HIGH POWER NEUTRON CONVERTER FOR LOW ENERGY PROTON/DEUTERON BEAMS: LIQUID METAL DRIVING SYSTEM*

M.Blinov, V.Golikov, K.Gubin, M.Kholopov, P.Logachev, V.Popov, S.Shiyankov, I.Zhul,
BINP, Novosibirsk, Russia,

Abstract

Nowadays in BINP, Russia, the high-power high-temperature rotated graphite-made neutron converter is proposed in order to use neutron source for SPES (INFN-LNL, Italy) and SPIRAL-II (GANIL, France). The target is designed to produce up to 10^{14} neutron per second within the energy range of several MeV under irradiation by proton/deuteron beam of power up to 200 kW. One of main problem on the converter development is to provide the reliable and effective driving gear and cooling systems. The main elements of the system must be liquid metal pumps and motors, cooling channels and heat exchanger. This paper describes proposed scheme, its basic technical parameters, estimations of the system whole as well as of separate elements. The lead-tin alloy is used as the transmission agent. At present the prototype of liquid metal motor/pump is successfully manufactured and operates for more than 16000 h in continuous regime.

INTRODUCTION

In the framework of SPES project [1] in INFN LNL (Legnaro, Italy) and ISTC project 2257 the high temperature rotated graphite-made converter (cooled by self thermal radiation) was proposed as the intense source of high-energy neutrons [2]. In nominal operating conditions the target with diameter close to 1.2 m should be exposed to the proton beam with power up to 200 kW and size close to 3 cm. Normal speed of target rotation could be around 20-50 Hz.

One of most complicated technical problem in order of target development is the design of target driving and cooling systems. Calculations of the target operational conditions and experiments with the target prototype demonstrate that temperatures near the shaft and bearing units can reach 300-400^{0}C in nominal regime [3]. This condition simultaneously with the vacuum up to 10^{-4} mbar and very hard radiation flux (up to 10^{14} neutron per second with energy in region of several MeV) allow impossibility the using of traditional mechanical methods. Additive difficulty is long-term necessary resource of system (not less 10000 h) in the presence of impossibility of target service and repair over the materials activation during the target operation. Radiation resistance also limits selection of the target materials and construction.

The liquid metal (LM below) driving gear seems most adequate for the performing of target motion in this case.

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LM SYSTEM DESIGN

The system, proposed to realize, is shown on Fig. 1 and consist of two different parts – "pumping" and "targets" connected by the pipelines. 3 LM pumps, moved by electromotors, placed inside special reservoir on the distance close to 5 m from target unit. This decision caused by the necessity to place all serviced equipment beyond the biological shielding. The special pipes connect both parts.

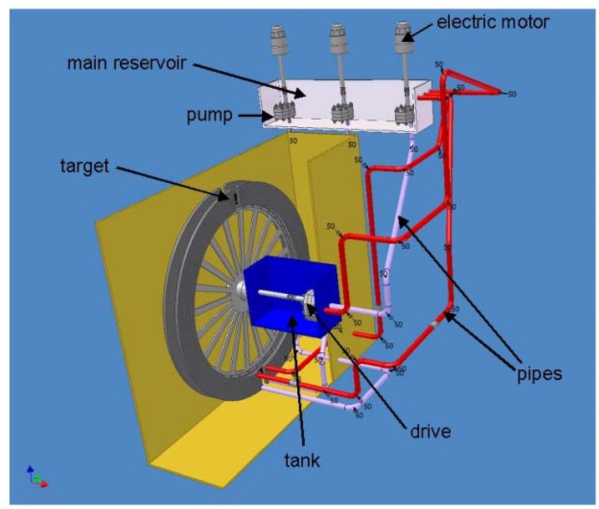

Figure 1: Layout of the liquid metal system.

LM gear/suspension prototype is located inside the cooled vacuum chamber. It consists (see Fig. 2) of a motor which design is reverse to the pump, a shaft connected to a motor, a suspension assembly with sliding bearings. LM delivered from the engine body to the tray surroundings via the special channels acts as a lubricant for the bearings.

All elements are mounded inside the special tank, filled by LM. Special LM motor/pump removes metal from this tank into the pumping reservoir. All elements of system have controlled stabilized temperatures, provided for special sectional system.

Another LM circuit is destined for cooling of target and consist of LM pump, cooling channels, heat exchanger.

Main parameters of facility are presented in Table 1.

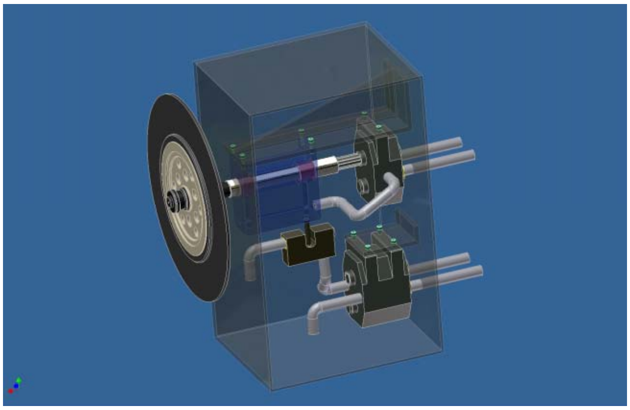

Figure 2: Layout of driving gear.

Table 1: Main parameters of the LM driving system

Driving agent	90% Pb + 10% Sn
Contour pressure	8-10 at (up to 20 at when approaching the nominal conditions)
Pumps consumption	up to 35-40 lpm
Drive/pumps rotation speed	up to 2000 rpm
Pumps/motors power	2500 W
Liquid metal total volume	~ 50 l
Operating temperatures	300-400 ^{0}C
Total heating power	up to 15 kW

Proposed liquid metal scheme of target motion has one more important feature: materials of target operate under very high radiation flux. One of most effective method, providing the removal of radiation damage, is the annealing. It means the work at sufficiently high temperatures and is realized automatically with using of the liquid lead alloy.

BASIC TECHNICAL SOLUTIONS.

Proposed system based on results of development of liquid metal positron target, performed in INP during 2004-2006 years.

The liquid lead-tin alloy is proposed to use as a transmission agent. This alloy has melting point 290^{0}C and enough low viscosity at operating temperatures. Its additive advantages are minimum slag productions and, from other hand, good lubrication of mobile surfaces by the tin.

Design and dimensions of cogwheel motors and pumps are fully identical. LM pump for the liquid metal have construction based on modified cogwheel layout (see Fig. 3, Tables 1 and 2). Pump useful capacity (volume of liquid passed through the pump per one turn of a cog) is V_0= 35.06 cm^3. The mechanical efficiency of a pump that is caused by the dry friction of movable parts and the viscosity of circulated liquid, is $\eta_M = 0.8$. The volume efficiency, which is result of the liquid leakage between the cogwheel heads and a pump body is $\eta_V = 0.9$. One of the most important pump characteristics, the non-uniformity is 20%. For cogwheel rotation, taking into account the efficiency, the engine with N=2.2 kW power is required. With power of motor 2.2 kW (rotation speed 30 Hz), the cogwheel pump reaches the torque moment M=13.9 N·m. For shaft and pump body sealing, the body is equipped with a spiral channel for liquid lead flow. The special drain channels for liquid lead supply to sliding bearings and their lubrication are also available.

The special oxide ceramic wear-resistive coating of inner surfaces treats pumps. This coating has a good chemical and radiation resistance also.

At the present time (June, 2008) the pump prototype successfully tested during more than 20000 h in continuous regime. The analogous coated sliding bearings prototypes have being tested at BINP demonstrated high reliability too. The also have a good result of tests.

Table 2: Pump design

Number of cogs	9
Primary circle diameter	50,0 mm
Vee diameter	39,0 mm
Cog head diameter	60,0 mm
Cogwheel thickness	20,5 mm

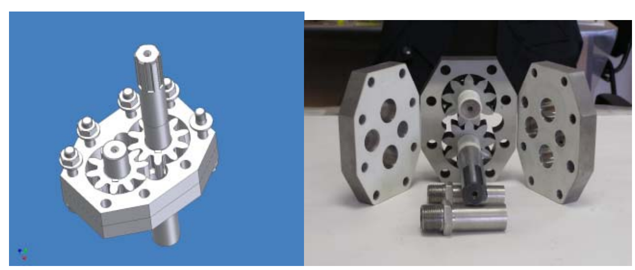

Figure 3: Design and basic elements of LM cogwheel pump.

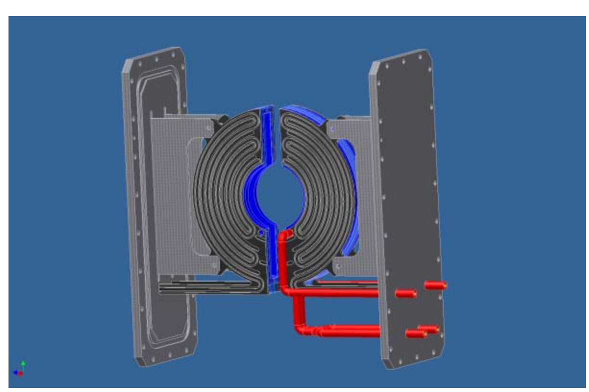

Figure 4: Cooling channels assembly design.

Table 3: Cooling channels section parameters

LM channel cross section	15 x 10 mm
Total length of LM channel	1385 cm
LM consumption	0.2 l/s
Total removed power	30 kW
Heating-up of LM	50 K
Pressure drop of LM	2.7 at

Design and parameters of cooling channels are shown on Fig. 4 and Table 3. Channels designed to remove 30 kW power from the target 30 cm in diameter (beam point) and have the rectangular cross-section 10x15 mm and double-wound position (in 5 units at the diameter from 195 to 435 mm on the frontal and rear panels; in 2 units at the diameter 460 mm on the lateral panels). Channels made of stainless steel and use LM as a heat carrier.

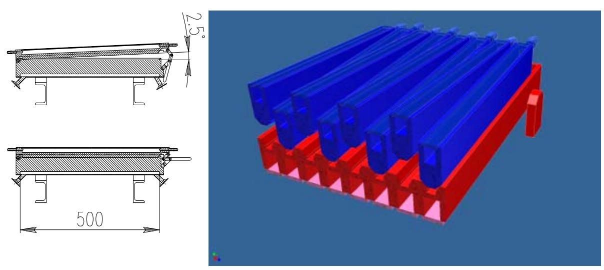

Figure 5: Heat exchanger design.

The scheme of heat exchanger suggested for developing is shown in Fig. 5. The device comprises two groups of channels for heat exchanging; one is intended for hot LM, the other one – for water from the external circuit. "Hot" channels have the cross-section 10 x 15 mm rigid sequential joint in two parallel sections with the total channel length of 4 m. (8 straight cuts 0.5 m each). Nominal LM consumption is 0.2 l/s per section, pressure drop over the heat exchanger is 0.8 at. Water group of channels has 8 response parallel sections. Each water section is independently movable and could be separated from LM group. This is done in order to minimize of power required for the initial heat-up and, at the same time, to provide the heat power removal control and tuning for different target operation modes.

CONCLUSION.

Nowadays prototype of this whole system is under construction. During 2008 – 2009 years it will be tested under electron beam with the power 30 kW. Tests will include long-time (~ 1 year) continuous test of prototype in nominal operational conditions.

At the same time the estimation of activation of complete system in conditions of SPES and SPIRAL-II projects and the system optimisation from the radiation safety are planned.

Solutions and experience of proposed facility could be efficient in view of development of high-power beam dump systems for accelerator complexes of next generations.

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