtain different stress levels and distributions on the mock-up is discussed.

ARTICLE INFO

Article history:
Received 31 August 2015
Received in revised form 8 December 2015
Accepted 13 December 2015
Available online xxx

Keywords:
Breeding blanket
High heat flux
Qualification
HELOKA

ABSTRACT

An experimental program based on a First Wall mock-up is presented as preparation for the qualification of breeding blanket mock-ups at high heat flux in the Helium Loop Karlsruhe (HELOKA) facility. Two objectives of the experimental program have been defined: testing of the experimental setup and a first validation of FE models. The design and manufacturing of mock-up representing about 1/3 of the heated zone of an ITER Test Blanket Module (TBM) First Wall is discussed. A modular attachment system concept has been developed for the fixation of the mock-up in order to be able to generate different stress distributions and levels on the plate, which is confirmed by thermo-mechanical analyses. The HELOKA facility is able to provide a TBM relevant helium cooling system and to generate the required surface heat flux by an electron beam gun. An installed IR camera can be used to measure the temperature distribution on the surface.

1. Introduction

The current designs of the European helium cooled breeding blanket concepts for the Test Blanket Module (TBM) program in ITER as well as for the installation in DEMO consist of complex box architectures with a high pressure zone for the coolant and a low pressure zone for the tritium breeder. The box design is characterized by a high number of cooled subcomponents with integrated cooling channels. The supply of the coolant is realized by a multi-stage distributor and collector system. The integral analysis of this complex structure is beyond the capabilities of present numerical simulation and the used models are still under development [1]. For instance, this applies in the case of the EU Helium Cooled Pebble Bed (HCPB) concept for the thermo-mechanical behavior of the pebble beds as well as the thermal properties of the bonding of the first wall coating under cyclic loading.

Consequently, the qualification of such a component based on numerical analyses can be difficult if too conservative assumptions have to be made. At the Karlsruhe Institute of Technology (KIT) an experimental program with mock-ups of different sizes is foreseen in the Helium Loop Karlsruhe (HELOKA) facility [2,3] to support the development of the implemented models. Since the HELOKA facility is able to provide ITER relevant operating conditions, it also qualifies the facility for the application for the design validation by the design-by-experiments method as covered for plasma facing components by the Structural Design Criteria for In-vessel Components (SDC-IC) code [4].

As a first step in preparation toward the experimental program in HELOKA, a First Wall Mock-up (FWM) is planned to be tested in the facility. The FWM, whose design and manufacturing is

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http://dx.doi.org/10.1016/j.fusengdes.2015.12.031
0920-3796/© 2016 Published by Elsevier B.V.

Table 1
Operational range of HELOKA.

Parameter	Range
Pressure	4–9.2 MPa
Temperature	70–500 °C
Flow rate	0.4–1.4 kg/s

discussed in Section 3, represents about 1/3 of the heated zone of the TBM First Wall. Two main objectives for this preparation step have been defined: (a) testing of instrumentation, data acquisition and components of the experimental setup; (b) validation of FE models used in the analysis of the breeding blanket concepts.

Part of the first objective is the development and testing of an instrumentation concept that would allow the measurement of temperatures and strains on the mock-up. This includes the selection of sensor technologies as well as finding a suitable installation concept. In addition, the capability to generate the required heat flux pattern by the installed electron beam gun as well as the overall performance of the experimental setup under a high number of cycles has to be demonstrated.

The second objective comprises the validation of thermo-hydraulic and thermo-mechanical models for specific thermal and mechanical boundary conditions. While the thermal boundary conditions can be adjusted during the testing, for example, by regulating the mass flow of the coolant or changing the settings or the scanning pattern of the electron beam gun, the mechanical boundary conditions remain fixed and are strongly depending on the attachment of the mock-up to the supporting structure. In Section 4, a modular attachment system for the FWM that is able to represent two different types of fixation is introduced and discussed.

2. Testing in HELOKA facility

The experiments will be performed in the HELOKA facility, which is able to provide ITER relevant helium cooling conditions and representative surface heat fluxes. The experimental capabilities of HELOKA and the instrumentation of the FWM are described in Sections 2.1 and 2.2, respectively. The testing program is discussed in Section 2.3.

2.1. Experimental capabilities of HELOKA

The operational range of the experimental loop is listed in Table 1. The experimental loop can be connected to two test sections, each one consisting of a 30 m^3 vacuum chamber that is able to accommodate a full-size TBM. The associated vacuum systems can generate and maintain a vacuum level of 10^{-5} mbar inside the chambers.

One of the vacuum chambers is equipped with an electron beam gun that has a maximum installed power of 800 kW and is capable to generate a TBM relevant surface heat flux of 0.5 MW on a surface of approx. 0.8 m^2 by guiding the beam in an appropriate pattern. The other test section uses infrared (IR) radiation heaters that can generate similar surface heating conditions [5]. While the capabilities of such a solution have been demonstrated in a separate experiment, the limited life time of the heaters has determined the selection of the EB gun test section as the first option for the FWM experiment.

In order to calibrate the electron beam gun and set-up an appropriate scanning pattern to produce a homogenous heat flux with a TBM relevant peak heat flux, a water-cooled dummy target with the dimensions of the TBM First Wall is installed in HELOKA (see Fig. 1). The target is made of steel P92 (1.4901), the same material used for the FWM.

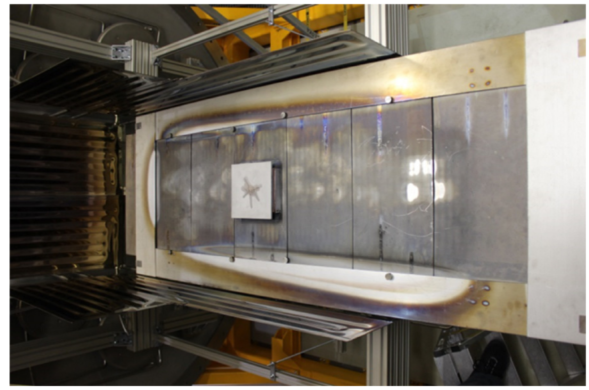

Fig. 1. Experimental setup with water-cooled target.

The initial testing has indicated that, at high power levels, the footprint of the scanning pattern has the tendency to rotate by a certain angle as it can be seen in Fig. 1. Currently studies for quantifying and compensating this effect are ongoing. In addition to that, the installation of an infrared camera (X6580sc from FLIR) is performed. This camera has an IR resolution of 640 × 512 with a maximum image frequency of 355 Hz for the full frame. However, the accuracy of the temperature measurements of the IR camera depends on the precise knowledge of the emissivity of FWM plate as well as the influence of reflections inside the vacuum chamber. For this reason, a dedicated calibration step is foreseen making use of the water-cooled dummy. For this purpose, thermocouples will be installed on the surface of the dummy to measure the temperatures at different power levels.

2.2. Instrumentation of the FWM

The physical quantities, which need to be measured on the FWM to validate the models and the results obtained by the FE analyses, are temperature and strain. Given the operating conditions of the TBM the sensors mounted on the mock-up will have to withstand high temperatures up to 500 °C and the energy deposition by the electron beam on the top side has to be considered.

In the case of wall surface temperature the infrared camera will be used. The camera is installed outside the vacuum chamber and looks at the top side of the mock-up via a mirrors system, which will be tested and qualified when the camera is calibrated. For other temperature measurements, thermocouples will be used.

Although a number of electrical resistance strain gauges are available that are able to work within the required temperature range, the lower thermal conductivity of the bonding material or the small contact area in case of spot welding has to be carefully considered when placing the strain gauges on the heated surface. In order to avoid this issue, only a placement of strain gauges on the top side outside the heated zone as well as on the lateral faces is foreseen.

2.3. Experimental program

Two objectives of the experimental program have been defined in Section 1: testing of the experimental setup and validation of FE models. During the experimental program, two types of fixation for the FWM are foreseen: one fixation that allows an almost free deformation of the plate (F1) and one fixation that strongly limits the deformation normal to the surface receiving the heat load (F2). Hence, F1 enables to vary the surface heat flux in a wide range, whereas a high stress level and a different stress distribution on the plate can be achieved with F2.

Please cite this article in press as: C. Zeile, et al., Conceptual design of a First Wall mock-up experiment in preparation for the qualification of breeding blanket technologies in the Helium Loop Karlsruhe (HELOKA) facility, Fusion Eng. Des. (2015), http://dx.doi.org/10.1016/j.fusengdes.2015.12.031