STUDY TO SET UP THE EXPERIMENTAL FACILITY FOR THE ULTRASONIC MEASUREMENTS IN THE LIQUID LEAD

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Abstract

The thermo-physical properties of heavy liquid metals (Lead or its alloys Lead Bismuth Eutectic) make them attractive as nuclear coolants of advanced nuclear systems (Lead Fast Reactor). For the opaque hot liquid metal environment, the ultrasonic wave is the only physical mean enable to receive feedback from operations that take place inside the reactor. The practical use of ultrasound in these harsh conditions still needs to be demonstrated by experiments. This goal requires experimental facilities and measurement methods specially adapted to them. The paper presents the stage of the experimental facilities for ultrasonic measurements developed within RATEN ICN. This is devoted to investigating the ultrasonic signal attenuation in the liquid lead by the pulse-echo technique. The acoustic parameters (attenuation coefficient and wetting factor) can be calculated from the measured values of the signals parameters (amplitude and the time of fly). The main concern for the measurements is the high temperature resistant ultrasonic transducer suitable for operating in liquid metal up to 450 °C. In the present stage, in the absence of an immersion transducer, we approached the variant with the external transducer in acoustic contact with a stainless steel waveguide submerged in the liquid metal. Paper includes the equipment description, the problems and difficulties encountered, as well as a prospection of the improvements for further development.

Keywords: *Heavy liquid metals, Ultrasonic measurements, Pulse-echo technique*

Introduction

The thermophysical properties of Heavy Liquid Metals (HLM), like lead (Pb) or its alloys, Lead Bismuth Eutectic (LBE), make 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 the frame of European projects aimed at Generation IV research activities. For safety as well as for licensing reasons, an imaging method for evaluation of the status of inner reactor parts submerged in the opaque hot liquid metal has to be developed.

The opaqueness, which is common to all liquid metals, disables all-optical methods. There are not many other physical means except for ultrasonic, which would enable us to ″see″ through liquid metal. Therefore visual inspection can be done using ultrasonic waves.
The possibility of ultrasonic imaging in liquid metals is very important for the establishment of quasi-visibility inside modern reactors cooled by lead alloys.

To obtain the necessary resolution and accuracy, a good knowledge of ultrasonic wave propagation characteristics in a liquid metal is needed. There are two main characteristics of the ultrasonic waves, which are necessary to determine: velocity and attenuation [5-7].

The practical use of ultrasound in the liquid lead still needs to be demonstrated by experiments. This goal requires measurement technologies specially adapted to them. For these reasons, an experimental facility for ultrasonic measurements in a stagnant liquid lead environment by pulse-echo technique has been developed in RATEN ICN.

The principle of measurements

Ultrasonic pulse-echo techniques are often used to perform non-destructive testing and characterization of materials due to their simplicity. These techniques can probe interiors of opaque environments and make measurements under elevated temperatures. Such techniques sometimes require ultrasonic transducers of large bandwidth, high signal-to-noise ratio, and to operate at elevated temperatures.

The main problems met in our case are caused by the high temperature (up to 460 °C) and the aggressive properties of the liquid lead. Therefore, a single element ultrasonic transducer suitable for harsh operating conditions has to be used [5-7]. In current development stage, the experimental facility is equipped with the ultrasonic transducer in acoustic contact with a stainless steel waveguide.

For this situation, the acoustic coupling between the ultrasonic transducer and the waveguide is an essential problem at high temperatures, the reason for which the contact surface must be flat and polished. To provide acoustic coupling the frontal surface of the transducer is pressed via silicone gel to the polished surface of the acoustic waveguide (stainless steel AISI 316 rod).

When the stainless steel waveguide is immersed in a liquid vessel, the ultrasonic signals reflected by the bottom face of the waveguide and the reflector placed in the liquid are exploited. Their amplitudes and time of fly values are measured. They are converted into a digital form using the digital oscilloscope. The digital data files are stored and processed on a personal computer. The investigation of ultrasonic waves attenuation consists of the evaluation of losses of the signal in propagation path, at various transducer - reflector distances to get quantitative information about the variation of signal amplitude versus a distance. Thus, the distance between bottom face of the waveguide and front surface of the reflector must be varied.

The transducer radiates and receives pulsed ultrasound using a pulser /receiver. The lead contained in a stainless steel vessel is heated by the heating system. A schematic diagram of the ultrasonic measurements in liquid lead using pulse-echo technique is shown in Fig.1.

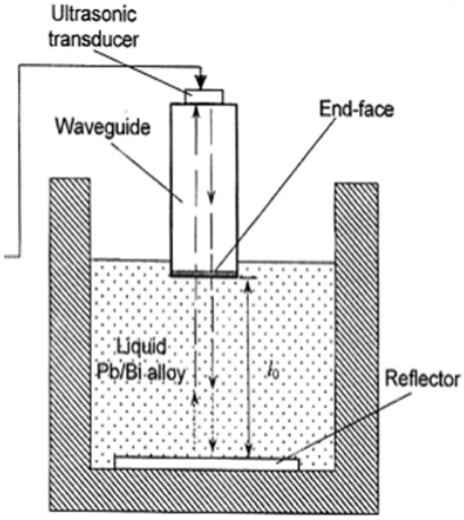


Fig.1. Experimental set-up for investigation of the high-temperature environment

2. 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.

The experimental facility, in current phase of construction, consists of the following parts (Figs. 2 and 3) [1-4]:
- *mechanical component*: the main vessel with accessories (guide device, thermal insulation, electric protection, etc);
- *electrical component*: heating system (electrical resistance around vessel, thermo-resistances, temperature controllers, power supply);
- *ultrasonic measurements component and data acquisition system* (a contact transducer acoustic coupled with a stainless steel waveguide, an ultrasonic pulser/receiver, a digital oscilloscope, a computer with MATLAB software).

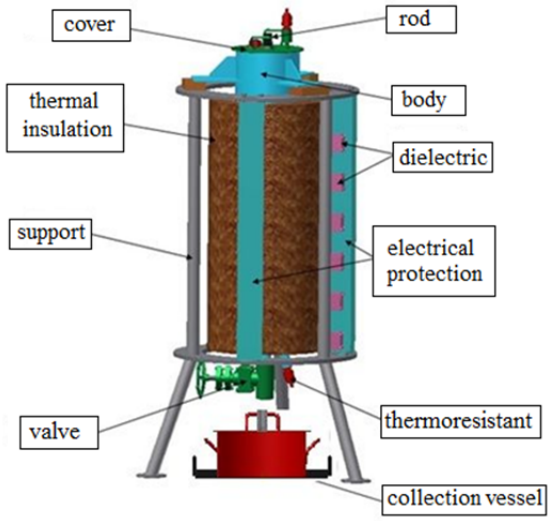


Fig.2. Main vessel with accessories (design)



Fig.3. Experimental facility

Mechanical component

The main component of the experimental device is a stainless steel vessel (see Fig.4) in which the lead is heated and maintained melted, in order to perform the ultrasonic measurements. At the top of the vessel there is a removable circular cover, provided with more slots for passage of ultrasonic transducer, thermocouple, thermal resistance, etc. The insulating layer is designed to allow a maximal temperature of 50 ^{0}C on outside of the vessel surface [2].



Fig.4. Main vessel with some accessories

For ultrasonic measurements by pulse-echo technique is necessary to have a good perpendicularity between the beam axis and the planar reflector surface. For this reason, the measurements were performed in a vertical tube equipped with a fixed reflector in the bottom end. The waveguide (Ø 19 mm, stainless steel rod) is a manually operated slide through the support tube (Ø 21 mm, stainless steel AISI 316) immersed in a liquid environment. The end surfaces of the waveguide must be polished. The reflector must ensure a stable good quality reflection of ultrasonic waves.

The vertical tube is fixed on the circular cover from the top as shown in Fig. 5. This assembly is called a *guide device*; it is fitted with holes to allow the movement of the lead output of the support tube. The maximum working distance (transducer - reflector) is not bigger than 300 mm. The transducer is connected to the ultrasound pulser/ receiver via a connector suitable for these high temperatures.



design finite product

Fig.5. Guide device

The geometry principle of the ultrasonic measurements with our experimental facilities is shown in Fig.6.

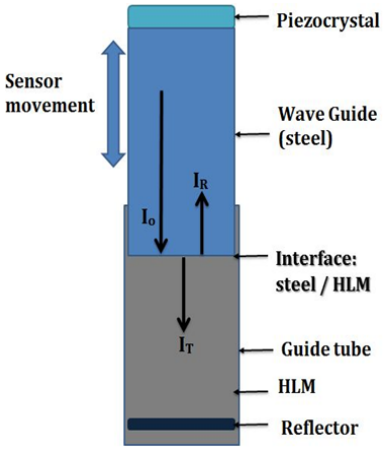


Fig.6. Geometry of the ultrasonic measurement

Electrical component

The electrical supply, control and automation installation have the functional role of ensuring power supply for [2]:

• two heating and temperature maintenance circuits around the vessel, inside the enclosure with temperature monitoring;

• execution of the related orders and signals, complying the norms of protection for electrical installations and personnel.

The electrical component of the device mainly consists of the following components:

• electrical panel;

• two supply and control circuits for the heating resistors around the vessel, inside the enclosure (three resistors per circuit connected in the star) as shown in Fig.7;

• automation, temperature measurement and control system: heat resistant and temperature regulators (Fig.7).



Fig.7. Electrical resistances uniformly distributed on the outside of the vessel's surface

Ultrasonic measurements component

The ultrasonic component (see Fig.8) is used for experimental measurements in molten lead and data processing. It has the following parts [3, 4]:

- an ultrasonic contact transducer Olympus V608, unfocused, resistant to high temperatures (up to about 100 °C), with a resonant frequency of 5 MHz and a diameter of 0.75 "(Ø 19 mm). The transducer can be connected to pulser/receiver with a high-temperature resistant mineral cable.
- a waveguide (AISI 316 stainless steel bar, $Ø_{ext}$ 19 mm, length 600 mm), ultrasonic transparent material and without defects. It is acoustic coupled with the contact transducer (see Fig.9) and allows measurements in high temperatures (up to 450 °C) environments by sliding inside the guide tube ($Ø_{int}$ 21 mm).
- a TecScan pulser/receiver system for the transmission/ reception of the ultrasonic signal;
- a digital oscilloscope for viewing and digitizing the received signals;
- a computer PC with MATLAB programming language.



Fig.8. Ultrasonic devices

The length of the waveguide is set so that the temperature at the contact surface with the piezocrystal is accepted in the transducer's operating specification. It is acoustically coupled to the front surface of the ultrasonic transducer and acts as a protector.



Fig.9. An ultrasonic transducer in acoustic contact with stiles steel waveguide

For data processing, it is necessary to establish mathematical relationships between the measured (amplitude and time of flight values for monitored signals) and the determined (attenuation coefficient and wetting parameter) parameters.

Thus, the following ultrasonic signals involved in the propagation of ultrasonic pulses through examined media are used (see Fig.10).

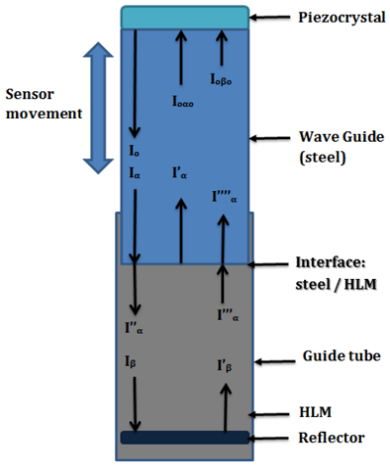


Fig.10. Schematic representation: ultrasonic signals used for ultrasonic attenuation measurements by pulse-echo technique

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

By moving the waveguide can be obtained different waveguide bottom surface - reflector distances. For every position, the ultrasonic pulse-type signals are received. The collected data (amplitude and time of flight values for monitored signals) are analysed by means of MATLAB software program.

Preliminary tests

Heating system preliminary tests

The inner environment temperature can be monitored by two thermocouples inserted in the vessel. The preliminary tests of the heating system targets are the heating capacity, the temperature monitoring and command of the system. They consist of measurements of temperature, for regular time intervals, at several points inside the vessel (air environment) and on the electrical resistance. The acquired values are graphically visualized in Fig.11.

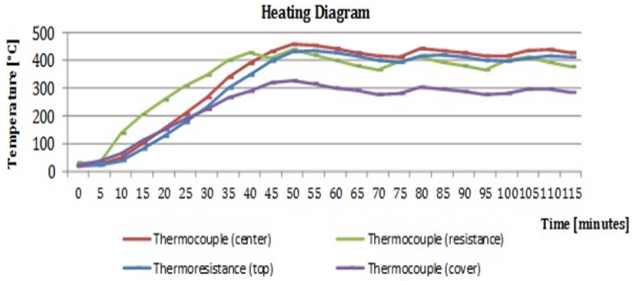


Fig.11. Heating Diagram

In the diagram, a level of the temperature around the value set (400 °C) can be noticed.

For next period, the heating system calibration is scheduled.

Ultrasonic measurements preliminary tests

Preliminary tests in water and liquid lead were performed to verify the functionality of the equipment and to develop a testing methodology for acquisition and processing of experimental data [3].

The signal received by the piezoelectric element is amplified by the pulser/receiver and visualized on the digital oscilloscope in representations A-scan (amplitude [V] - time [μs]). These representations can be saved using the oscilloscope, as .jpg picture format files or .csv data files. The .csv data files are viewed and processed using the MATLAB software application. Representations of Signal Amplitude [V] vs. Time [sec] (Fig.12) are obtained.

Now, the acoustic parameters (attenuation coefficient and wetting parameter) can be calculated from measured values of the signals parameters (amplitude and the time of fly).

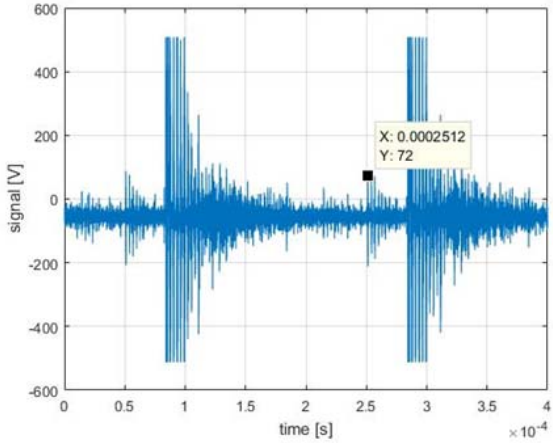


Fig.12. Viewing data files in the MATLAB program: first reflector echo

Conclusions

The device presented in this paper represents the first experimental facility from RATEN ICN designed for the ultrasonic characterization of the heavy liquid metals.

This work contributes to the development of the guidelines for studies of the heavy liquid metals acoustic properties.

The preliminary tests presented in this report highlighted the need for some improvements in the installation design, as follows:
- a planar Titanium reflector (this material is not wetted by the liquid lead and ensures a stable good quality reflection of ultrasonic waves)[5];
- a liquid metal (lead) with a higher level of purity;
- a better perpendicularity between the beam axis and the planar reflector surface;
- a better acoustic contact between transducer surface and top waveguide surface (by means of glycerine gel);
- a high temperature resistant ultrasonic transducer of 5 MHz frequency, with Ø 10 mm in diameter, suitable for operating long time, immersed in liquid metal up to 450 °C (this eliminates the attenuation due to the metallic waveguide);
- an oxygen control system for measuring and adjusting the oxygen concentration (it allows maintaining oxygen concentration in the field of interest).

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