4.1.2 Progress on design and R&D of CN solid breeder TBM

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The helium-cooled/solid breeder with the pebble bed concept has been adopted in Chinese ITER test blanket modules (TBM) design. The structure dimension of HCSB TBM design is based on 1/2 ITER test port divided vertically. The current structure of HCSB TBM is by using the $2 \times 6$ modularized sub-module (SM) arrangement (Fig. 1) to replace original $3 \times 6$ SM arrangement as shown in the Fig. 1. In order to meet the requirement of reduction mass of TBM’s RAFM material, an updated structure design and performances analysis of HCSB TBM have been carried out recently.

![Fig. 1. 2-D model of the HCSB TBM module.](a) $3 \times 6$ arrangement of sub-modules, (b) Modified $2 \times 6$ arrangement of sub-module.

According to the latest experimental research, the material of RAFMs in TBM would influence highly on the magnetic field ripple effects of ITER, therefore, ITER has an additional requirement that is for the material weight limit of RAFMs in TBM. As a result, the design of TBM is necessary to modify and to decrease the material weight of RAFMs.

Updated design were exhibited that the coolant flow of FW has been changed from the toroidal direction to the poloidal direction of FW; and every 3 coolant channels are to form a cooling loop, and there are 9 loops in total inside the FW. Moreover, a modification for sub-module has also considered, the number of tritium breeding zone ($\text{Li}_2\text{SiO}_3$) and neutron multiplier zones (Be pebble bed) consist of 2 zones and 3 zones respectively in the modified design of sub-module. The arrangement direction of pebble beds is adjusted to be vertical on the surface of FW. The detailed design and performance analysis on structure optimization design and performance analyses on structure, neutronics, thermal hydraulic, thermal mechanical EM assessment and TBM-induced TF ripple analyses, etc., are being performed.

The generation of the TF ripple due to TBM’s structure material RAFM have been evaluated by establishing a 40-degree 3-D solid model along toroidal with Finite Element Models (FEM). As shown in Fig. 2, it has been shown that the TF ripple due to the discreteness of TF coils exceeds $\pm 1\%$ at 8.2 m of plasma edge near the equatorial plane. The introduction of ferromagnetic inserts (FIIs) and the recession of TBM have been verified to lower TF ripple, which does not bring obvious benefit.

![Fig. 2. Ripple distribution at $R = 8.2$ m, $Z = 0.38$ m without FIIs.](image)

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Chinese Low-activated Ferritic/martensitic steel, CLF-1, as TBM structural materials is developing towards industrially level. A 350 kg of CLF-1 steel was recently produced by vacuum induction melting and electroslag remelting method. The ingot was hot forged and hot rolled into different plates and rods. Some mechanical properties such as tensile and impact properties have been tested.

Exploration study of neutron multiplier Be pebbles fabrication technology has been done. Related performance test is on-going. Be alloy pebbles are prepared by powder metallurgical (PM) methods. In additional, some of test facilities including TBM electromagnetism test facility, Be pebbles of diameters 0.5 mm and 1.0 mm as the neutron multiplier and the lithium orthosilicate, Li₅SiO₄ pebbles with lithium 90% enriched in ⁶Li as tritium breeding materials of HCSB TBM have been fabricated at laboratory level.

Two kinds of the solid tritium breeder, Li₂TiO₃ and Li₂SiO₄, have been investigated in China. Preliminary test results shows that Li₂TiO₃ pebbles prepared by using sol-gel method have good surface feature and Li₂SiO₄ pebbles prepared by freeze-sintering process have good mechanical intensity. The extrusion-spherisation-sintering process was selected for sphericity of Li₂SiO₄ pebbles, as it proved to be the most appropriate one to obtain the goal characteristics.

The design of a test helium loop working at high pressure (8 MPa) and high temperature (550 °C) prior to TBM's installation in ITER have been completed. Related R&D on key components is undergoing.