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DYNAMIC MEASUREMENT OF LIQUID FILM THICKNESS IN STRATIFIED FLOW BY USING ULTRASONIC ECHO TECHNIQUE

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ABSTRACT

We developed a technique to measure time-dependent local film thickness in stratified air-water flow over a horizontal plate by using a time of flight of ultrasonic transmission. The ultrasonic echos reflected at the liquid/air interfaces are detected by a conventional ultrasonic instrumentation, and the signals are analyzed by a personal computer after being digitalized by an A/D converter to give the time of flight for the ultrasonic waves to run over a distance of twice of the film thickness. A 3.8 mm diameter probe type ultrasonic transducer was used in the present work which transmits and receives 10 MHz frerquency ultrasonic waves. The estimated spatial resolution with this arrangement is 0.075 mm in film thickness for water. The time resolution, which depends on both the A/D converter and the memory capacity was up to several tens Hz. We also dicussed the sensitivity of the method to the inclination angle of the interfaces.

1.INTRODUCTION

One of the most important problems encountered, associated with an accurate prediction of core thermal hydraulics during postulated loss of coolnat accidents in boiling water reactor is a modelling of the dynamic behaviors of liquid film flows over surfaces of the fuel rods. This happens also in an accurate estimation of heat transfer characteristics of refrigerators where evaporation and condensation take place inside fine tubes. Although a fairly amount of information has been accumulated so far of the steady state characteristics of such film flows, almost nothing has been reported as to the time- and spatially-dependent film flow behaviors. This is mainly ascribed to a lack in measurement techniques to allow time sequences of the liquid film thickness irrespective of one- or multi-dimensional way. Some techniques can be referred to impedance or conductance probes [1,2]. However, in order to avoid significant effects due to additional diturbances to the flow caused by intrusive techniques, we have to rely on non-intrusive techniques.

Ultrasonic transmission techniques have been applied to studying gas-liquid two-phase flows. Chang et al.[3] applied a pulse echo technique to investigate gas slug behaviors in a horizontal channel. They also discussed on some problems associated with its application to bubbly flows. Bensler et al.[4] developed technique simultaneously to determine the volumetric interfacial area, volumetric fraction and bubble Sauter mean diameter, using ultrasonic attenuation by the mixture. However, the latter method gives us merely a volume- or line-averaged quantities, not local instantaneous quantities. A recent development of a transmission mode ultrasonic computerised tomography made by Xu and Chen [5], using 36 transducers mounted in the pipe wall, made it possible to obtain the reconstructed images of the cross-sectional distribution of the dispersed phase at a speed of 10 frames per second. They succeeded in imaging three bubbles existing at a given cross section. However, this method needs ellaborative modification of the algorithm if it is intended to be applied for more densely packed bubbly flow.

In the present work, we applied an ultrasonic transmission technique, based on a time of flight, to measure time and space-dependent film thickness. The results obtained with this method were well compared with those obtained by a laser displacement gauge and also by an impedance probe. We found that there are, however, conflicting demands in optimizing the size of the sensitive zone and the reflection angle of the interfaces. This work thus describes the results and the problems associated with the ultrasonic transmission technique.

2. PRINCIPLE AND PROCEDURES

Figure 1 shows a shematic of the ultrasonic transmission system used in the present work. The ultrasound reflects at the junction between the water film and the wall material and also at the air-water interface. There are also multiple reflections at these surfaces, but these are usually removed by a conventional ultrasonic instrumentation (SONIC MARK Inc. FTS-MARK2). A typical output signal from the system is demonstrated in Fig.2, indicating two peaks originating from the reflections at the two boundaries. The time difference between these two peaks corresponds to the twice of the flight time over a distance of the film thickness. The ultrasonic signals are fed to a personal computer through an A/D converter to calculate the local instantaneous film thickness. In the present sampling system, the signals over a 40 micro-seconds time duration was divided and memorized into 1000 channels, and therefore, if we assume the sound speed in the water film to be 1,500 m/s, the spatial resolution due to this sampling procedure is about 30 μm. On the other hand, from a simple wave theory, the spatial resolution can be calculated as a half wave length of the ultrasound, i.e., 150 μm and 75 μm for

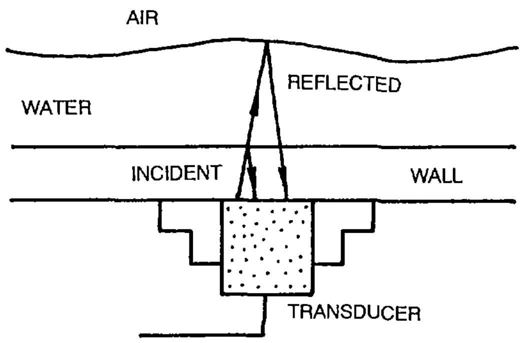

Fig.1 Ultrasonic transmission system

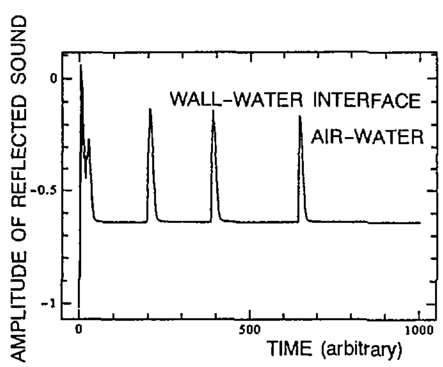

Fig.2 Reflected sound signal

5 MHz and 10MHz, respectively. Therefore, the total measurement accuracy in the film thickness is estimated to be 75 μm for 10 MHz and 150 μm for 5 MHz. Whereas, the spatial resolution in the flow direction is determined both by a sampling rate and the velocity of the liquid film. In the present case, the sampling rate was 2.78 seconds for 256 samplings, that is, 0.011 second/sampling. For the liquid film velocity at 1m/s, this value becomes to be about 1cm. In order to obtain higher resolution in the flow direction, we need a faster A/D converter.

We used two different sized ultrasonic probes acting as a transmitter and also as a receiver, one is 3.75 mm in diameter emitting 10 MHz ultrasound and the other 12.7 mm in diameter with 5 MHz waves. These ultrasonic waves are transmitted in band pulses of the frequency 3 and 0.7MHz, respectively.

Figure 3 represents a comparison of the values of the liquid film thickness obtained with the ultrasonic transmission technique mentioned above with those obtained visually by using still water. An excellent agreement was thus obtained.

In order to examine the applicability of this method we tested it in air-water stratified flow and compared it with other three methods, that is, a commercially sold laser displacement gauge, an impedance probe method and a contact probe method. The experimental rig used for this purpose is schematically shown in Fig.4. The test section consists of a 1 m long horizontal acrylic rectangular channel with a 100 mm width x 50 mm height cross section. Water is supplied from a constant level water tank to the test section in paralle to the air flow, as shown in Fig.4. A laser displacement gauge (KEYENCE LB-080) was set at the same spot as the ultrasonic beam from above the liquid film surface. In order to enhance the detection sensitivity for the laser displacement gauge, a small amount of milk was added in the water flow. The operational principle for the laser displacement gauge is given in Fig.5. The incident light with 1.5 mm in diameter emitted from a LED is focused on the object by optical lenses and then, the reflected light generates an image spot on the position-detector through the optical lenses. This image spot moves in correspondence with the magnitude of the displacement of the object.

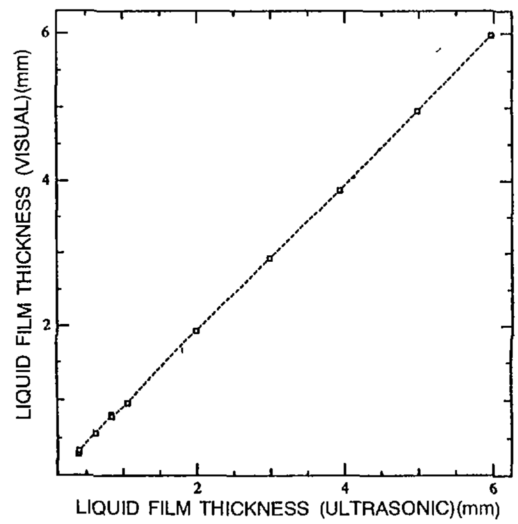

Fig.3 Comparison of the results obtained by ultrasonic transmission technique and by visualization in still water

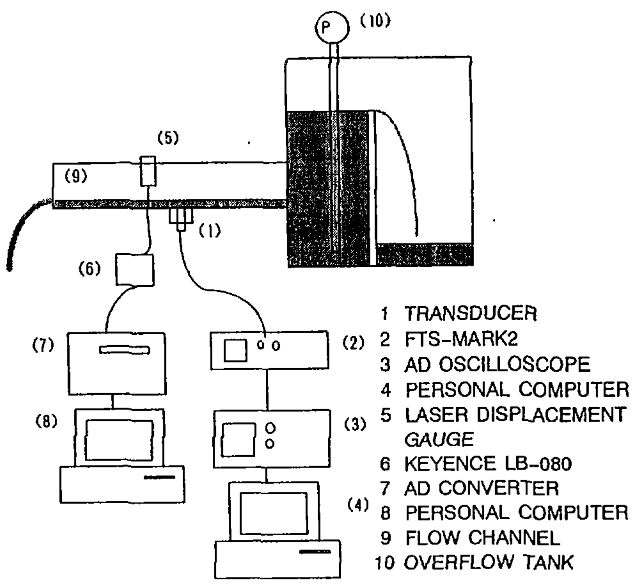

Fig.4 A schematic of the flow test section and measurement arrangement

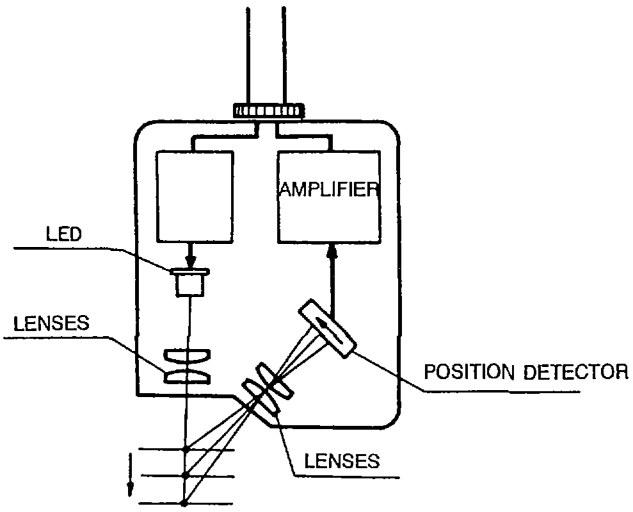

Fig.5 Operational principle of a laser displacement gauge

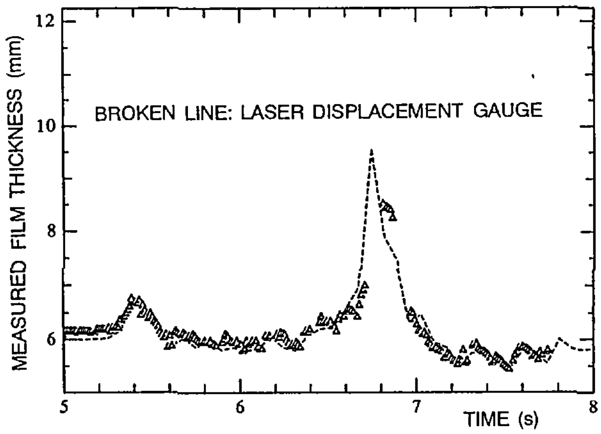

Fig.7 Comparison of the ultrasonic transmission technique with laser technique for standing wave

3. RESULTS AND DISCUSSIONS

Figures 6 and 7 demonstrate comparisons of the film thickness measurements obtained by the ultrasonic transmission technique with those by the laser technique for a standing wave generated in still water. Over-all agreement is thus excellent except for the regions of a sharp increase in film thickness where the ultrasonic signals are missing.

Figures 8 and 9 show the time-dependent liquid film thickness obtained under different flow conditions in air-water stratified flow. These results reveal that the ultrasonic transmission technique is successfully applied to construct time-dependent images of the local film thickness in stratified two-phase flow. This has been confirmed again in Figs.10 and 11 for the passage of a large but slowly traveling wave which compare the ultrasonic transmission technique with the results obtained by impedance probe method.

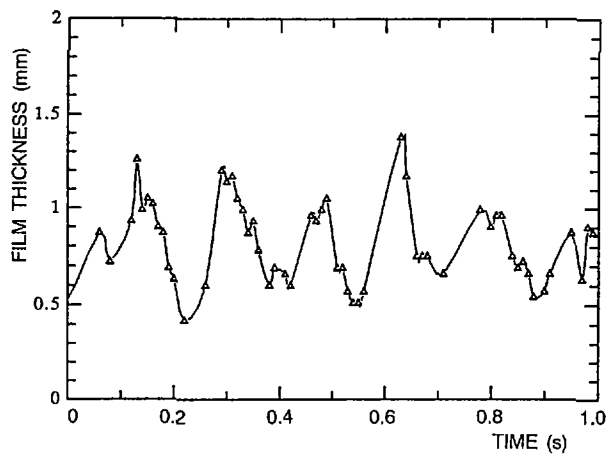

Fig.8 Time-dependent film thickness in stratified flow

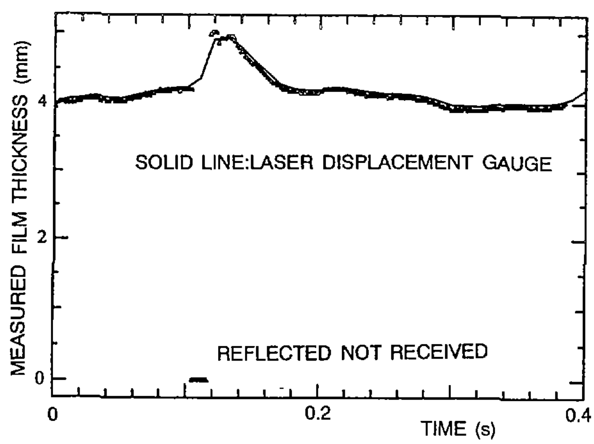

Fig.6 Comparison of the ultrasonic transmission technique with laser technique for standing wave

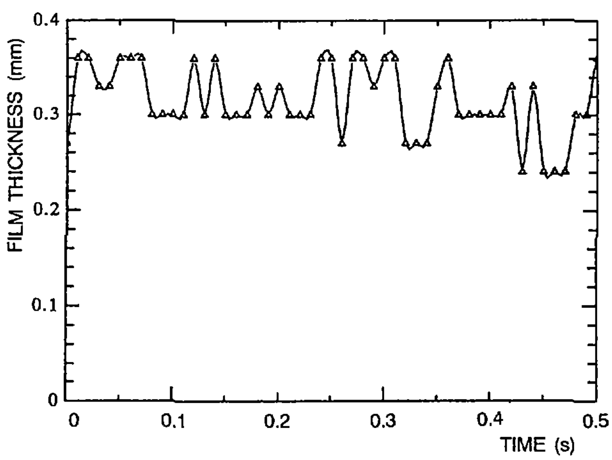

Fig.9 Time-dependent film thickness in stratified flow

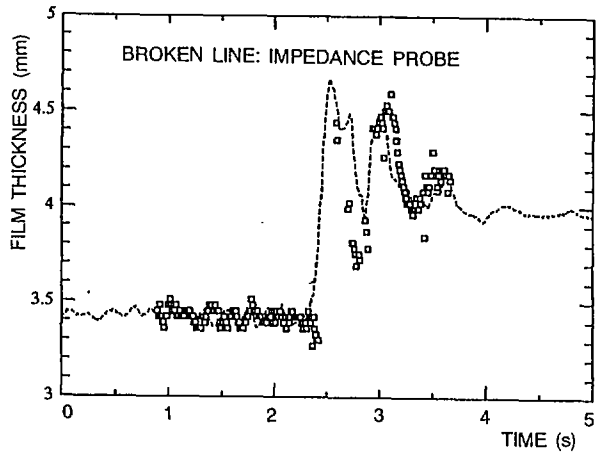

Fig.10 Comparison of the ultrasonic transmission technique with impedance probe method

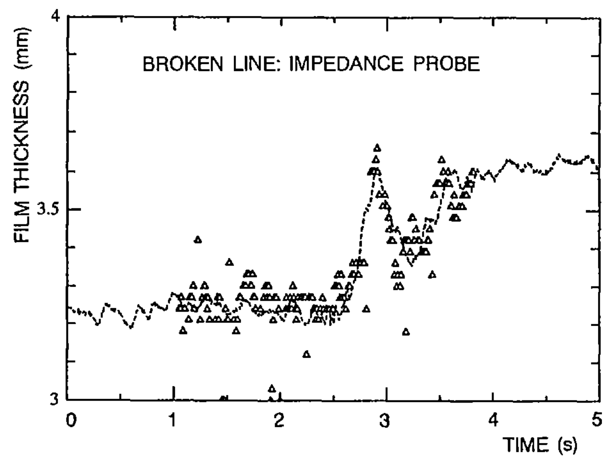

Fig.11 Comparison of the ultrasonic transmission technique with impedance probe method

As is clear in the earlier discussions, the major problems associated with the ultrasonic transmission technique are (1) a fairly large sensing area and (2) incapability of detecting a sharp edge of the interfacial waves. The first problem is purely a technical matter in the fabricatoin of a transducer probe. However, it is still related to the second problem as will be mentioned later. In order to examine the capability of detecting a sharp edge of the interfaces, we investigated the effect of the slope of the reflection interface on the output signals from the ultrasonic transmission system. In this experiment, the reflection interface was simulated by using an inclined solid surface placed in water. The result is given in Fig.12 in a plot of measured film thickness *versus* inclination angle of the interface from horizontal, showing that the upper limit of the inclination angle at which the reflected ultrasound can be detected is up to only several degrees at most. It also indicates that a narrower beam has poorer detect- ion capability due to smaller scattering angles at the reflection interface, as shown in Fig.13. It is noted that the measured film thickness is a decreasing trend with an increase in the angle θ. The discrepancy $\Delta\delta$ is of course a function of the beam half width W as is given by

$$\Delta\delta = W \tan\theta$$

Localized measurement generally requires a narrower beam for the ultrasonic transducer. However, in view of the above results, one can understand that there are oonflicting requirements related to the measurement accuracy. Namely, a narrower beam has poorer detection ability so far as the inclination angle of the reflection interface is concerned, but the error $\Delta\delta$ becomes smaller. Thus there should exist a proper choice to compromise these conflicting requirements. As stated earlier, use of a higher frequency ultrasonic transmission improves thye sspatial resolut- ion in the direction of its propagation.

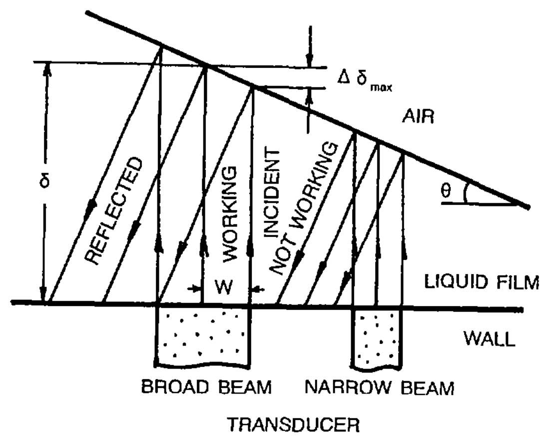

Fig.12 Sensitivity to the inclination angle of the reflection interface

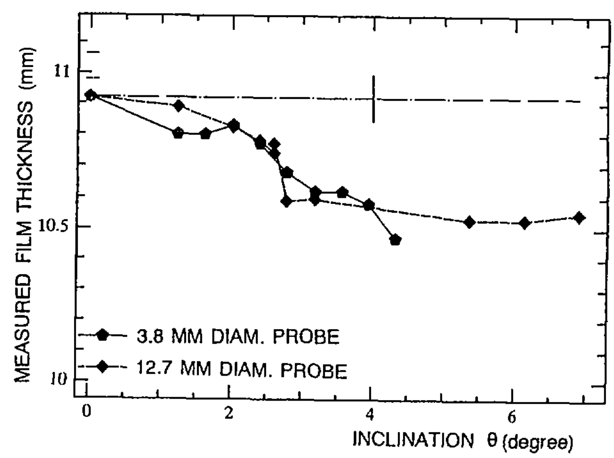

Fig.13 Measurement accuracy

4. CONCLUSIONS

The ultrasonic emission technique has been studied for its application to the measurement of time- and space-dependent film thickness in stratified flow over a horizontal plate. The results indicated an excellent agreement with those obtained by conventional intrusive and non-intrusive techniques. The advantage of this technique over conventional ones lies in the fact that it can be applied even for opaque tubes and that it does not generate additional disturbances to the flow because of a non-intrusive method with easy handling. Major technical difficulties with this technique are (1) a rather poor detection sensitivity to the inclination angle of the reflection interfaces, and (2) spatial resolution is not always satisfactory at moment because of the difficulty in fabricating small transducers. Some discusions have been made on these problems.

REFERENCES

1. G.F. Hewitt: Measurement of Two-Phase Flow Parameters, Academic Press(1978).
2. H.C. Kang and M.H. Kim: The development of flush wire probe and calibration technique for measuring liquid film thickness, Int. J. Multiphase Flow, Vol.18, pp.423-438 (1992).
3. J.S. Chang, Y. Ichikawa and G. Iron: Flow Regime Characterization and Liquid Film Thickness Measurement in Horizontal Gas-Liquid Flow by an Ultrasonic Method, in Measurement in Polyphase Flow, Heindrick, T.R. and Patel, B.R. ed., ASME Press, N.Y., pp.7-12 (1982).
4. H.P. Bensler, J.M. Delhaye and C. Favreau: Determination of the Volumetric Interfacial Area, Volumetric Void Frcation and Sauter Mean Diameter in Bubbly Flow by Means of Ultrasound Attenuation, Proc. of the Second World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics, Dubrovnik, June 23-28, 1991 (1991).
5. L.Xu and Z. Chen: A Transmission Mode Ultrasonic Computerised Tomographyic System for Gas/liquid Twwo-Phase Flow Visualization, Proc. of the International Symposium on Visualization, pp.414-417 (1991).

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