INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 7053–7058

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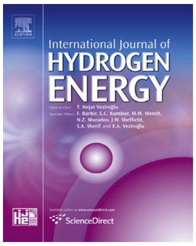

Preliminary structural analysis of the new HCPB blanket for EU DEMO reactor

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ARTICLE INFO

Article history:
Received 1 October 2015
Received in revised form
13 January 2016
Accepted 14 January 2016
Available online 24 February 2016

Keywords:
Nuclear fusion energy
DEMO reactor
Solid breeder blanket
RCC-MR
SDC-IC
Structural analyses

ABSTRACT

Currently the HCPB blanket concept is one of the four breeding blankets concepts under development for the European DEMO. This work reports on the results of an investigation of the thermal and structural performances of a new design of this blanket, proposed in 2015 by the KIT HCPB Team aimed at establishing a baseline design of the HCPB breeding blanket following the updated EU DEMO plant specifications. The thermal analyses have been reported in another paper, while the structural analyses are presented and discussed in this paper. A 3D slice model of the DEMO HCPB blanket has been set up to run thermo-mechanical analyses of the blanket under steady state and DEMO transient pulsed conditions. The analyses for the blanket have been assessed with respect to the structural design criteria and standards (mainly RCC-MR, completed by SDC-IC). The results identify some problematic regions in the design, concentrated in the connection regions of the cooling plates with the blanket back supporting structure. For monotonic damage modes, the blanket structure shows a global satisfying behavior in immediate plastic collapse and plastic instability damage modes, and thermal creep damage mode. While it fails to fulfill the criteria to prevent immediate plastic flow localization damage mode in some regions. Counter-actions to improve the design have been proposed and will be implemented in future design revisions. Considering the cyclic loadings, the FW shows a satisfying behavior against ratcheting and fatigue damage modes during plasma ramp-up and ramp-down phases.

Introduction

Breeding blanket having the main functions of tritium self-sufficiency and electricity production is a key component in a fusion reactor [1]. Solid breeder blanket concepts have been studied in KIT (formerly called KfK and FZK) since the 1980s [2–5]. This kind of solid breeder blanket concept has later evolved to the so called Helium Cooled Pebble Bed (HCPB) blanket, been chosen as one of the European blanket concepts

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http://dx.doi.org/10.1016/j.ijhydene.2016.01.064

to be tested in ITER and to be developed for European DEMO [6–10]. The present work has been focused on performing thermo-mechanical analyses aimed at consolidating the present knowledge on the performance of a new design proposed by the KIT HCPB Team in 2015; the results will be used, among other studies, to establish a baseline design of the EU DEMO HCPB breeding blanket following the EUROfusion DEMO plant specifications [10]. The present thermo-mechanical analyses are based on stationary and transient thermal analyses that have been reported separately in another paper [11]. From these analyses critical points in the time have been identified in which the stresses are higher, and for each of these time points a complete thermo-mechanical assessment has been conducted. The results have been assessed with respect to the design codes (mainly RCC-MR [12], completed by SDC-IC [13]).

Description of the blanket

The blanket uses lithium orthosilicate (Li_4SiO_4) pebbles as tritium breeder, beryllium (Be) pebbles as neutron multiplier, 8 MPa helium gas with a temperature of 300–500 °C as coolant, EUROFER as structural material, helium (+0.1% vol. H_2) with a pressure of about 0.2 MPa as purge gas, and tungsten as FW armor material. The blanket is designed as a “sandwich” arrangement of flat cooling plates and alternating Li_4SiO_4 and Be pebble beds (see Fig. 1). More details on the current HCPB design version have been reported in Ref. [10]. The 3D slice model for structural analyses is derived from the thermal ANSYS model used in Ref. [11]; this allows a direct import of the thermal field calculated in the thermal analyses. As only the behavior of the steel box is of interest in this investigation, Li_4SiO_4 and beryllium pebble beds are not included in this analysis; previous investigation have already shown their negligible impact on the overall stress of the box for the load considered in section 3.1. Also the tungsten armor was excluded from the structural model assuming that design features are implemented (e.g. castellation) to reduce its influence on the box stresses.

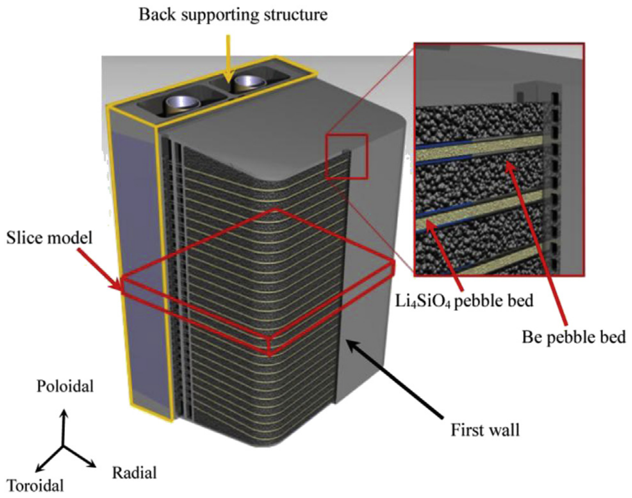

Fig. 1 – The equatorial outboard blanket module.

Numerical models

The FEM mesh used for the structural analysis has been generated with the midside nodes kept in ANSYS Workbench 16.0, taking advantage of the symmetry of the design in order to save meshing and computation time. The mesh has a total of 855,688 elements and 4,208,964 nodes. The 3D slice model is shown in Fig. 2.

Loads

The blanket will have to withstand (among others) thermal and mechanical loadings during normal operation. In this condition thermal loadings are due to two main sources: the radiation from plasma that is applied as a surface heat flux on first wall and the volumetric nuclear heating caused by neutron deposited on the blanket materials. The mechanical loadings are due to the coolant helium pressure in the cooling channels and purge gas pressure in the purge gas loop. During DEMO pulsed operation, the thermal loadings will follow the plasma pulse evolution (as described in Ref. [11]) while the mechanical loadings will remain constant. Electromagnetic forces produced due to the interaction between the magnetic materials and the external magnetic field is still under study at KIT and therefore has not been included in the present paper.

The loadings considered here are listed as follows:

- Internal pressure in all cooling channels and in the manifold equal to 8 MPa, corresponding to the operating pressure of the helium coolant loop
- Internal pressure on all surfaces in contact with the purge gas equal to 0.2 MPa, corresponding to the operating pressure of the purge gas loop
- Temperature field imported by thermal analyses performed in Ref. [11].

Sub-components maximum temperature evolutions following DEMO pulse is shown in Fig. 3. Three time instants have been chosen as critical for the following stress analyses; the three time instants have been selected as follows:

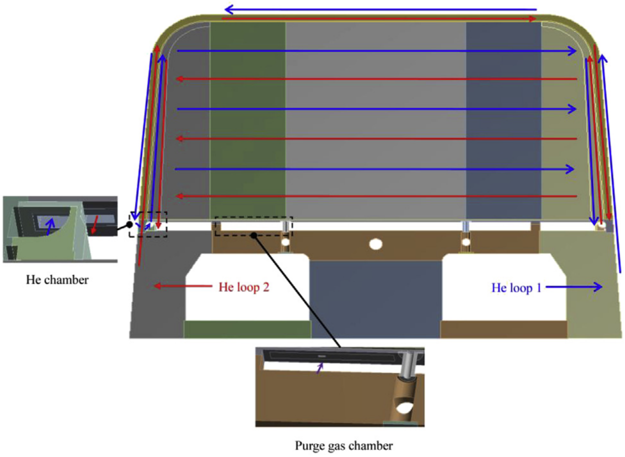

Fig. 2 – The 3D slice model.