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FLOW MEASUREMENT IN A SINQ MOCKUP TARGET USING MERCURY

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ABSTRACT

An investigation on a flow behaviour of SINQ target is under progress. The experiment is performed using mercury as a model liquid in a mockup target geometry. Measurement is by using ultrasonic Doppler method and one- and two-dimensional stationary flow has been in fully investigated for the hemispherical geometry in the form of velocity profiles and flow maps. Effects of gap geometry and flow rate was investigated. The velocity level was found to be quite low in a deep pocket region of the window, but the flow field is quite symmetric to the beam axis as a time-averaged behaviour.

INTRODUCTION

Flow behaviour around the beam entry window is of utmost importance in relation to heat transport in liquid metal target and to cooling of window by target liquid itself. Design criteria has not yet been clarified and it is an urgent need to investigate flow and temperature behaviour in this region. However, measurement of a flow, a velocity at any point or its spatial and temporal distribution, has been one of the most difficult tasks in using liquid metals and, because of it, its application to the study in physics and to industrial devices has been largely limited.

For overcoming such difficulties, the ultrasonic Doppler method has been developed at PSI and is established after a long development effort [1-3]. This method uses a pulsed echography of ultrasonic beam. From the echo signal, a position information is derived from a time difference between pulse emission and echo reception, and velocity information is from instantaneous frequency at each instant of echo reception. By processing the echo signal such that the instantaneous frequency is obtained as a function of time after pulse emission, instantaneous velocity profile can be obtained.

In this paper, we present our latest results of the measurement of mercury flow in the SINQ mockup target geometry. The investigation is only about flow behaviour and the use of mercury in a forced convection loop can be justified because the investigation is about local flow behaviour and mercury has very similar physical and thermal properties to Lead-Bismuth Eutectic which is a target material of SINQ.

EXPERIMENTAL SET-UP

Mercury loop

The mercury loop of IPLU (Inst. Physics Latvian University) consists of an electromagnetic (EM) pump, two coolers, EM flow meter, a reservoir tank and SINQ target test section. The total mercury inventory is 4.6 m^3 (6 tons) and the maximum flow rate by this EM pump is 4.2 *l*/s. The loop is operated under the room temperature.

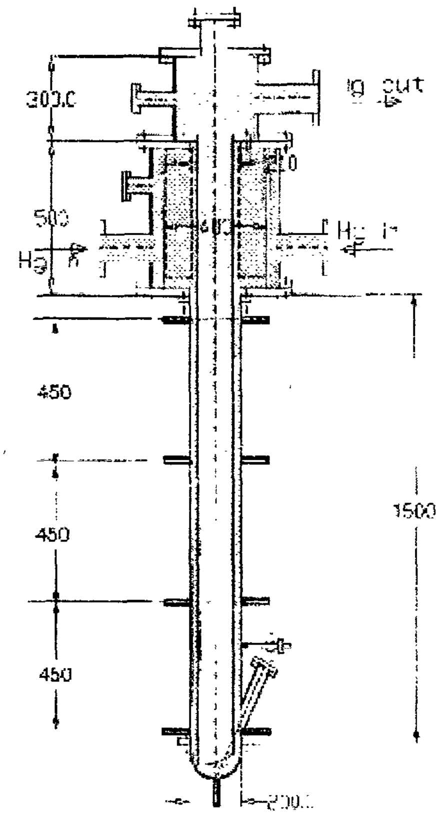

Figure 1 Test section (SINQ Target geometry)

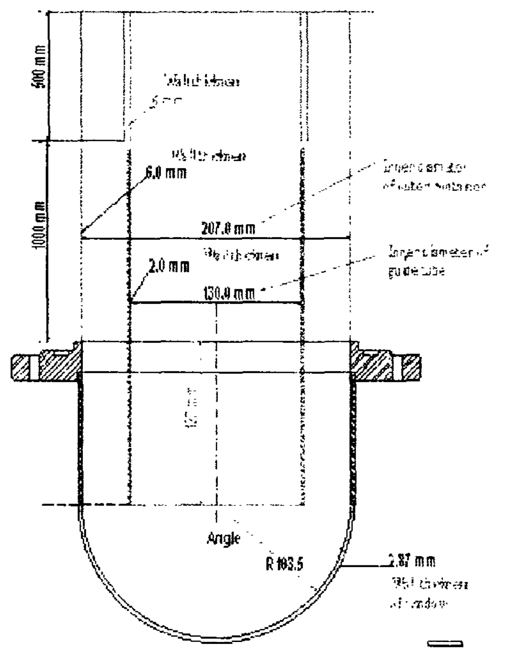

Figure 2 Geomtry of SINQ target window region

Test section

The SINQ target test section is illustrated in Fig.1 and 2. It consists of double coaxial cylinders and has two buffle chambers at the top for inlet and outlet flow respectively. The mercury is fed into this chamber through 6 inlet tubes connected to it. It then flows down in the annular channel toward the bottom part called "window". The fluid turns there into a inner circular channel inside the inner guide tube and flows up to the second chamber for outlet. The diameter of the outer tube is 207 mm and the total length of the test section including these chambers is ca. 2.3m.

We have prepared two kinds of windows having different shapes. The one is a hemispherical window and another has a so-called Kloepperboden shape. The hemispherical window is, however, a reference shape in this study. The radius is 103.5 mm with its center at the exact edge of the guide tube. The geometry of the flow channel is given in Fig.2 and Fig.3 shows this window mounted on the test section.

The Kloepperboden is a structural element and has a flatter structure. Due to a space limitation, the results would be reported separately, and only the result of hemispherical window is reported. All the components and windows are made of stainless steel.

Instrumentation

Flow measurement was made using ultrasonic Doppler method (UVP). The device was developed at PSI aiming at the measurement of flow velocity of liquid metal. In order to be able to measure the flow from

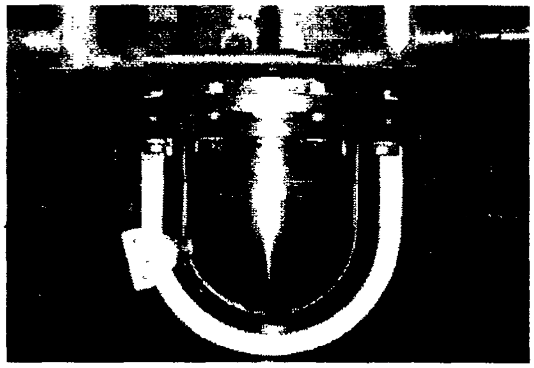

Figure 3 SINQ target window mounted on test section

outside the container wall, the wall thickness was selected as 2.87mm. The standard normal temperature transducer was set on the wall using a positioning device.

For the UVP to work successfully, it is a condition that the fluid includes tiny particles as a reflector of ultrasound wave with fairly high concentration. Due to a large density of mercury, most of impurities and gas bubbles are segregated before the loop is started. Therefore, nitrogen gas was injected prior to startup of the loop to mix small bubbles in the liquid as a reflector of ultrasound.

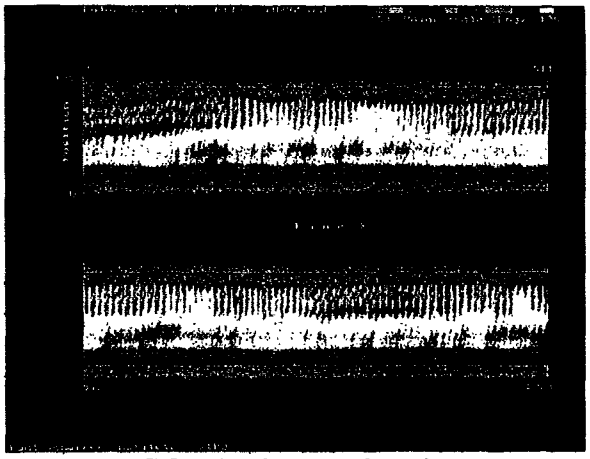

Figure 5 Color density plot of spatio-temporal behavior of the Mercury flow.

One of the worries supposed before the experiment was a problem of wetting of Mercury to the stainless steel wall. It is well known that Mercury has a poor wetting to stainless steel. If the wetting is poor and there remains a thin gas layer between Mercury and the wall, ultrasonic pulse cannot be transmitted to the liquid and measurement might be failed. However no such problem was encountered during the experiment. The ultrasonic beam was transmitted through the stainless wall to Mercury and back-scattered echo signal of sufficient amplitude was received from the beginning of the experiment.

Measurements

We performed series of measurements. The first one was aimed at obtaining one dimensional velocity profiles covering as wide area as possible in the window area. This series was done basically for confirming all the experimental elements such as a loop, a test section and instrumentation to be successfully prepared. And thus, measuring lines of UVP were set rather freely.

The second one was to obtain vector flow maps in the region of returning flow near the edge of the guide tube.

The third one was to study the effects of geometry and flow rate. The effect of the geometry was investigated mainly for the hemispherical window in terms of the gap distance between the edge of the guide tube and the bottom surface. Three gap distances were studied for 2, 4 and 8 cm. The flow rate was changed for 0.6, 1.2 and 2.4 *l*/s.

Experimental condition

The mercury was first well mixed in the reservoir tank by injecting gas from the bottom and then filled into the loop. After starting the EM pump, the flow rate was increased gradually. Temperature was not regulated and it was more or less room temperature around 15°C. It was however observed that it increased slightly when the power of EM pump was increased.

RESULTS AND DATA ANALYSIS

Instantaneous Velocity profiles

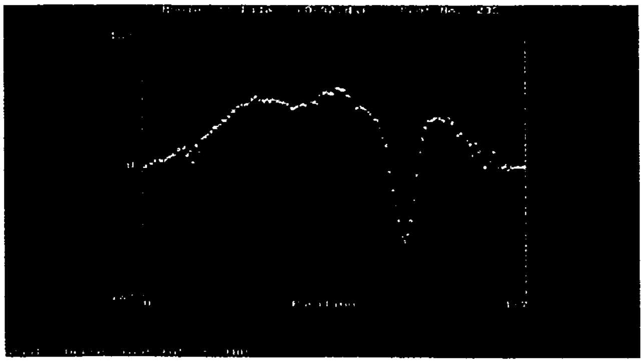

Figure 4 is a typical example of an instantaneous velocity

Fig.4 is a typical example of an instantaneous velocity profile. It shows a successful application of UVP to the mercury flow. As seen in this example, there is a large vortex structure in the flow, which shows a typical chaotic fluctuation as displayed on the color density plot in Fig. 5. The typical time resolution for one instantaneous velocity profile is 100-150 msec. When the profiles are displayed continuously on the computer screen, it reproduces the measurement in motion. However, the display in color density reveals the spatio-temporal behaviour of the flow field more clearly.

Average profiles

A typical data set consists of 1024 instantaneous velocity profiles. For investigating a stationary flow field, the time-averaged velocity profiles were computed. Fig. 6 shows averaged profiles on the center line. It should be noted that the velocity obtained by this method is a component of the velocity vector projected onto the measuring line. In this example, it is therefore a distribution of the axial component as a function of axial position on the center line; Vz(z, r=0).

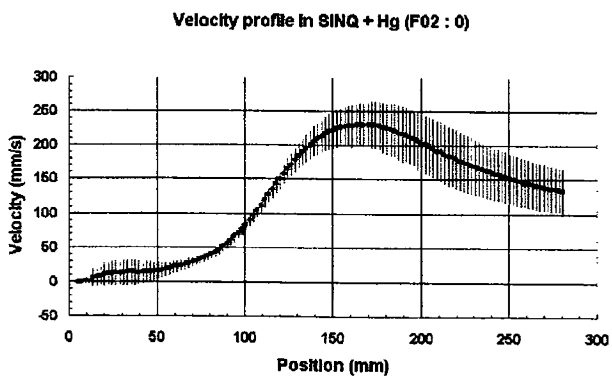

Figure 6 Time-averaged velocity profile on the center line.

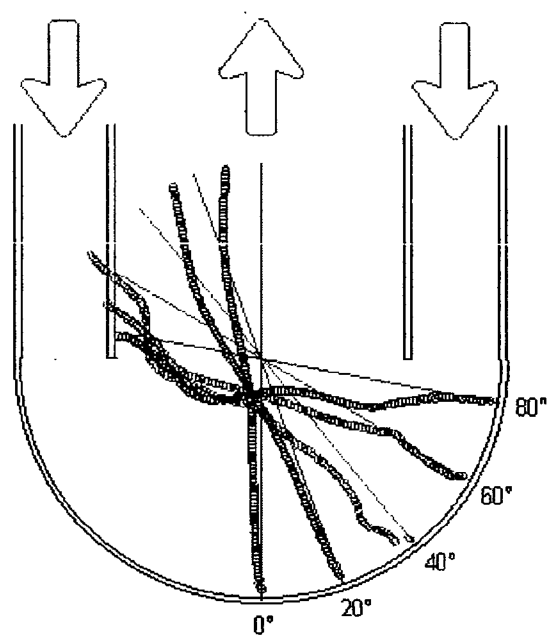

Figure 7 One-dimensional velocity profiles.

Two series of measurements were made for obtaining a one-dimensional distribution. The one is for the interior region, shown in Fig. 7. Simply it shows that the velocity is pretty low near the wall, namely inside the deep pocket of the spherical window (up to ca. 80mm) but then it is high beyond this point. Fig. 8 is a similar plot of the measurements fanned from the center of the window. It shows a fairly good (axial) symmetry and a good agreement with the nature shown in Fig.7.

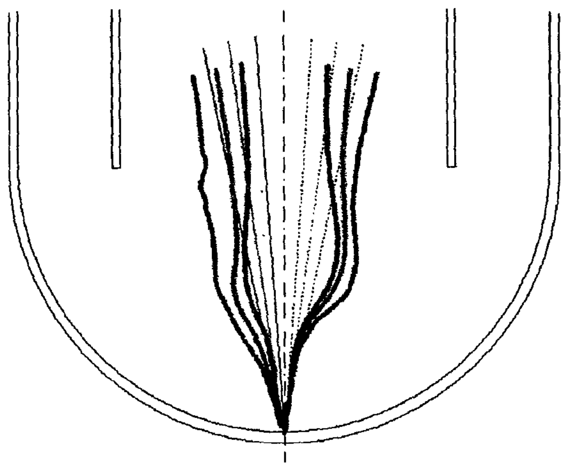

Figure 8 Flow around the centerline. (The sign of velocity coordinate is opposite for plus and minus inclination for display purpose.)

Vector map

Since all the measuring lines are aligned non-parallel, it is possible to obtain two velocity components at the crossing points of measuring lines. Even if these two components are not orthogonal, it is still possible to form a velocity vector on the crossing point from them. The second series of measurement was made for this vector map measurement, in such a way that all the measuring lines are organized suitably for forming the vectors. The details of the method to form the vector in this data analysis is given in [4].

The vector field was computed for the second series of measurement which consists of 36 measuring lines (Fig.9a). This generates in total 379 vectors in the field, when eliminating the points where two crossing angle is less than 15°. The computed vector field is plotted in Fig.9b.

The vector maps thus obtained for different gap distances and flow rate for the third series measurements are shown in Fig.10.

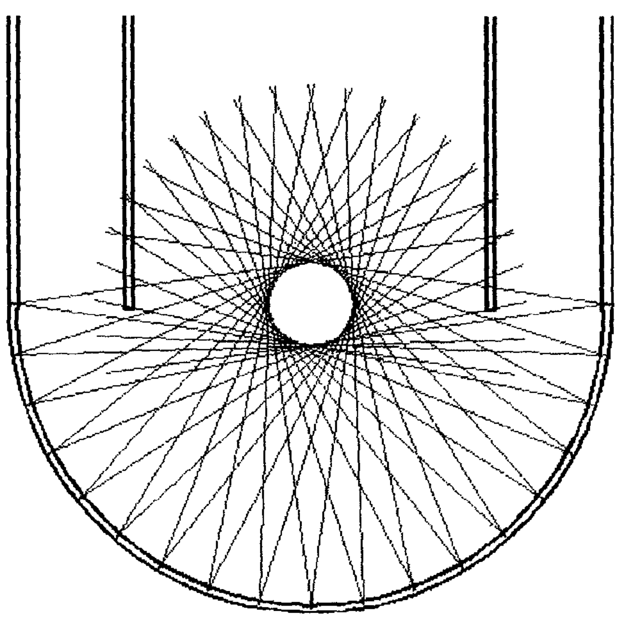

Figure 9a Measuring lines for vector map measurement

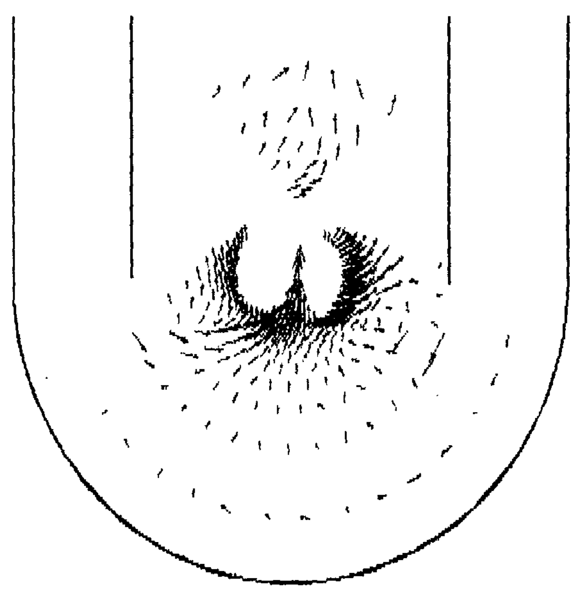

Figure 9b Obtained vector field

DISCUSSION

Flow field

As observed in Fig. 8 & 9, the velocity is very small deep inside the spherical region, especially near its top, although it is not stagnant. Since the measured velocity is a component along the measuring line, it may not be easy to read the result. The easiest case is for the angle of 0° of Fig.8 (same as Fig.6). The axial velocity is low from the bottom of the window until 100mm, namely the center of the sphere. From other measurements we know that there is a recirculation zone just behind the edge of the inner tube. This makes an effective flow area smaller in this region for a main circulation. The position where the velocity distribution shows its maximum value is roughly corresponding to this recirculating region.

When observing a flow on the color density plot or in motion picture, a typical chaotic structure could be recognized in this region; near the edge of the inner guide tube (see Fig. 5). This is a significant flow structure especially for the gap distance of 8 cm. For the smaller gap distance, independent of the flow rate, such chaotic motion is weakened.

We can observe on the plot in Fig.8 a fairly strong jet behavior of the flow exiting from the annular channel. The velocity profiles at the angle from 80° down to 40° have a portion of a flat velocity distribution near the window wall, showing an evidence of jet flow. The width of this jet becomes smaller for approaching to the angle of 40° and it disappears at the angle of 20°.

Axial symmetry

In Fig. 7 and 8, it is clearly seen that the flow field is not necessarily symmetric for the spherical window with gap distance of 8 cm. This seems to be due to the spatio-temporal chaotic flow which is generated near the edge of the inner guide tube. The large eddy is generated in this region, which is totally spatio-temporal. Time characteristics has to be studied in more detail, but it seems that our total measurement time is not sufficient to smear out this characteristics. It may be also due to a non-symmetric inlet condition in the annular channel.

Effects of flow rate

The effect of flow rate is seen in Fig.10 such that it becomes more symmetric for the large flow rate, although it is not a strong effect. A feature in the vector fields appears similar for three flow rates studied here when the gap distance is constant. Again the flow is very non-symmetric for 8 cm gap distance, but it ii similar for other cases.

Effects of gap distance

The effect of gap distance is significantly large as seen in Fig. 10. Even for the smallest flow rate with gap distance 2 mm, the flow appears quite symmetric. It is also seen that the region of very low velocity (dead layer) becomes smaller. It is obvious because the inlet flow velocity at the exit of the annular channel is high.

CONCLUSION

Flow behaviour has been investigated for a window region of SINQ target geometry using mercury and ultrasonic Doppler method. The geometry is still axisymmetry but flow rate and gap distance between the edge of the inner tube and window bottom has been studied. Following conclusions are drawn.

The Ultrasonic Doppler method was successfully applied to mercury flow contained in a stainless steel wall. The system used in this experiment works fine and needs no special modification for this kind of measurement. The ultrasonic transducers can be set outside the stainless steel wall. It enables us to use multiple transducer system for very efficient flow mapping. As a reflector of ultrasonic pulse, gas bubbles and/or impurities included in the mercury might be used. No wetting problem arose for the transmission of ultrasound pulse through the wall to mercury.

Time dependent one-dimensional velocity profiles were successfully measured, which show a strong vortex shedding behind the edge of the guide tube for 8 cm gap distance. The time-averaged profile on the centerline indicates that the recirculation inside the guide tube near the edge is strong.

The flow field is globally axisymmetric on the time-averaged profiles except for the case with gap distance of 8 cm. The effect of the gap distance is much stronger than that of the flow rate for the range studied in the work.

It is, however, proved that the inflow from the annular channel is still weak and may not be sufficient to cool down the central part of the window directly where the temperature is supposed to be highest. This is mainly due to a large dead zone in this region arising from a deep pocket of the hemispherical window and the symmetrical geometry of the total configuration. This requires us to study further in a three-dimensional configuration.

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Fig. 10 Vector flow fields for different gap distances and flow rates