MHD PbLi LOOP AT IPUL

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Abstract: The report describes the MHD PbLi loop at IPUL, the equipment and operations. The loop operation parameters are the maximum magnetic field 5 T, the magnet bore 30 cm, PbLi temperature up to 400°C, the maximum PbLi flowrate with/without magnetic field 0.5/2 l/s, the maximum pressure head 0.48 MPa.

1. Introduction

Eutectic lead–lithium (PbLi) alloy has been proposed as a tritium breeder and coolant fluid in several liquid metal blanket concepts for future fusion power plants [1],[2],[3], including self-cooled lead–lithium (SCLL), dual-coolant lead–lithium (DCLL), helium-cooled lead–lithium (HCLL), water-cooled lead–lithium (WCLL), and Lead-Lithium Ceramic Breeder (LLCB) blankets. Various studies, both experimental and theoretical, were performed focusing on various aspects of PbLi flows [4],[5],[6],[7] and associated heat and mass transfer phenomena with and without magnetic field.

There are only a few magnetohydrodynamic (MHD) PbLi facilities currently in operation: a loop at the Institute of Physics in Latvia, several MHD PbLi loops DRAGON I–IV at the Institute of Plasma Physics of the Chinese Academy of Sciences, an ELLI loop at the Korea Atomic Energy Research Institute, and an MHD PbLi facility at UCLA (USA).

Some loop modifications were used in experiments with models of LLCB channel units (blanket concepts for DEMO of India) performed with Indian colleagues from the Institute of Plasma Research, Bhabha Atomic Research Center, Veermata Jijabai Technological Institute. [8, 9, 10].

Below we are described the special feature of the MHD facilities at IPUL such as the loop; the magnet; the pump and the flowmeter; pressure gauges; a system for measuring pressure drops in the channel; probes to register electric potential variations on the channel walls; loop heating and insulation; heat shielding of the magnet; a system of thermal stabilization; a system of melting and oxide removal; the procedure of the loop filling and pouring out; a sampling system and sampling data processing to minimize measuring errors; supplement devices – a system of vacuuming, inert gas supply and pressure release.

2. Magnet

For an experimental study of the flows of the conducting liquids in the strong magnetic field to order of IPUL is created the Cryogen-Free magnet system (Fig.1). The 5 Tesla Cryogen-Free magnet system (CFM) is one of a range of cryogen-free magnet systems produced by Cryogenic Ltd [11]. The system utilizes a single two stage cryocooler to produce temperatures of around 4.2Kelvin at the magnet. This magnet comprises a single winding designed to generate a homogeneous field up to 5 Tesla. The CFM has an 300 mm room temperature bore. The whole cryostat can also be rotated through 90 degrees in 10 degree intervals from the horizontal to the vertical position. The outer case of the CFM is manufactured from aluminium alloy. The room temperature bore is manufactured from stainless steel. The cryostat vacuum jacket has ports for the cryocooler, magnet current leads, magnet protection

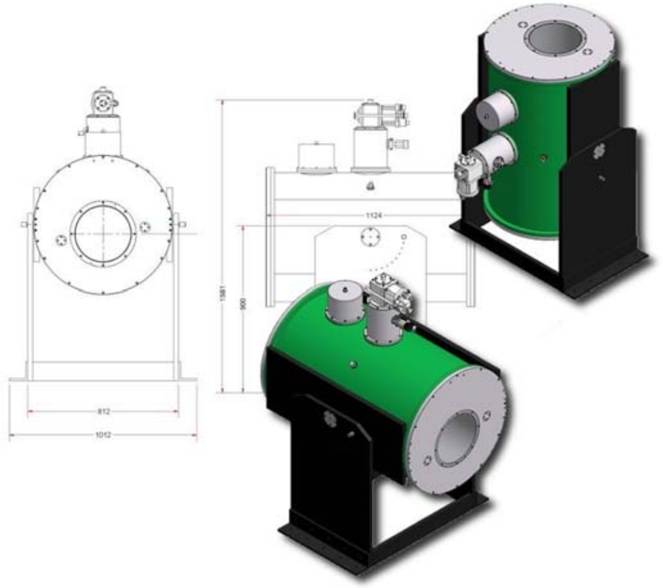

Figure 1: Cryogen-Free magnet system (CFM) produced by Cryogenic Ltd.

leads, instrumentation and evacuation. Radiation heat load to the magnet is minimized by means of a high purity aluminium radiation shield connected to the first stage of the cryocooler used in conjunction with multilayer super insulation between the room temperature outer wall and the shield. The radiation shield is attached to the first stage of the cryocooler and in operation cools to approximately 35-40K. The second stage is attached directly to the magnet and has a base temperature of <4.2K. High Temperature Superconductor (HTS) current leads are located and thermally linked (whilst electrically isolated) between the first and second stages of the cryocooler. Electrically resistive current leads extend from room temperature to the HTS lead sat the 1st stage. Temperature sensors are located throughout the system to monitor various internal components during the cooldown and subsequent operation of the system. Data from the thermometers may be displayed on a computer graphically and stored in data files for further analysis. Carbon ceramic sensors are used throughout the system as they are robust and have exhibit low magneto-resistance. The thermometers are wired to an 1l pin and 16 pin Fischer connectors located on the cryocooler turret. An overpressure valve for the cryostat is on the cryocooler turret.

3. Loop

The PbLi MHD experimental loop is a closed loop system and consists of a dump tank of capacity ~10 l, seven expansion tanks, one electromagnetic pump for circulation of liquid metal in the loop and one solenoidal super conducting magnet (SCM). A schematic of the loop is shown in Fig.2. The loop is made with circular pipe of 27.3 mm ID and has a total flow length of ~6.5 m (both way).The SCM produces an axial magnetic field within its central hole, which is ~1000 mm long and has a diameter ~300 mm. This puts restriction on the flow length of liquid metal in transverse magnetic field direction and hence the test section is accordingly designed to get maximum possible flow length perpendicular to magnetic field. The argon gas is used as a covered gas on all expansion tanks and is used to estimate the total liquid metal pressure drops in the loop. It is also used to initially fill the loop by pressuring the dump tank. The isothermal (T = 350^{o}C) PBLi loop was equipped with a rotational magnetic pump with permanent magnets [12], which is allowed to vary by wide range of the

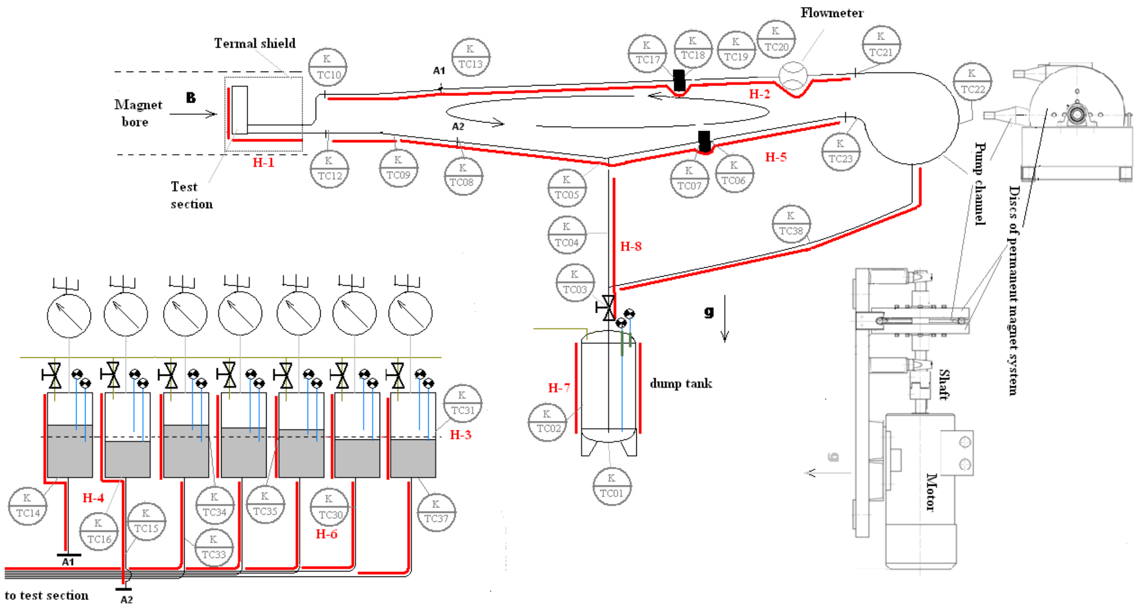

Figure 2: PbLi loop.

liquid metal flow rates (in both directions of the Pb17Li flow). A simplest Faraday flow meter gauge (probe) was installed in the loop. The prism-shaped duct of the probe (its cross-section of about 5 x 42 mm^2, length 65 mm) was formed by tapering the central part of the tube of D_{inner} = 28 mm of thickness 2 mm. The magnetic field B ~ 0.5 T in the probe duct was induced by an imposed symmetric C-shaped magnetic system with permanent magnets, the active surface of which was 60 x 60 mm^2. Pins for electric potential measuring were welded to the end walls in the middle of the prism-shaped duct.

The calibration of flowmeter is carried out on potential measurements on the walls of channel of the test section [13].

On the system of measurement of pressure drop. Local static pressures in the PbLi loop by the tubes of the selection of pressure are transferred to the expansion tanks, where in each tank is located its level of the free surface of PbLi. Above the free surface of PbLi is located inert gas argon, whose pressure is measured through the thin tubes cooled to room temperature by gas manometers GDH of 14 AN. Identical expansion tanks are fixed at one height, they have the identical *level of filling* (LF), are equipped with *indicators of level of fillings* (ILF). LF is located approximately in the middle of tanks. Expansion tanks are selected so as to in entire range of the measurements of pressures the level of free surface is located inside them. ILF has two contact devices that switch on with contact from PbLi. The level of the free surface of PbLi, with which operate the contact device is used for calculation the *initial gas volume* above PbLi, pressure in which is measured by pressure sensor. Two contact sensors make possible to determine the position of the free surface of PbLi within the limits of their levels. For achievement accuracy are necessary the following operations:

1) All valves connecting expansion tanks with the general gas-vacuum main are opened with the filling of PbLi loop. Entire system including loop, expansion tanks and pressure sensors is thoroughly heated to 600÷620 K and is evacuated.

2) By the pressure of inert gas by that supplied to the melting tank PbLi is rises into the loop and the expansion tanks to the contact only with the lower contact device of the ILF of each tank (with the turned-off electromagnetic pump);

3) After establishing the level of the free surface of liquid metal in the tank to the LF we know *the initial volume* V_{ig} of gas, utilized for calculating the correction for a difference in columns in the tanks. The effective height of the initial gas column is $h_{ig} = V_{ig}/(\pi R^2)$, where R - inside radius of tanks.

4) After the establishment of the level in all tanks at the LF overlaps the circuit leading to the melting tank, the identical pressure of inert gas of argon simultaneously into all measuring tanks will be given.

5) After the warming up of added argon in the expansion tanks they are disconnected from the general gas-vacuum main, are recorded the *initial pressures* P_{ig}, pump for the warming up of the badly heat-insulated parts of the loop (channels of pump and flow meter) is switched on and begin steps in the measurement of losses of pressure in the test section. After the installation of with the aid of the pump of the value the requisite flowrate, a pause for stabilization of regime are making, whereupon all values are recorded.

6) With data processing for determining the losses of pressure in test section the formula is used

$$\Delta p = p_{1fg} - p_{2fg} + \rho g \cdot 10^{5} \cdot \left\{ h_{2ig} \cdot \frac{p_{2ig}}{p_{2fg}} - h_{1ig} \cdot \frac{p_{1ig}}{p_{1fg}} \right\}$$

To a gas pressure difference (from pressure sensors) the correction for columns difference in expansion tanks is added. This difference is of calculated from the pressures of gas (pressure of sensors). The value of this correction is less than 10%.

On the accuracy of the method of measurement of pressure drop. The gas volume above LF approximately 1 liter, 94% of volume of gas - in the expansion tank with stabilized temperature of 600±6 K, 6% - in the thin tube leading from the expansion tank (with temperature 600 K) to the pressure sensor (300±6 K). The accuracy of temperature stabilization in the tanks gives an error in measuring the correction of pressure on a change in the columns of PbLi connected with a change of the volume of gas in the tanks less than 1%. The conditions of heating expansion tanks and cooling of tubes are identical. Assuming that the free surface of PbLi after the correct operate ILF exactly in the middle between them we obtain the error in determination of the initial volume of gas connected with the accuracy ILF - 3%. Thus the error in determination of the volume of gas from the deviation of temperature and error in determination of initial volume in each tank is 4%. For a difference in the levels error is 8%. Since the correction of pressure connected with the difference of levels is less than 10% of the difference of gas pressures, then error connected with the computable correction is less than 0.8%. Error of the gas manometer (GDH of 14 AN) is 0.01 bar. With drop measurement into 1 bar the error of manometers is 2%. Accumulated error is less than 2.8%. With a pressure drop in 2 bars the error is less than 1.8%. With drop measurements of 0.2 bars the error is less than 10.8%.

4. Conclusion

The experience of the IPUL team in the design and manufacturing of EM pumps, in the production of eutectic lead–lithium alloy as well as the skills of mechanical, electrical and technological works makes it possible to quickly produce optimal equipment for the loops and systems for experiments. These skills allow to properly adjusting the loop for various tasks of the lead–lithium blankets.

In the near future, we plan to model the processes in the channels of a blanket with ceramic inserts and prepare experiments on heat/mass transfer in the PbLi flow channel in a strong magnetic field.

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