EXPERIENCE OF CALCULATION, DESIGN, FABRICATION AND TESTING OF ELECTROMAGNETIC PUMP SYSTEM FOR MEGAPIE TARGET

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Introduction. Transmutation is a promising and feasible technology worldwide for significantly reducing the amount, and thereby, the long-term radiotoxicity of highly radioactive waste produced by the operation of nuclear power plants such as light water reactors. Plutonium, minor actinides and long-lived fission products can be transmuted in an Accelerator Driven System (ADS).

A key component of an ADS is the spallation target which uses the heavy liquid metal lead (Pb) or lead-bismuth eutectic (Pb-Bi) both as spallation material and as coolant. Such a heavy liquid metal (HLM) spallation target has never been tested before.

The objectives of the MEGAPIE-TEST Project are to develop, improve and validate expertise, knowledge and experience about the design and the operation of a HLM spallation target and to verify its feasibility under realistic operating conditions.

Electromagnetic Pumps System (EMPS) for MEGAPIE target was developed, built and tested during recent two years in the frame of MEGAPIE-TEST Project (MEGAWatt Pilot Experiment – TESTing). The system maintains lead bismuth eutectic (LBE) flow between MEGAPIE target's heat exchanger and beam entrance window to ensure thermal power evacuation. Development of EMPS able to operate under the target conditions during minimum 10.000 hours is not trivial task because of following reasons:

- The EMPS operates submerged in lead bismuth eutectic (LBE) which temperature fluctuates depending on proton beam trip in the range 230–380°C with rate of temperature change up to 5–10°C/s. Thin-walled austenitic steel 316L protective hull liable to withstand min. 10.000 thermal fatigue cycles is necessary to protect EM pumps and flowmeters from direct contact with LBE;
- Volume for the pumps is very restricted in the target therefore loads of electrical and magnetic circuits of the pumps are close to limit what leads to intensive heat release. Heat transfer between the EM pumps and LBE is only one mechanism of the EMPS cooling. Minimization of heat release on the one band and thermal resistance between the pumps inductors and protective hull (minimal gaps, filling with thermal conductive materials etc) on the other band are the ways to better efficiency of the cooling;
- Operating conditions of the EMPS (high temperature, irradiation, magnetic field, mechanical stresses) apply strong restrictions on structural and active material.

Problem solving has required development of original procedure of the EMPS calculation for optimization of design and technology as well as comprehensive

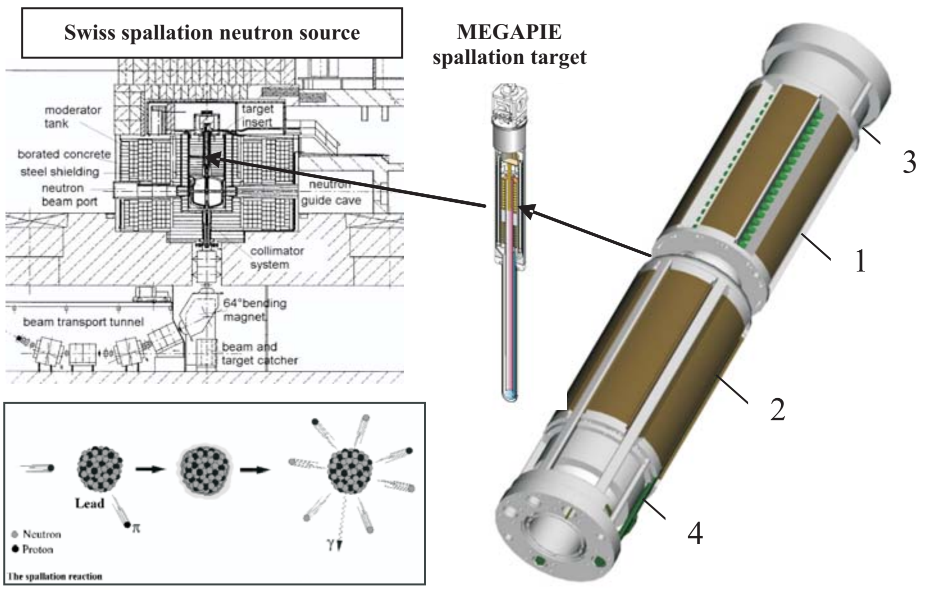

Fig. 1.

testing of the system. The numerical modeling of thermal hydraulic processes, both in stationary modes of operations of a proton beam and in modes of switching-off of the beam, has allowed determining thermo stresses in the EMPS housings and coils temperature [1]. Results of these modeling are used for a substantiation of feasibility of system in conditions of MEGAPIE TEST.

1. Design of EMPS. The electromagnetic pumps system (EMPS) constitutes a block consisting of 2 electromagnetic pumps and flowmeters. Design of the EMPS is presented in Fig. 1. The main pump (EMP1, pos.1) maintains LBE flow between the target's proton beam entrance window and heat exchanger (nominal flow rate – 4 L/s, pressure head – 200 mbar). The by-pass pump (EMP2, pos.2, 0.35 L/s, 350 mbar) controls flow structure in the beam entrance window to optimize cooling conditions. The both pumps constitute 2 poles, 18 coils linear cylindrical induction pumps with passive magnetic cores.

Two independent 3-phase power supplies based on autotransformers were designed and fabricated for EMP1 and EMP2 electrical feeding (50 Hz, 0–150 V, 0–37 A). LBE flow rate in the pump's channel is adjusted through manual control of electrical current in the pump. Built in the power source CIRCUTOR (3-phase net analyzer) measures electrical feeding parameters.

Electromagnetic induction type flowmeters (EMF1 and EMF2, pos. 3 and 4) were designed for monitoring of LBE flow rate in the main and by-pass LBE paths. A flowmeter consists of 2 excitation coils inducing radial magnetic field in LBE channel, sensing coil and ARMCO shield protecting flowmeter from EM pumps leakage magnetic flux. Special electronic circuit is designed for EM flowmeters. It consists of stabilized AC current sources (817 and 917 Hz, 1.5 A) for excitation coils power supply, amplifiers and based on PC data acquisition system for sensing coils signals measurements and processing. Thermocouples (12 pieces, THERMOCOAX, K-type) measure temperature of the EM pump's coils during operation to prevent its overheating.

Russia made temperature and irradiation stable wire POZH-700, compound OC-51 and silicone electro technical steel 1713 were used for the pumps and flowmeters fabrication.

The EM pumps and flowmeters are protected from direct contact with LBE by

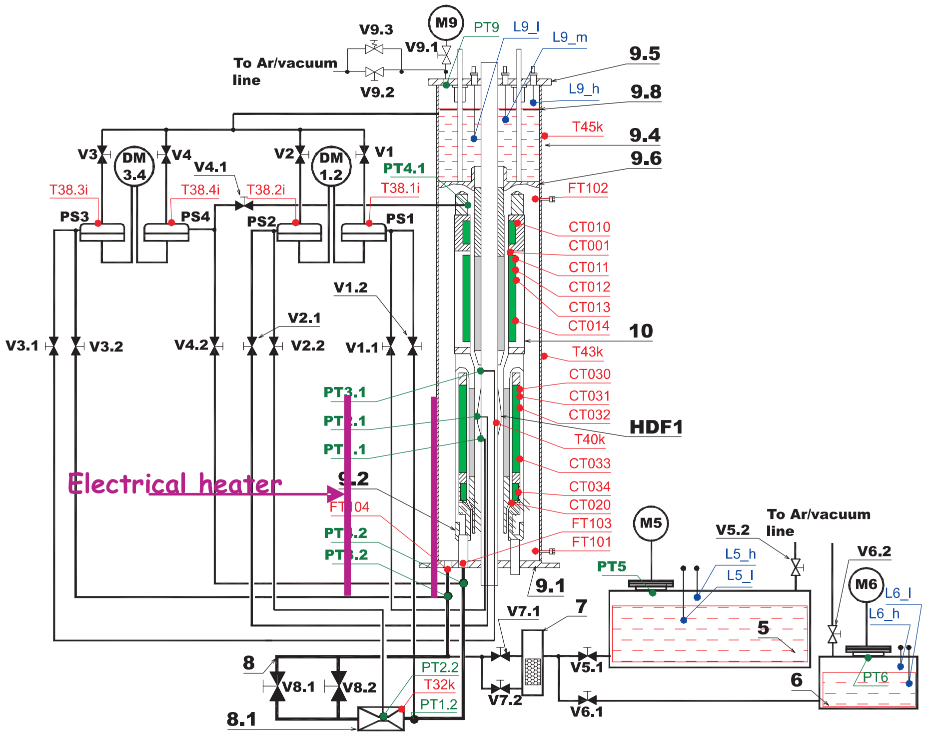

Fig. 2.

thin-walled austenitic steel 316L protective hull. The protective hull was designed to withstand 14 bar overpressure without loss of integrity at temperature up to 350°C and 10.000 fatigue cycles caused by the changes of LBE temperature in the main channel (230–380°C/10°C/s). Special bellow units and ceramic heat shield prevent destruction of the protective hull from the thermal expansions.

The system was designed, fabricated and preliminary tested in IPUL. TUV Nord Baltic supervised and checked design and fabrication process to ensure proper quality and reliability of the protective hull and LBE channels.

2. Thermo hydraulic Test Rig. Special LBE test rig was developed [2] and built for thermo hydraulic and reliability test of the MEGAPIE targets EMPS, see Fig. 2. Performances attributes:

- Hydraulic fluid-lead bismuth eutectic (LBE), app. 100 L
- Shielding medium (cover gas) – He, pressure 0.1…2 bar
- Temperature of LBE – 200°…450°C, automatic control
- Max LBE flow rate: main path- 5 L/s; by-pass path- 0.5 L/s
- Controllable hydraulic resistance of external path: EMF1 – 0.15…0.5 bar; EMF2 – 0.1…0.5 bar; control step is app. 0.05 bar
- Reference flowmeters: main path- special design hydrodynamic flowmeter; by-pass path- Venture flowmeter, accuracy 4%
- Data acquisition system based on Field Point blocks and LABVIEW

The test operated successfully over 600hours. During the test reliability of the EMPS's protective hull was checked and operating characteristics of pumps measured. Electromagnetic pumps (EMP1/EMP2) correspond to technical specification [3]. Quality of assemblage is good. There are technical problems with electromagnetic flowmeters electrical/electronic circuit. Additional actions are necessary.

3. EMPS operating characteristic.

3.1. EMP1 operating characteristic.

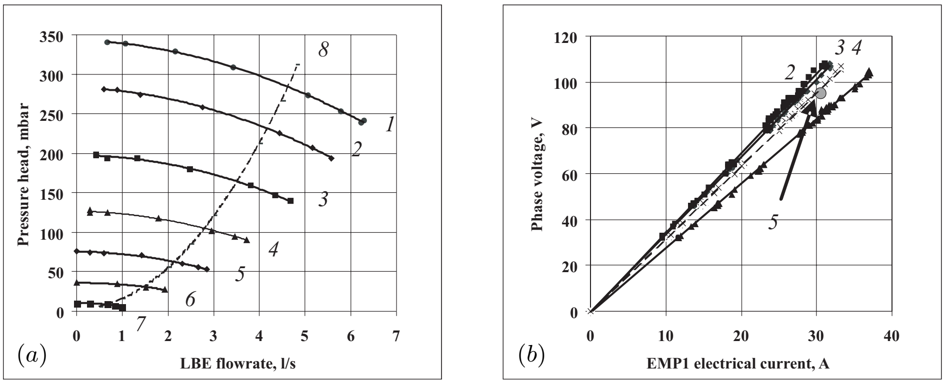

Fig. 3. (*a*) EMP currents, A: *1* – 33.2; *2* – 29.9; *3* – 25; *4* – 20; *5* – 15.2; *6* – 10.4; *7* – 5.1.; *8* – hydraulic characteristic of the MEGAPIE target main channel. (*b*) *1* – phase "R"; *2* – phase "S"; *3* – phase "T", *4* – average, *5* – rated nominal value.

3.2. EMP2 operating characteristic.

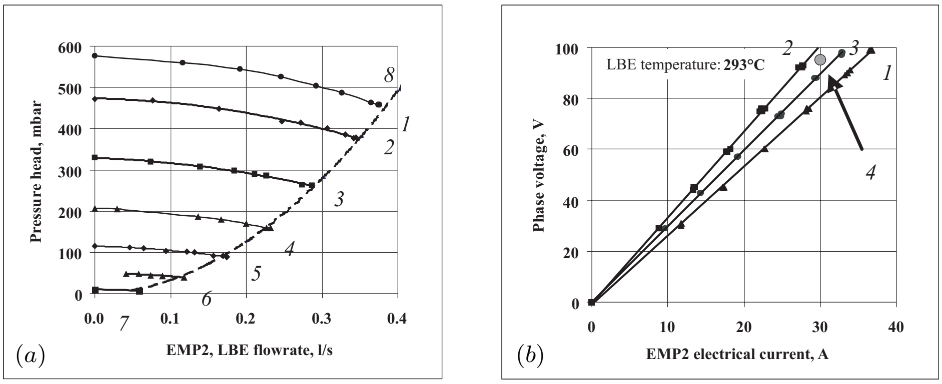

Fig. 4. (*a*) EMP currents, A: *1* – 33.2; *2* – 30.2; *3* – 25.1; *4* – 19.9; *5* – 15; *6* – 10.1; *7* – 5; *8* – hydraulic characteristic of the MEGAPIE target by-pass channel. (*b*) *1* – phase "R"; *2* – phase "S"; *3* – phase "T", *4* – rated nominal value.

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