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Thermo-mechanical analysis on the full module of water cooled ceramic breeder blanket for CFETR

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ABSTRACT

As one of blanket candidates for Chinese Fusion Engineering Test Reactor (CFETR), the concept design of the Water Cooled Ceramic Breeder (WCCB) blanket is being carried out and the analyses of the neutronics and thermal hydraulics have been finished. To investigate the thermo-mechanical behavior of the current WCCB blanket design version under normal operation and accidental operation scenarios (e.g. in-box loss of coolant accident (LOCA)), the finite element thermo-mechanical analyses of a full blanket module were performed by using ANSYS Multiphysics code. The stress results were assessed referring to ITER SDC-IC code. Under normal operation scenario, the blanket shows a satisfying mechanical behavior withstanding 15.5 MPa coolant pressure on its cooling channel walls and thermal deformations. However, under in-box LOCA scenario, the blanket fails to withstand 15.5 MPa coolant pressure on its internal walls at normal operation thermal level. In this situation, the relief valve is proposed as a mitigation measure to release coolant pressure to maintain the structural integrity of blanket box under in-box LOCA accident.

1. Introduction

As one of Chinese Fusion Engineering Test Reactor (CFETR) breeding blanket candidates, the Water Cooled Ceramic Breeder blanket (WCCB) concept [1] is being developed in Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP). The analyses of the neutronics and the thermal hydraulics have been accomplished [2,3]. The results show the present structural design of WCCB blanket can meet the tritium breeding and thermal hydraulic requirements. In order to investigate the thermo-mechanical performances of WCCB blanket, the thermo-mechanical analyses on full blanket module under normal operation scenario and accidental operation scenario have been conducted. In order to avoid errors caused by inappropriate boundary conditions and assumptions in simulations with partial blanket model (e.g., slice model), a three-dimensional finite element (FE) model of full blanket module is developed using ANSYS Multiphysics code. The W/steel functionally graded (FG) interlayer [4,5] located at the tungsten/first wall (W/FW) interface has been considered in this FEM model. The purpose is to achieve graded transition and reduce thermal stress caused by the large difference of thermal mechanical properties between tungsten and reduced activation ferritic/martensitic (RAFM) steel. The thermo-mechanical analyses under normal operation and accidental operation scenarios (e.g. in-box loss of coolant accident (LOCA)) have been analyzed, respectively. The stresses on blanket structure were assessed referring to the available design criteria SDC-IC [6]. The results obtained and discussions are presented in this paper.

2. Description of the WCCB blanket module

In the WCCB blanket conceptual design, RAFM steel (e.g., CLF-1 [7], CLAM [8]) is employed as structural material. Tungsten armor acts as a plasma facing component to protect the FW from plasma thermal exposure, corrosion and erosion. Mixed pebble beds of Li_2TiO_3 and $Be_{12}Ti$ function as the tritium breeder and primary neutron multiplier, respectively. In addition, two thin layers of beryllium pebble bed are adopted as additional neutron multiplier to improve the neutronics performance.

The typical WCCB blanket consists of a U-shaped first wall (FW), a tungsten armor, several cooling plates (CPs), stiffening plates (SPs), side walls (SWs) and manifolds (MFs), and a back plate (BP). The layout of the WCCB blanket employs the layered breeder outside the tube (BOT) design concept. The pebble bed is separated into 16 sub-modules by the parallel-arranged FW/CPs placed along poloidal-toroidal planes and the parallel-arranged SWs/SPs placed along poloidal-radial planes. In case of a LOCA, three SPs are employed to reinforce the blanket box to guarantee the structural integrity against the over pressurization. Fig. 1 shows the structure of the equatorial outboard WCCB blanket.

As the water cooling system is widely and maturely applied in the

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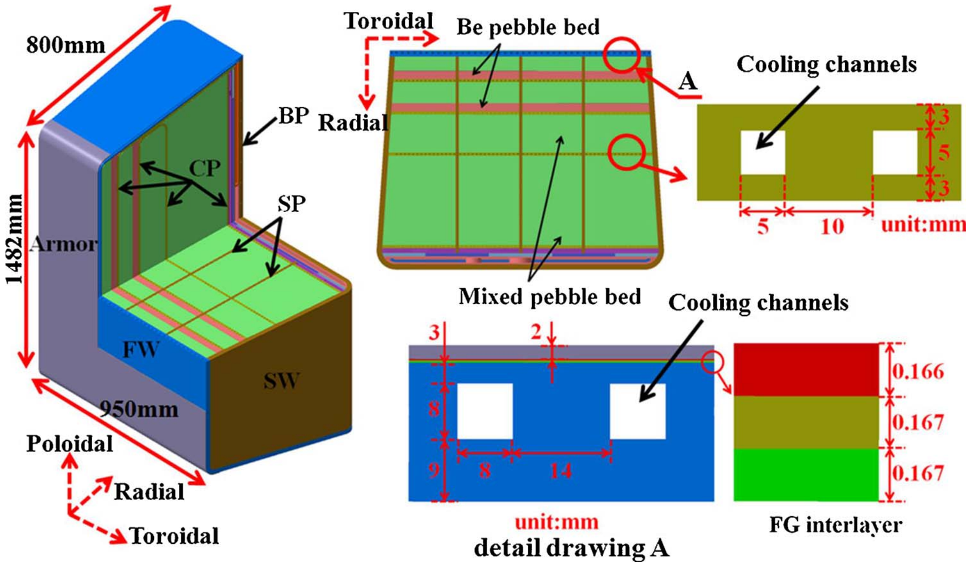

Fig. 1. The equatorial outboard WCCB blanket.

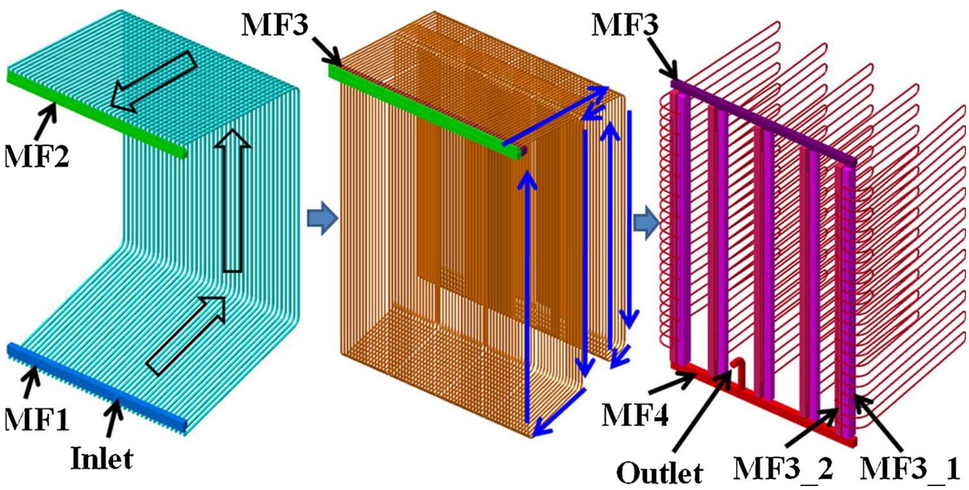

Fig. 2. Coolant manifold of WCCB blanket.

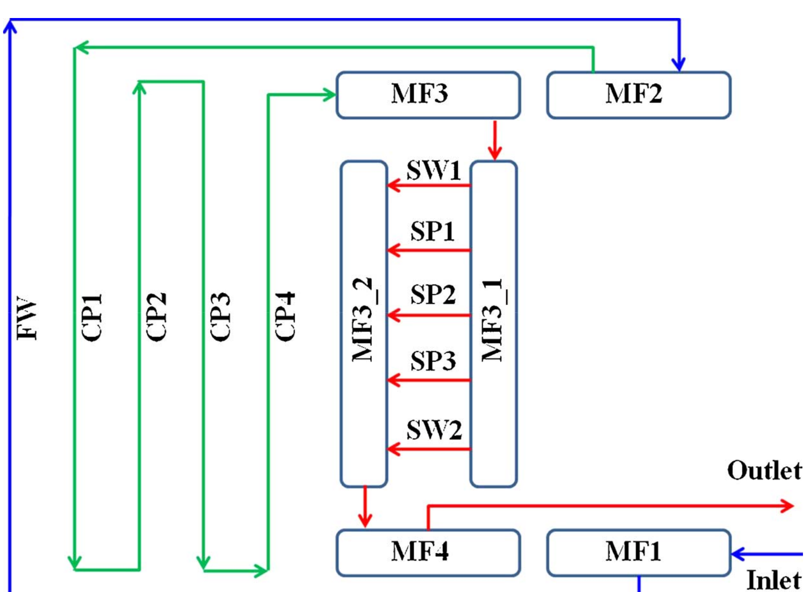

Fig. 3. Cooling scheme of WCCB blanket.