4.1.2 Overview of design and R&D of solid breeder TBM in China[①]

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Testing TBM is one of important engineering test objectives in ITER project. China is implementing the TBM design and R&D plan based on Chinese development strategy of fusion DEMO. Helium-cooled test blanket module concept with ceramic breeder for testing during ITER operation period will be one of the basic options in China. Different design of HCSB TBM on module size, sub-module arrangement and modification and optimization of system have been carried out since 2004. In order to accommodate HCSB TBM design, related sub-system design, such as, tritium exaction system (TES), coolant purification system (CPS), helium cooling system (HCS), have being developed since that time.

The current design progress and R&D on structure material, function materials, heilum test loop of CH HCSB (China helium-cooled solid breeder) TBM are introduced. The results of modified designs and performance analyses were presented. Under the cooperation of domestic institutes, an updated design description document (DDD) of HCSB TBM have been completed in 2008. Modified design and analysis have shown that the HCSB TBM design is feasible within the existing technologies.

1 Design description

A modified design of the HCSB TBM based on 2×6 sub-modules arrangement and 3-D global neutronics calculation have been completed. The structure design outline of CH HCSB module based on "half-port" size of ITER test port is described. The HCSB TBM is located in vertical frame of the equatorial test port. Dimension of the frame is 1700 mm in poloidal direction, 524 mm in toroidal direction and 800 mm in radial direction. Taking into account about 20 mm gap between TBM and frame, the dimension of HCSB TBM is 1666 mm height and 484 mm width. Facing plasma side of HCSB TBM is needed to be protected by beryllium layer of 2 mm. The radial dimension of the HCSB TBM is 670 mm except for beryllium layer thickness. The HCSB TBM consists of the following main components: U-shaped first wall, caps, back-plate, grid, breeding sub-modules, and support plate.

The reduced-activation ferritic/martensitic (RAFM) steel and the helium gas are used as structure material and coolant, respectively. To assure an adequate tritium breeding ratio (TBR), beryllium pebbles with diameters of 0.5～1 mm with pebble-bed structure are adopted as neutron multiplier. The lithium orthosilicate (Li_4SiO_4) with enriched Li_6 of 80% is used as tritium breeder. The pressure of the helium cooling system and the tritium extraction system are 8 MPa and 0.12 MPa, respectively.

The tritium extraction system, helium-cooling system and the coolant purification system have been designed as auxiliary systems. Main design parameters for the tritium extraction system are as follows: the composition of purge gas is He＋0.1%H_2, pressure at the inlet of TBM blanket is 0.12 MPa, extracted amount of tritium is 0.1 g/d, helium mass flow is 0.65 g/s, and tritium extraction efficiency ⩾95%.

2 Performance analysis

Three-dimensional neutronics calculation based on the ITER structure model using MCNP/4C code and the data library FENDL2.0 give the total energy deposition of 0.567 MW, and a peak power density of 5.85 W/cm^3 under a neutron wall loading of 0.78 MW/m^2. The power density distribution in the radial zones is shown in Fig.1. The tritium generation amount is 0.0127 g for a full power day (FPD). In order to improve the power density in the blanket module, the arrangement of the Be neutron multiplier in the breeding zone has been optimized. Binary Be pebbles with diameter 0.5 mm and 1 mm were are chosen in the breeding zone.

Activation analysis has been performed assuming a continuous irradiation over 1 year at full fusion power (500 MW). Neutron fluxes are provided in 46 energy groups by 3-D neutron transport code MCNP for each specified material zone. Activation and dose calculations are performed by means of computation codes FDKR and DOSE. The composition data of structure material in the module is from reference material

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EUROFER97. The results show that the total activation inventory is 7.86×10^{16} Bq at shutdown time and drops slowly thereafter and reaches an extremely low level value of 1.09×10^{13} Bq after 100 years. The dose rate is 3.34×10^{7} mSv/h at shutdown time. Thereafter the dose rate declines rapidly and reaches 2.62 mSv/h after 10 years. Considering ITER operation factor 0.22, after 10 years' cooling, the dose rate is enough to meet ALARA threshold.

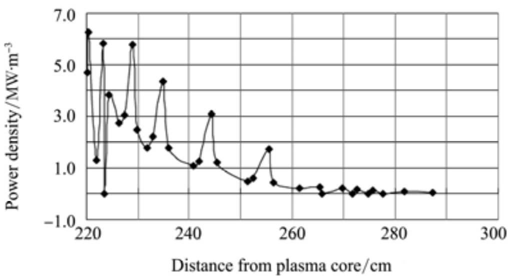

Fig.1. Power density distribution in the radial zones.

The Ex-Vessel LOCA will induce the melting of first wall beryllium armor after about 80 s of the LOCA initiation and some controlling measures have to be taken before melting. The pressurization of vacuum vessel induced by In-Vessel LOCA is about 26 kPa, and it's within the allowable value （200 kPa） of ITER design. The variety of the temperature in Ex-Vessel LOCA and the variety of the VV helium pressure in In-Vessel LOCA is shown in Fig.2, respectively. The In-Box accident would lead to pressurization of the TBM box including all pebble beds and the pressure of purge gas pipes to the system pressure of 8 MPa in about 2 s. So there must have a pressure relief system for the blanket box, and at the same time the fast isolating action has to be taken from TBM to keep the TES safety.

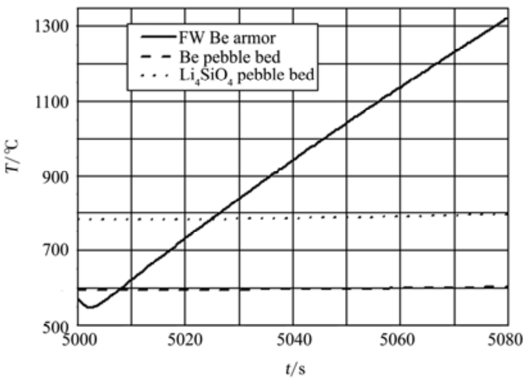

Fig.2. Temperature in Ex-Vessel LOCA.

3 R&D progress

In order to validate TBM design, especially regarding mass flow and heat transition processes in narrow cooling channels, it is indispensable to test mock-ups in a helium loop under realistic pressure and temperature profiles.

The loop includes the primary helium heat transport loop and the secondary water loop. Main components of the primary loop are, besides the test module, a heat exchanger, circulator, electrical heater, dust filter, control valves and pipe work. The primary loop is directly connected to the helium purification subsystem via small pipes by taking a small bypass flow. Another interface to the pressure control unit is needed for system evacuation, helium supply and protection against overpressure. Thermal stress has been calculated by software CAESAR II. Corrugated pipe is not used. If use it, the footprint will be smaller and the pipeline could be simpler.

The study on experimental technologies relative to pebble bed has also been started. The influence of Li_4SiO_4 pebble diameter and packing factor on pebble bed properties have primarily been investigated. In order to study the heat transfer in the blanket, the experimental apparatus will be planed to design and measure the effective thermal conductivity of Li_4SiO_4 pebble beds.

The study on experimental technologies relative to beryllium pebble bed has also been started. We primarily investigated the influence of pebble bed dimensions and packing factor on beryllium pebble bed properties. In order to study the heat transfer in the blanket, the experimental apparatus will be planed to design and measure the effective thermal conductivity of beryllium pebble bed.

Chinese low-activated Ferritic/martensitic steel, CLF-1, is being developed. The CLF-1 steel is used as the primary candidate structural material for Chinese HCSB TBM design. Several 50 kg ingots of CLF-1 steel have been melted in vacuum induction furnace in the past three years and a new heat of 350 kg was recently produced. The ingots were hot forged and hot rolled into different plates, rods and welding wires.

4 Summary

A modification design and performance analysis of China ITER HCSB TBM has been completed. Preliminary design and performance analysis for the TBM module have been performed. The results show that the current design of HCSB TBM is feasible within the existing technologies. It is characterised by simple structure, mature technique in China. Updated design description document of HCSB TBM has been carried out in 2008. The further design works will update and optimize the structure design as well as ancillary subsystem parameters. The fabrication technology of components and ceramic breeder for HCSB TBM are being developed in China.