EXPERIMENTAL TESTING FACILITIES FOR ULTRASONIC MEASUREMENTS IN HEAVY LIQUID METAL

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ABSTRACT

The thermo-physical properties of Heavy Liquid Metals (HLM), like lead or its alloy, Lead Bismuth Eutectic (LBE), makes them attractive as coolant candidates in advanced nuclear systems. The opaqueness, that is common to all liquid metals, disables all optical methods. For this reason ultrasound waves are used in different applications in heavy liquid metal technology, for example for flow and velocity measurements and for inspection techniques.
The practical use of ultrasound in heavy liquid metals still needs to be demonstrated by experiments. This goal requires heavy liquid metal technology facility especially adapted to this task.
In this paper is presented an experimental testing facility for investigations of Heavy Liquid Metals acoustic properties, designed and constructed in RATEN ICN.

Key words: Heavy Liquid Metals, ultrasonic HLM testing

Introduction

The thermo-physical properties of Heavy Liquid Metals (HLM), like lead (Pb) or its alloy, Lead Bismuth Eutectic (LBE), makes them attractive as working fluids in advanced nuclear systems such as Lead Fast Reactor (LFR). For the demonstration of the LFR technology chains, further facilities (either existing or under construction) are required. Romanian option to host LFR Demonstrator ALFRED (Advanced Lead Fast Reactor European Demonstrator) involves RATEN ICN in future developments of technology, in frame of European projects aimed to Generation IV research activities. For safety as well as for licensing reasons, an imaging method for evaluation of status of inner reactor, parts submerged in the opaque hot liquid metal, has to be developed.

The opaqueness, that is common to all liquid metals, disables all optical methods. There are not many other physical means except ultrasonic, which would enable to “see” through liquid metal. Therefore visual inspection is done using ultrasonic waves. In the image, it would be possible to show the bottom profile of the reactor vessel, to recognize separate elements and estimate their dimensions and positions. The advantage of such an approach is that the ultrasonic image of the reactor interior will be constructed, in which elements of the construction may be recognized. High temperature ultrasonic transducers (sensors) are suitable for operation inside the HLM.

Ultrasound Doppler velocimetry of hot melts flows is an important field of high temperature ultrasonic transducers applications. Until now, no velocity measuring technique for liquid metals flows is available commercially. Apart from high temperatures, wetting and corrosiveness are the main difficulties of the measurements in liquid metals. Wetting behaviour can be evaluated by means of ultrasonic technique. In this case a positive feature is ultrasound propagation in liquid metals.

without significant attenuation. Therefore, ultrasonic methods are promising for on-line monitoring of molten metal properties. Possibility of ultrasonic ranging and imaging in liquid metals is very important for establishment of quasi-visibility inside modern reactors, cooled by Pb alloy

The practical use of ultrasound in liquid lead still needs to be demonstrated by experiments. This goal requires measurement technologies especially adapted to them.

The attenuation and velocities of ultrasound waves in HLM, the reflection properties of HLM, the wetting parameter, etc can be investigated by pulse echo technique, in a liquid metal pool, at different temperature (up to 450oC), in static conditions, using a special measurement configuration (with hard reflector). For transmission and reception of ultrasonic signals, an ultrasonic transducer with 5 MHz piezoelectric element suitable for high temperature conditions is necessary.

In this situation, a regular right-angled between beam axis and reflector surface are necessary. For this reason we chose to perform the measurements in a vertical tube equipped with a mobile reflector (upside) and a fix ultrasonic transducer (bottom). This device is immersed in liquid environment.
The investigation of ultrasound waves attenuation consist in evaluation of losses of the signal in propagation path, at various transducer - reflector distances for get valuable quantitative information about the variation of signal amplitude versus a distance.

An experimental facility for measurement of liquid lead acoustic properties (sound velocity and damping) by pulse echo technique has been developed in RATEN ICN.

This type of measurement is possible by characterisation with ultrasound waves in stagnant heavy liquid metal environment.

Experimental facility description

Experimental ultrasonic testing includes the necessary elements to realize the transmission and acquisition of ultrasound for the manual movement of the reflector, to heat up and also to maintain the molten lead to different temperatures to isolate enclosure and subsequently for measuring and adjusting the concentration of oxygen.

This experimental facility consists of three main parts (figure 1) [ref.1,2]:

- mechanical system;
- heating system (electrical resistance around vessel, thermoresistants, thermoregulator and thermal insulation);
- ultrasonic system;

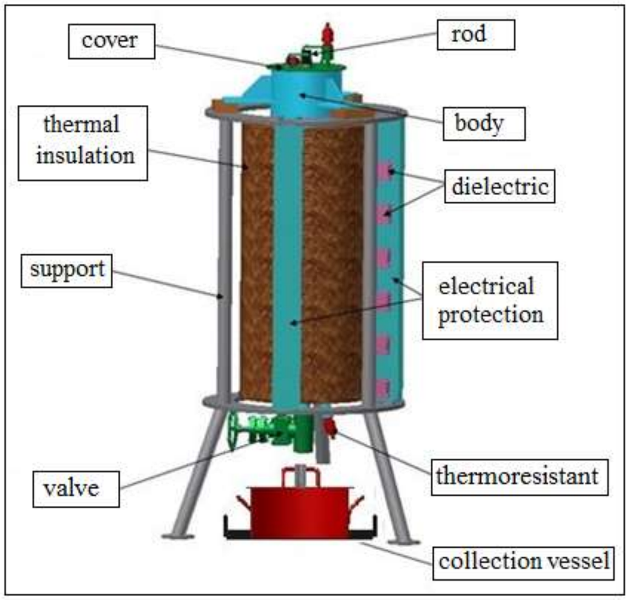

Fig. 1*- Experimental facility: design*

The main component of the experimental device is a stainless steel container in which the melt lead is filled in and maintained. At the top of it is a removable circular cover, provided with more slots for the passage of ultrasonic transducer, thermocouple, thermal resistance, etc.

Measurements of ultrasound signal attenuation in liquid environment were performed using pulse echo technique. In this situation it is necessary to have a good perpendicularity between beam axis and reflector surface. For this reason we chose to perform the measurements in a vertical tube support provided with a mobile reflector as shown in figure 2.

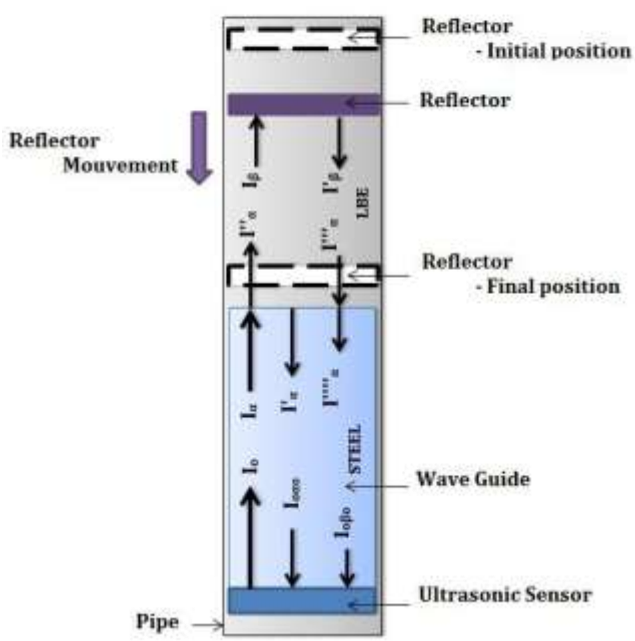

Fig. 2 *Schematic representation: experimental device and ultrasonic signals used for ultrasonic attenuation measurements by pulse echo technique, in HLM.*

The vertical tube is fixed on the circular cover from top. The reflector is manually operated slide through this support tube; it is fitted with holes to allow the movement of lead output of support tube (figure 3 - right). Maximum working distance (transducer - reflector) is not bigger than 500mm. The transducer is connected to the ultrasound pulser-receiver via a connector suitable for these high temperatures.

The ultrasonic system is intended for generation and acquisition of ultrasonic signals. It consists of an ultrasound pulser-receiver, a piezoelectric ultrasonic transducer suitable for high temperature conditions, with a stainless steel waveguide (for transmission and reception of ultrasonic signals), a oscilloscope (for data visualization and automatic sampling).

Ultrasonic transducers, suitable for operation inside the HLM, have to meet the following requirements:

- continuous operation at high temperatures (up to 450^{o} C)
- corrosion-resistant to HLM;
- pressure resistant;
- radiation resistant (not for our device)
- good electro-acoustic efficiency

Taking into account these requirements, the following problems have to be solved by the researchers from this field of activities.

By moving the reflector can be obtained different transducer - reflector distances. For every position we receive the ultrasonic pulse type signals. The collected data (ultrasonic pulse type signals) were analysed by means of MATLAB software program.

Fig.3 *R*emovable circular cover – top view (left); reflector and support tube (right)

At the bottom, the container is equipped with a valve for discharging molten lead.

The heating system is intended for heavy liquid metal (Pb) melting and keeping it at the preset temperature. It consists of heat source (electrical resistances uniformly distributed on the outside of the container's surface) (figure 4 - left), thermal resistance, thermo-regulator and thermal insulation (a cover with a heat insulating layer) (figure 4 - right). This insulating layer is designed to allow a max 50 degrees temperature on the outside of the vessel surface.

To regulate and maintain a constant temperature it is used two thermoresistances which measure the temperature. It is able to maintain a max temperature of 450°C.

Fig. 4 *- Experimental facility: intermediate stage - without insulation (left)/ with insulation (right)*

The oxygen level from the liquid lead is not adjusted (no oxygen control system).

Preliminary tests of heating system

The temperature of the inner environment can be monitored by two thermocouples inserted in the vessel. The preliminary tests of heating system [ref.2] aim heating capacity, temperature monitoring and command of system. They consist in measurements of temperature, at regular intervals, in several points inside the vessel (air environment) and on the electrical resistance. The acquired values are graphically visualized in figure 5.

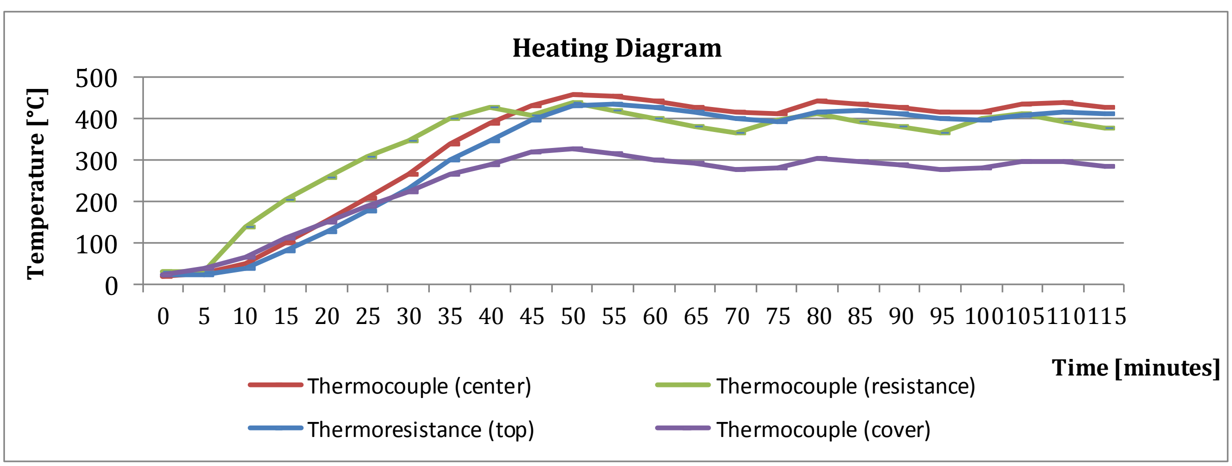

Fig. 5 *- Heating Diagram*

In the diagram we can see obtaining a level of the temperature around the value set (400°C).
In the next period is scheduled the calibration of the heating system.

Conclusions

- This device is the first experimental facility from ICN for ultrasonic characterization of HLM.
- This is the first test operation of heating capacity and temperature monitoring of this experimental facility.
- This work contribute at development of guidelines for studies of acoustic properties of HLM

References

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