TEMPERATURE MONITORING OF LEAD BISMUTH EUTECTIC FLOW IN THE MEGAPIE TARGET

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Introduction. An Electromagnetic Pumps System for the MEGAPIE target has been developed, produced and tested at the Institute of Physics, University of Latvia, during the recent two years in the framework of the MEGAPIE-TEST Project (MEGAWatt Pilot Experiment – TESTing) funded within the Euratom 5th Framework Programme as an implementation of transmutation technology [1]. The EMPS operates being submerged in lead bismuth eutectic (LBE), whose temperature fluctuates depending on the proton beam trip in the range 220–380°C with the temperature changing rate 5–10°C/s.

The electromagnetic pump system is responsible for the lead bismuth eutectic flow in the MEGAPIE target. Stop of the flow, e.g., as a result of the channel plugging with He bubbles, leads to local overheating of the proton beam inlet window and very likely to its disintegration. Therefore, monitoring of the flow during the target operation is a very important task.

Results of original electrodynamics and thermo hydraulic calculations of the electromagnetic pump system are presented in the report. These results assume the procedure of lead bismuth eutectic flow monitoring through electrical regimes for electromagnetic pumps and lead bismuth eutectic temperatures measurements. The procedure is based on the strong correlation between the lead bismuth eutectic temperature at the EMPS inlet and outlet, the flow rate and the electrical regime for the pump.

A special PC code, which allows controlling the intensity of the lead bismuth eutectic flow in the EMPS channel at steady and transient temperature regimes of the target operation, has been developed and proposed. There are recommendations on the PC code adoption for the MEGAPIE target control system at the end of the presentation.

1. The description of installation. The proton beam through a target window 3 will penetrate the liquid LBE and heat up it. The electromagnetic pump EMP1 (1 – inductors, 2 – core) transfers the warmed-over LBE by the main channel to the heat exchanger 4. LBE cooled in the heat exchanger is split into two flows. The main LBE flow passes in the annular channel 5. The minor LBE is being pumped by the EMP2 (7 – inductors, 8 – core) in the by-pass channel. The by-pass flow in the annular channel 9 falls in the upper ring collector 10, then through three pipes 11 falls in the lower collector 12 and then through the pipe 13 passes up to the nozzle 14. The jet of the by-pass flow together with the main flow provide of heat pick up from the target window at permissible thermal stresses in the material of the window. Without the bypass jet thermal stresses exceed the permissible ones.

From the upper collector up to the input into the heat exchanger a pipe 15 is built. Its task is to provide passing of helium bubbles arising in the target and floating up in the channels 5 and 9 of the collector 10 in the main flow 16 and further to the LBE free surface. Closing of the pipe 15 will cause congestion of helium, blocking the by-pass channel and decrease of efficiency of heat loss from

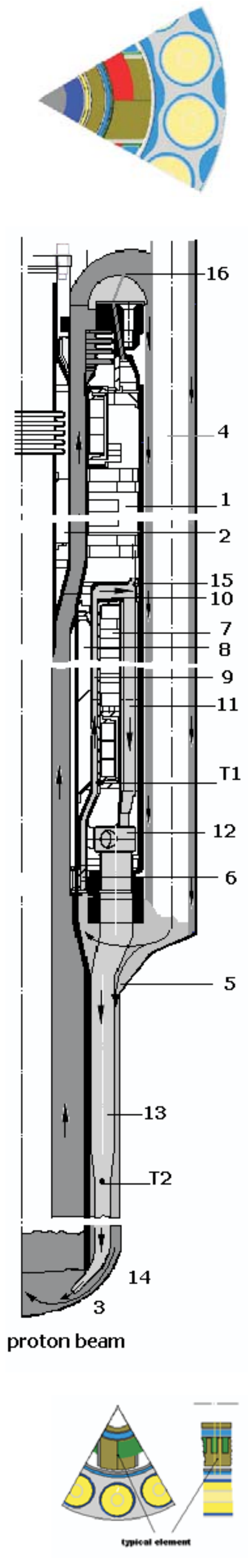

Fig. 1.

the target window that can result in destruction of the target. The control of the flow rate in the by-pass channel therefore is indispensable. The availability of thermocouples at "cold" input T1 and "hot" output T2 and the capability of calculation of thermal output in the inside EMPS LBE flow forms the ground for an attempt to create a system for indirect control of the flow rate in the by-pass channel resting upon the monitoring standard parameters (temperatures and pump current).

2. Calculation of the by-pass flow heating for operating regime (steady-state mode). Thermal output 581 kW from the target window is provided by the LBE flows in the main channel ($G_m = 40$ kg/s) and in the by-pass channel ($G_b = 2.5$ kg/s) at the pump currents $\bar{I}_m = 22.8$ A and $\bar{I}_b = 17.8$ A, correspondingly. At those parameters the temperatures at the heat exchanger input and output are $t_m = 327°$C and $t_b = 230°$C, correspondingly [2].

The preliminary analysis has shown that inside the wall, dividing the main and by-pass flows, the absolute predominance of radial heat flux above longitudinal takes place. Conductive heat transfer in LBE can be neglected compared to the convective one. Changes of the main flow rate G_m and temperatures t_m, t_b due to the by-pass channel choking are very small (less than 2%). These circumstances are utilized for simplification of the problem, practically, without losing final result accuracy.

Calculations of the temperature start from the input EMPS LBE element, where the temperature is known $tb_0 = t_b$, $tm_0 = t_m$. Further, we advance along the channel with a small step h. On each step i we define heat transfer coefficients, heat fluxes onto the walls of the channels and internal Joule heat from the inductive currents. Having divided influx (or outflow) of heat in the considered element in heat capacity C and flow rate, we obtain a temperature change,

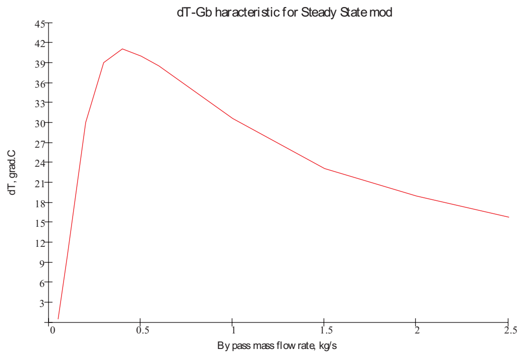

Fig. 2.

which is used for thermal calculation at the following step:

$$tb_{i+1} = tb_i + \sum_j q_i^j \cdot h/(C(tb_i) \cdot G_b(tb_i)) \,, \qquad tm_i \approx t_m$$

where q_i^1 is the line density of heat outputs from inductive currents in the LBE element; $q_i^2$is the linear heat flux on the wall of the inductor; $q_i^3$is the linear heat flux in the dividing flows, multilayer cylindrical wall, which has its own heat losses in the channel wall and in the core in the area of the inductor field. $q_i^1$is defined from the solution of an electromagnetic problem in a non-magnetic gap of a bounded inductor at a given longitudinal current distribution in coils; q_i^2 is defined for a typical inductor element from the solution of the set of equations for an equivalent thermal circuit at given LBE temperatures.

Heat transport calculations in the bypass channel of EMPS at operating regimes and different flow rates are performed. The outcomes are shown in Fig. 2 as a dependence between the temperature drop in the by-pass flow $\Delta T_{12} = T_2 - T_1$ between positions, marked T1 and T2 and the flow rate. Thus, at fixed values of the input-output temperatures of the heat exchanger and fixed values of power supply currents of the pumps, a unique dependence $\Delta T_{12} = T_2 - T_1$ from the flow rate results.

3. Strategy of flow rate control by means of external parameters monitoring. The process of accumulation of helium in the upper collector slowly develops. On the contrary, the parameters are measured rather frequently. In Fig. 3 the real record of intensity of a beam is submitted. Steady state modes

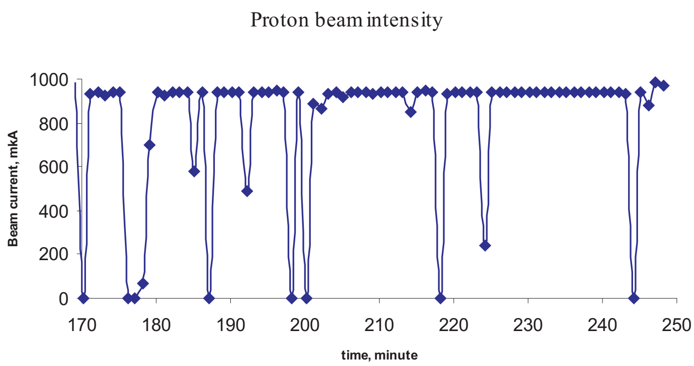

Fig. 3.

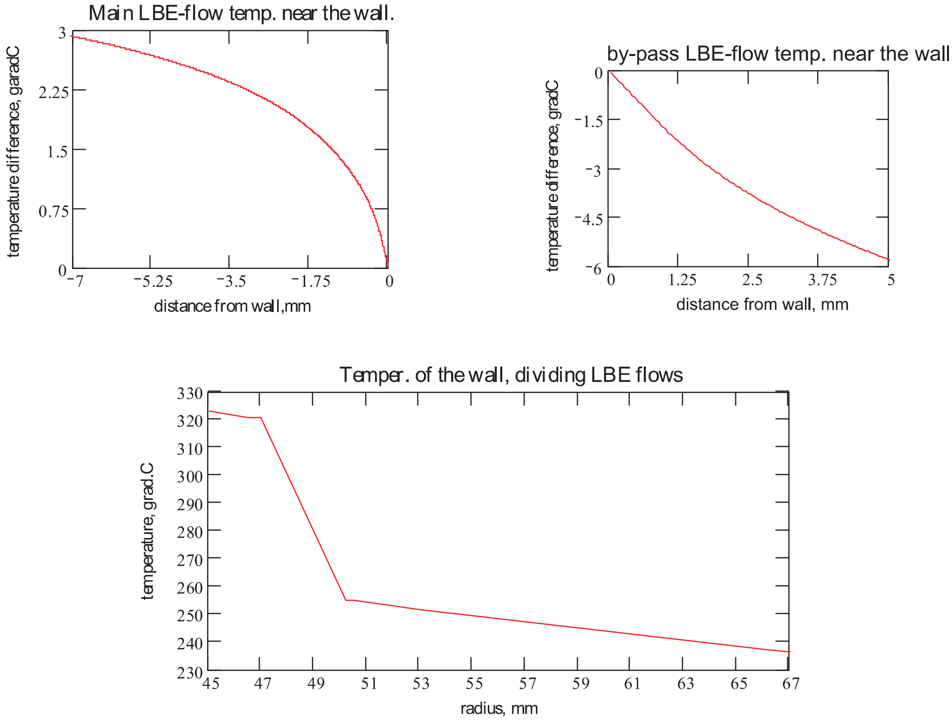

Fig. 4.

frequently interrupt by short-term switching-off ("beam trips"). The "beam trip" temperature transition lasts $\sim$ 400 sec. After that there comes a Steady state temperature mode, if not there is a new "beam trip". The part of an interval of time between occurring one behind another "beam trips" can be used for indirect measurement of the by-pass flowrate on a difference of temperatures $\Delta T_{12} = T_2 - T_1$. This period should begin in 400 seconds (less than 7 minutes) from a start of the previous "beam trip" and come to an end prior to the start the following "beam trip".

4. Thermocouples and the LBE temperatures. The distribution of temperature in section appropriate to a location of the thermocouple T1 is received on the basis of calculation according to [3]. The results are show on Fig. 4. On adiabatic wall of the by-pass channel, in the location of the thermocouple, temperature is lower than average temperature in LBE on 1.2–1.3°C. Thermocouple T2 is fixed inside the channel and measures the by-pass flow temperature directly.

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