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Progress on solid breeder TBM at SWIP

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ABSTRACT

Current progress on the design and R&D of Chinese helium-cooled solid breeder test blanket module, CN HCSB TBM is presented. The updated design on structural, neutronics, thermal-hydraulics and safety analysis has been completed. In order to accommodate the HCSB TBM ancillary system, the design and necessary R&Ds corresponding sub-systems have being developed. Current status on the development of function materials, structure material and the helium test loop are also presented. The Chinese low-activation ferritic/martensitic steels CLF-1, which is the structural material for the HCSB TBM is being manufactured by industry. The neutron multiplier Be and tritium breeder Li_4SiO_4 pebbles are being prepared in laboratory scale.

1. Introduction

ITER will be used to test tritium breeding module concepts, which will lead to the design of DEMO fusion reactor design demonstrating tritium self-sufficiency and the extraction of high grade heat for electricity production. The helium-cooled/solid tritium breeder (HCSB) with the pebble bed concept was selected as Chinese test blanket module (TBM) design. Dimensions of HCSB TBM occupying half of the ITER test port is shown in Fig. 1. Previous configuration of the HCSB TBM with the 3×6 modularized sub-module (SM) arrangement has been replaced by the 2×6 modularized SM arrangement [1]. The new configuration will better satisfy the ITER TBM design requirements [2]. Corresponding design optimization on structural, neutronics, and detailed performance analyses has been performed. Furthermore, in order to reduce the impacts of the RAFM steel material impact on the magnetic field ripple, the last design has been modified to minimize the mass of RAFM steel.

Updated structure design based on originally design that is shown in Figs. 1 and 2 has been performed. Progress on module configuration, analysis on structure, neutronics, thermal hydraulic, thermal mechanical, EM assessment on induced field ripple are presented. Necessary R&Ds on the low-activated CLF-1 steel, neutron multiplier Be pebbles, and the tritium breeding materials Li_4SiO_4 pebbles are moving towards industrial production level.

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2. Modification design

Main design modification of HCSB TBM is focused on the structure and configuration of breeding zone of the sub-module. In the former design, the backside of the blanket module is the back-plate forming the flow plenum and distributors. The stiffening grid plate is welded into the box; and each grid plate is cooled by helium flowing with internal channels that are fed from the back. Breeding sub-modules (shown in Fig. 2) are separated by the grid plates. Each sub-module has its own independent cooling and tritium purge gas circuits. Tritium breeder and neutron multiplier are separated by the cooling channel of the sub-module.

The structure design of the sub-module has been modified based on the neutronics results from a 3-D MCNP global model. The modified configuration of the HCSB TBM is shown in Fig. 3a. Main modifications of new modular design include: (1) The TBM is composed of two materials; RAFM steel is used for the FW, caps, grid and sub-modules section, and 316 stainless steel is used for the back-plate and support-plate. (2) The total radial length of the TBM is retained at 670 mm, but the radial dimension of the U-shape FW and breeder sub-modules were decreased to 350 mm and 320 mm, respectively. Subsequently, the total mass of the RAFM steel in TBM is reduced to 720 kg. The explored view of the TBM module is shown in Fig. 3b. (3) The width of the CP is decreased by 5 mm while keeping the area of the cross-section of the helium gas channel. (4) Arrangement of pebble beds in sub-module is changed from the former transverse direction to the current vertical direction, which has the advantages of simplifying the helium cooling loop, improving the neutronics performance. The corresponding RAFM steel of the sub-module is reduced. Schematic of the sub-module is shown

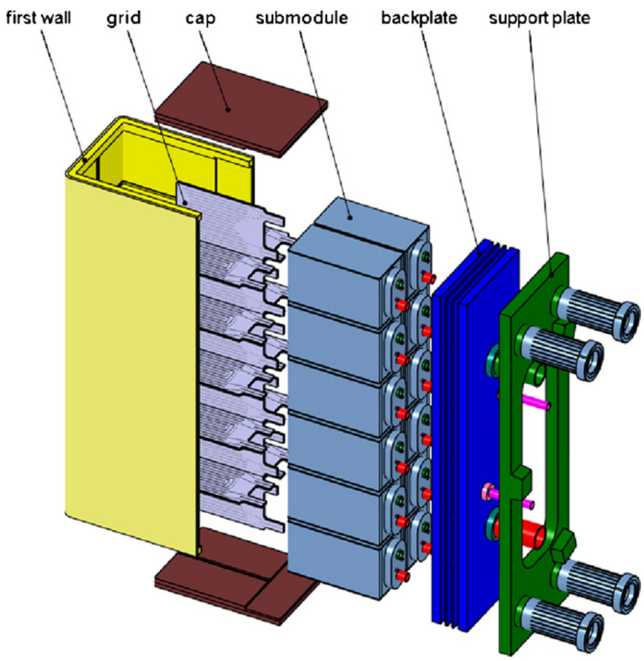

Fig. 1. Schematic view of the HCSB TBM.

Table 1
Main parameters of HCSB TBM.

Neutron wall loading (MW/m^2)	0.78
Max. surface heat flux (MWm^2)	0.50
Tritium production rate (g/day)	0.0707
Max. power density, (MW/m^3)	10.64
Tritium breeder	Lithium orthosilicate, Li_4SiO_4
Form	Diameter (D) = 1.0 mm, pebble bed
^{6}Li enrichment, %	80
Peak temperature (°C)	703
Neutron multiplier	Beryllium
Form	Binary, diameter (D) = 0.5–1.0 mm, pebble bed
Peak temperature (°C)	516
Coolant	Helium (He)
Pressure (MPa)	8
T_{in}/T_{out} (°C)	300/500
Pressure drop (Δp)	0.12
Structural material	LAFM(CLF-1)
Max. temperature (°C)	516

in Fig. 3c. Main parameters of the modified HCSB TBM design are listed in Table 1.

Presently, the modified HCSB TBM has the FW coolant flow routed in the poloidal direction, as shown in Fig. 3a and b. Every 3 poloidal coolant channels are to form a cooling loop, with a total of 9 loops cooling the FW. Moreover, the modified sub-module has three breeder and multiplier zones. The cross-section of the sub-module is shown in Fig. 3c.

At the TBM's back-plate there are two helium systems, the Helium Coolant Manifold System (HCMS) and the Purge Gas Manifolds System (PGMS). The structure of the back-plate was shown in Fig. 4. The larger pipes are helium inlet, outlet and bypass. Their diameters are 85.5 mm inside and 101.6 mm outside, the smaller pipe diameters are 30 mm inside and 35 mm outside are for purge gas inlet and outlet flows. The coolant inlet pipe is attached to outside plate, and the remaining pipes are attached to closure plates. Ribs are used to connect the outside plate, middle plate and the inside plate in back-plate. These also plates form the coolant manifolds. Between the outside plate and inside plate, there are 2 middle plates. Conducting pipes are set between two middle plates. The temperature distribution of back-plate is shown in Fig. 5.

3. Performance analyses

3.1. Thermal mechanical

Neutronics results based on 3-D MCNP model were generated for the optimized design are shown in Table 2. It was shown that the neutronics performance of modified module design is obviously improved comparison with former design. These results were used as basic input parameters for the of HCSB TBM analysis. Fig. 5 shows results of the thermal and mechanical analysis for the middle plate

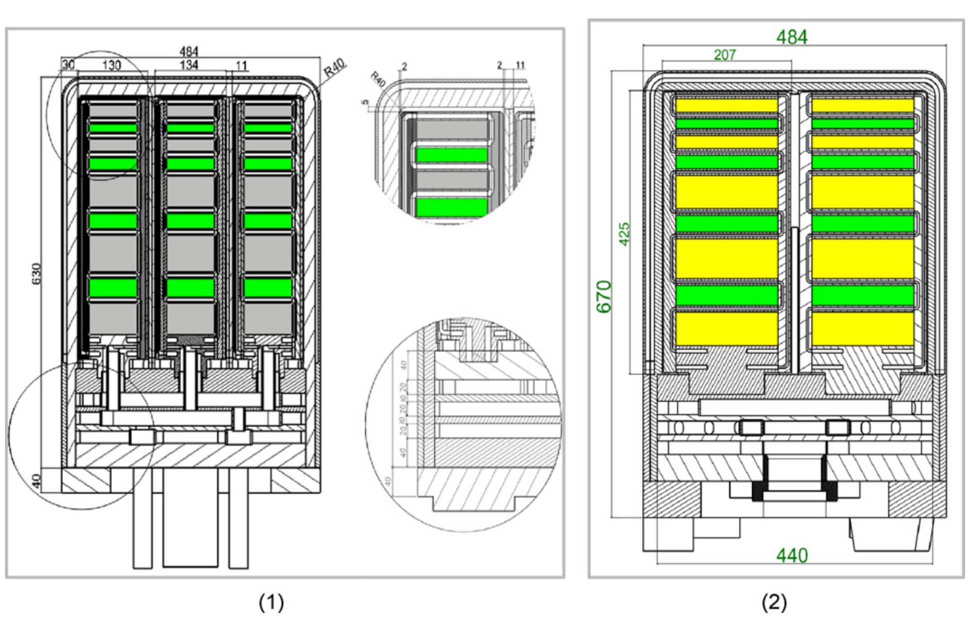

Fig. 2. 2-D model of the HCSB TBM blanket module. (a) 3 × 6 arrangement of sub-modules and (b) modified 2 × 6 arrangement of sub-module.