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Status of Indian LLCB TBM program and R&D activities

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ABSTRACT

The Indian LLCB TBM, currently under development, will be tested from the first phase of ITER operation (H–H phase) in one-half of the ITER port no-2. The present LLCB TBM design has been optimized based on the neutronic as well as thermal hydraulic analysis results. LLCB TBM R&D activities are primarily focused on (i) development of technologies related to various process systems such as Helium, Pb–Li liquid metal and tritium, (ii) development and qualification of blanket materials viz., structural material (IN-RAFMS), tritium breeding materials (Pb–Li, and Li_2TiO_3), (iii) development and qualification of fabrication technologies for TBM system. The present status of LLCB TBM design activities as well as the progress made in major R&D areas is presented in this paper.

1. Introduction

Tritium breeding blanket research and its development is recognized as one of the most important areas for realizing an energy-producing fusion reactor worldwide and in India, LLCB blanket is being developed as a primary option for its DEMO reactor [1]. Successful development and testing of LLCB TBM in ITER is one of the major milestones in Indian DEMO program.

The LLCB TBM will be tested from the first phase of ITER operation (H–H phase) in one-half of the ITER port no-2. In the present design of LLCB TBM, the Pb–Li flow paths have been selected as parallel flow configuration based on the consideration that MHD pressure drop and generation of corrosion products would be minimum due to reduction in flow velocity in the individual channel [2]. The design of the water cooled SS shield block is under progress. The mechanical design of the TBM support structure integrated with the shield block and ITER port plug has been initiated. Preliminary process design of LLCB TBM auxiliary systems such as first wall helium cooling systems (FWHCS), lead–lithium helium cooling system (LLHCS) lead–lithium cooling system (LLCS), tritium extraction system (TES) and coolant purification system (CPS) has been performed [3].

The Indian TBM R&D activities are primarily focused on (i) development of technologies related to Pb–Li liquid metal, tritium as well as high pressure and high temperature helium process systems, (ii) development and qualification of blanket materials such as structural material (IN-RAFMS), tritium breeding materials (Pb–Li, and Li_2TiO_3), (iii) Development and testing of manufacturing technologies for TBM system. The progress made in all those areas till 2011 have already been reported in Refs. [2,3]. This paper provides an overview on recent progress in LLCB TBM design and related R&D activities, which has been made during last two years starting from 2012.

All the R&D activities have been initiated in Institute for Plasma Research (IPR), Gandhinagar in collaboration with Bhabha Atomic Research Center (BARC), Mumbai, Indira Gandhi Center for Atomic Research (IGCAR), Kalpakkam and other research institutions and universities within India.

2. LLCB TBM set description

The LLCB TBM has both the features of solid breeder and liquid breeder blankets [4]. LLCB TBM contains lithium titanate as ceramic breeder (CB) material in the form of packed pebble beds and PbLi eutectic as tritium breeder, neutron multiplier, and coolant for the CB zones. Reduced activation ferritic martensitic steel (RAFMS) is used as the structural material for first wall (FW), which is actively cooled by high-pressure helium (He) gas. The tritium produced in the ceramic breeder zones is extracted by low-pressure purge helium circuit at 1.2 bar + 0.1% of hydrogen to enhance the isotope exchange of H and T. The tritium produced in the PbLi circuit is extracted separately by an external system. The molten Pb–Li eutectic flows separately around the lithium ceramic breeder pebble bed compartments to extract heat from the CBs. The Pb–Li flow velocity inside individual channel is moderate enough to minimize the MHD issues, but sufficient to extract its self-generated heat and

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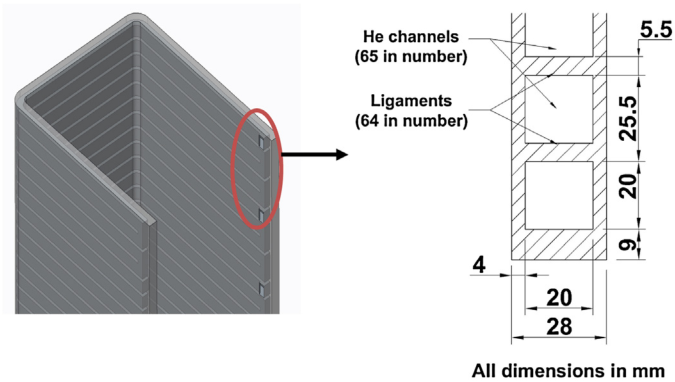

Fig. 1. FW configuration of LLCB TBM.

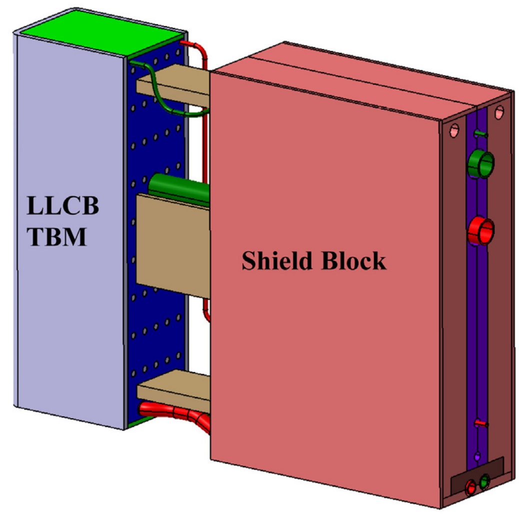

Fig. 2. LLCB TBM with shield block and attachment plates.

the heat transferred from the ceramic breeder zones. Tritium produced in the ceramic breeder zones and Pb–Li circuit is extracted separately by low-pressure purge helium gas mixed with hydrogen and external detritiation system, respectively.

2.1. LLCB TBM set design and analysis

The LLCB TBM design and optimization has been performed focusing on parallel flow configuration of liquid metal inside TBM [2]. The optimization is performed with respect to neutronic performance and high-grade heat extraction by keeping the temperature of all components within the allowable limits [5]. The neutronic performance of various variants of LLCB TBM has been examined by varying the radial build up of Pb–Li channels as well as CB zones to get the optimal temperature distribution in CB zones. The reference ITER neutronic model B-lite was used and LLCB TBM was placed at the equatorial mid plane of port #2. The present overall dimensions of LLCB TBM are 1.67 m $(h) \times 0.559$ m $(w) \times 0.462(t)$.

The finite element simulation of FW and other different parts of LLCB TBM have been carried out using ANSYS. The heat load on LLCB is considered as the average surface heat flux on the FW (0.3 MW/m^2) and the nuclear heat deposition on each component in the TBM module and is taken as inputs for thermal analysis and design. Helium, which is used to extract heat from FW, is flown in the grooves or slots made in the FW, as shown in Fig. 1. There are total 65 grooves or rectangular channels in the FW. Each channel has dimension of 20 mm × 20 mm. The channels are arranged with 13 such circuits of 5 passes. The helium is flown from the inlet header side and after passing through the five passes the helium is collected in the outlet header, which is on the other side of the inlet header.

Preliminary Pb–Li flow analysis has been performed without considering the liquid metal MHD effects and flow velocity has been optimized for keeping the Pb–Li, FMS and CB zones within their temperature limits. The detailed thermo-fluid MHD analysis of the module will be taken up after successful benchmarking of MHD codes with experimental results.

LLCB TBM set consists of LLCB TBM and its shield block, as shown in Fig. 2. LLCB TBM will be assembled along with shield block (SB) and their attachment systems with manifolds and piping. The shield block is attached to the TBM back plate using attachment system in the port plug to act as neutron radiation shield, to allow passages for process pipes to the TBM as well as to hold the TBM in cantilever position relative to shield block. All the pipes, carrying process fluid as well as the instrumentation cable, pass through the shield block and are connected at TBM back plate. The shield block dimension is 1.74 m $(h) \times 0.532$ m $(t) \times 1.2$ m (w) and is connected to the PP with 60 mm thick flange. The SB is water cooled with water to SS ratio ~40:60. Water from ITER blanket cooling water system enters from the backside of the SB at a temperature and pressure of 70 °C and 4.0 MPa and flows in parallel between the SS plates. The mass flow rate is 5.5 kg/s. Details thermal-hydraulic analysis for shield block is in progress.

3. LLCB TBM R&D Activities

The R&D activities have been identified in many areas such as liquid metal technology development, ceramic pebble development and its characterization, development and qualification of structural material and fabrication technology, development of tritium technology, performing experiments and simulations related to LLCB TBM safety analysis. In the following sections, the ongoing R&D activities in some of those major areas will be summarized.

3.1. Liquid metal technology related R&D

Liquid metal R&D activities are focused on, liquid metal MHD studies as well as code benchmarking, liquid metal diagnostics development and liquid metal corrosion studies. Although, the design of LLCB TBM considers electrical insulation coating on internal walls of Pb–Li flow channels, the lifetime of coating is still unknown. In order to address various MHD related issues at characteristics parameters of high Hartman number and interaction parameter and for benchmarking of thermo-fluid MHD codes, MHD experiments are being performed jointly at Institute of Physics, University of Latvia (IPUL) [6]. Till now experiments have been performed with three different test sections as shown in Fig. 3. As can be seen, the first test section consists of different types of 90° bends, the 2nd one has transition from rectangular to circular flow cross-section and vice versa where as the third test section has electrically coupled parallel and anti-parallel flow paths as similar to LLCB TBM flow configuration. These test sections are assembled in a liquid metal loop and is placed in a strong transverse magnetic field of up to 4.0 T. MHD experiments are performed by circulation of Pb–Li liquid metal in the loop at ~350 °C. The results for first two test sections are reported in Ref. [6]. Preliminary analysis of the experimental data for third test section suggests asymmetrical flow distribution in the two parallel paths as shown in Fig. 4. The detailed analysis is under progress.

As the IPUL magnet is of solenoid type having internal hole diameter of ~300 mm, all the test sections have restriction in total flow length. As an alternate approach, an experimental Pb–Li facility is currently being setup at IPR for carrying out MHD experiments