Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Development of Methodology for Measuring Liquid Film Thickness Based on Three-ring Conductance Method

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1. Introduction

Liquid film thickness is an important factor for understanding the two-phase annular / film flow. Generally, measuring the liquid film thickness with high time and spatial resolution has been limited in two-phase flow experiments. Recently, measurement of the local liquid film thickness with high time and spatial resolution have achieved by combining electrical conductance method with wire-mesh circuitry (Damsohn et al. [1]). Though this methodology has high resolutions, the applicability is limited in applying dynamic temperature conditions which involve heat transfer since the electric conductivity of the liquid is affected by its temperature. Electrical conductivity of the water generally increases about 2% when the water temperature increases 1℃ (Hayashi [2]). Therefore, experiments applying electrical methods have limited to isothermal flow condition despite the fact that most two-phase flows involve heat transfer.

The objective of this study is developing a measurement methodology for measuring local liquid film thickness in varying temperature condition. Three-ring conductance method (Kim et al. [3]) is adopted for applying on the dynamic temperature condition. For extending the application of this sensor to curved surface and relatively high temperature flow conditions, the sensor is fabricated on FPCB. The measurement methodology and liquid film flow experiment are introduced in this paper.

2. Measurement methodology

2.1 Three-ring conductance method

The general electrical conductance method measures the local liquid film thickness by using the current flowing transmitter electrode (A) to receiver electrode (B) as shown in Fig. 1-(a). As the current is affected by its temperature, this method cannot be applied on varying temperature conditions. However, the three-ring conductance method has an additional receiver as presented in Fig. 1-(b). By using the current ratio (I_1/I_2), measurement of the film thickness is conducted. As the current ratio compensates the conductivity change which is caused by temperature variation, the measurement error from temperature varying condition is minimized.

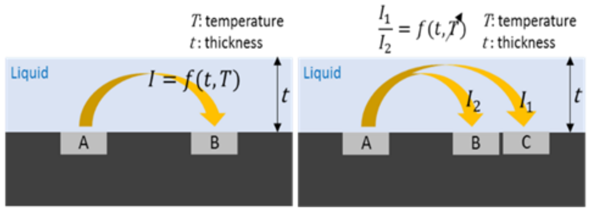
There was an experimental research of three-ring conductance method for the liquid film thickness measurement (Kim et al [3]). It was confirmed that current ratio is proportional to the liquid film thickness and the electrode geometry has an effect on the sensor characteristics. Besides the function of temperature compensation was identified. However, since the sensor was fabricated on the PCB, the application was limited in curved surface or high temperature conditions. In this study, the sensor was fabricated on the FPCB for extending its applicability on curved surface or relatively high temperature condition.

2.2 Sensor characteristics

Fig. 2-(a) shows the ring-type sensor proposed in this study, and Fig. 2-(b) presents the ground electrode and disposition of the multiple sensors. Because of the enclosed geometry, the electric current flow pattern is radial symmetry. Also, the enclosed shape prevents the end effect which means a bypass current generated around the edge of electrode. As a result, it is easy to arrange the multiple sensors. Specific dimensions of the electrode are determined by the electrical potential field simulation using COMSOL ver. 5. 1. The sensor proposed in this study can measure the film thickness from 0.5 mm to 3.5 mm which is the range of Yang et al.'s experiment (Yang et al. [4]). Also, it has a square resolution of 15 mm × 15 mm. The specific design process of the sensor is described in Lee et al. [5].

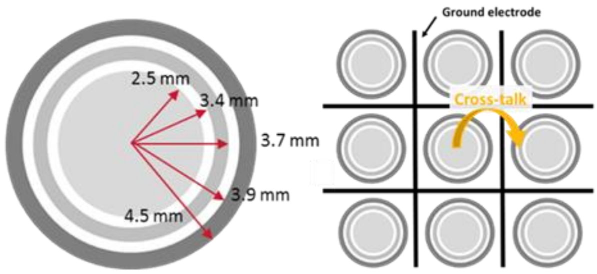
2.3 Parallel circuitry system

For measuring the local liquid film thickness with multiple locations, a lot of signal transmitting system and DAQ (data acquisition) system are required. Especially in case of using the three-ring conductance method, three signal lines for each probe are demanded with general signal processing methods. However, the wire-mesh circuitry system (Prasser et al. [6]) can reduce the above system effectively with crossing the transmitter and receiver signals. In this study, the parallel circuitry system is modified as illustrated in Fig. 3 to apply on the three-ring conductance method since the wire-mesh circuitry is designed based on the conventional electrical method.



(a) (b)

Fig. 1. Principle of liquid film thickness measurement of general electrical method (a) and three-ring conductance method (b)



(a) (b)

Fig. 2. Dimensions of the electrodes (a) and geometry of ground electrode (b)

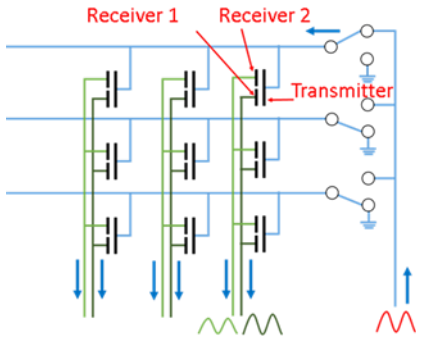


Fig. 3. Schematic diagram of parallel circuitry system

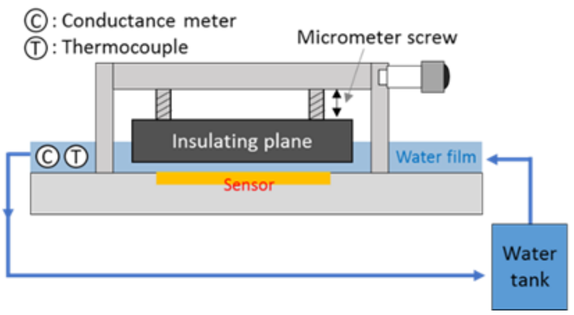


Fig. 4. Geometry of calibration device

Table I: Specific configuration of experiment apparatus

Injection nozzle	Nozzle diameter: 21 mm Distance nozzle to FPCB: 25 mm
FPCB sensor	Width: 180 mm (12 columns) Length: 360 mm (24 rows)

3. Liquid film flow experiment

3.1 Calibration of the liquid film sensor

Fig. 4 describes the geometry of calibration device. Calibration range was 0.5 ~ 4.0 mm with 0.5 mm step and the water condition of the calibration was 18℃ and 22 μS/cm. AC 10V, 500 Hz frequency signal is induced to the transmitter lines from the function generator and DAS measures the voltage signals which is converted from current signals. With this calibration device, the characteristics of the liquid film sensor are measured as shown in Fig. 5 and Fig. 6. Fig.5 shows the repeatability of the sensor and Fig. 6 shows the accuracy of the sensor including the external noises. For film thickness up to 1.5 mm, a maximum absolute error is 0.025 mm and relative error is 1.6%. For up to 3.5 mm, the accuracy is reduced to 0.25 mm and 4.0%.

In order to confirm the temperature compensation effect, additional calibration was conducted with controlling the water temperature (23~33℃). As shown in Fig. 7, as temperature increases, the current ratio also become smaller. However, the discrepancy and the measurement error is confined to around 10% which is improved result of the conventional electrical method (Fig. 8). The temperature change condition is confined because of the distortion of the calibration device which is caused by the temperature increasing. However, this varying temperature condition test will be conducted with modifying the calibration device.

3.2 Experiment setup and conditions

In this study, liquid film flow experiment was performed with using the liquid film sensor. The experimental apparatus of the liquid film flow experiment which was designed based on the experiment of Yang et al [4] (Fig. 9). For simplifying the flow condition, lateral air blowing was not considered. In this experiment, water temperature is controlled at the water storage tank. In the test section, as shown in Fig. 10, the water is injected from nozzle to the FPCB sensor. And the injected water develops downward liquid film flow which has parabolic shape. The FPCB sensor measures the local liquid film thickness of the liquid film flow. The major dimensions of the apparatus are described in Table 1.

The FPCB sensor has 288 probes (transmitter channel: 24 × receiver-1, 2 line: 12). Thus 288 different calibration curves were prepared with above calibration experiment for measuring the liquid film flow. In this experiment, inducing channel transferring system was proposed for the replacement of the wire-mesh system to cover the signals of the whole sensors (Fig. 11). In this experiment, the frequency of channel switching is confined to 50 Hz because of the performance limitation of DAQ module. However, this measurement frequency can be enhanced with applying the wire-mesh circuitry system.

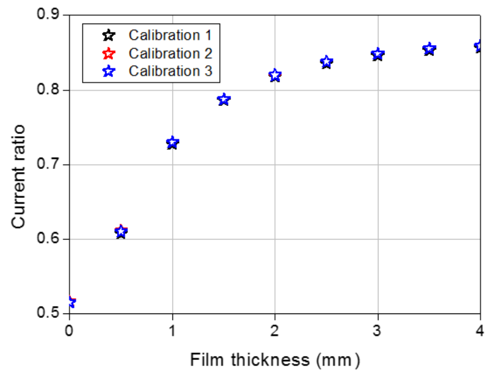


Fig. 5. Calibration result of the liquid film sensor

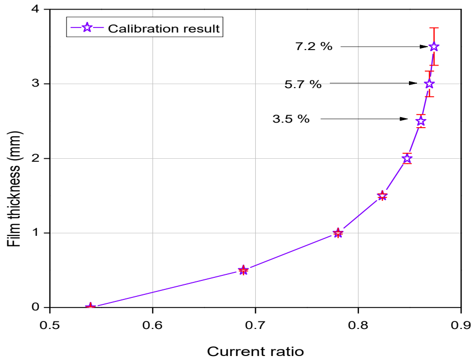


Fig. 6. Measurement error of the liquid film sensor

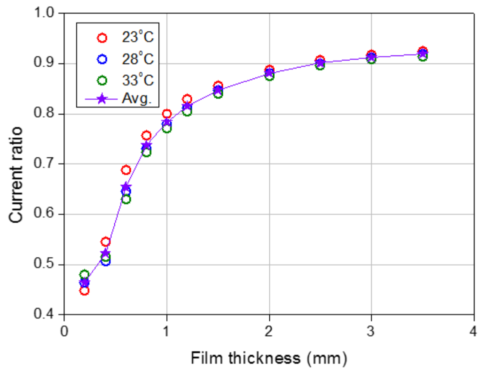


Fig. 7. Result of the calibration (various temperature)

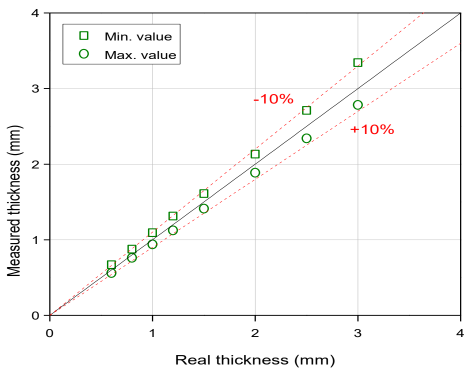


Fig. 8. Error distribution with 10℃ range

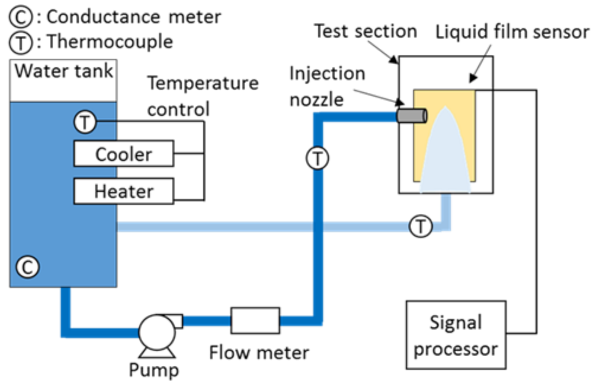


Fig. 9. Schematic diagram of experimental apparatus

Fig. 10. FPCB Liquid film sensor and downward liquid film flow of the experiment

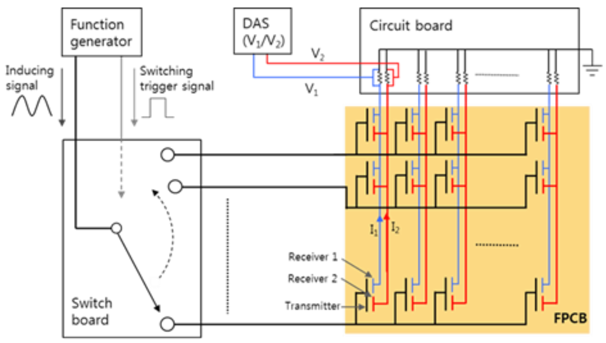


Fig. 11. Signal transferring process of FPCB

3.3 Experiment result

Liquid film flow experiment was conducted based on the calibration curves. With controlling the velocity of injecting water (0.48, 0.63, 0.87 m/s), local liquid film thickness was measured with changing the inducing channel. To figure out the time-averaged film thickness, measurement for each transmitter channel was conducted for 10 seconds. The results are shown in Fig. 12 ~ 14. The pictures on the left side are the real liquid film flow observed by camera and the right pictures are liquid film thickness contour measured by FPCB sensor. The point at (0, 0) represents center point of the injecting nozzle. There are a few features in this results. Relatively thick

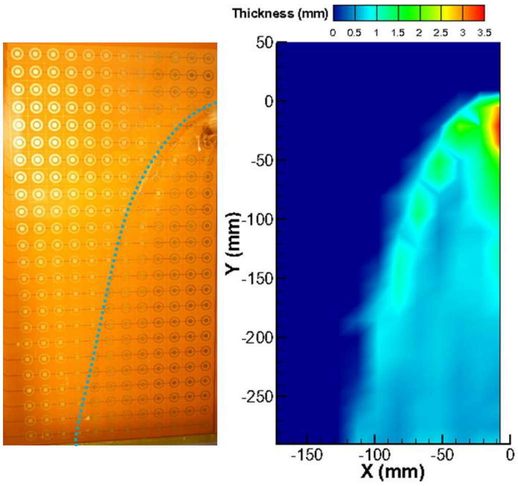


Fig. 12. Liquid film flow and contour of the liquid film thickness (V_{in}=0.48 m/s)

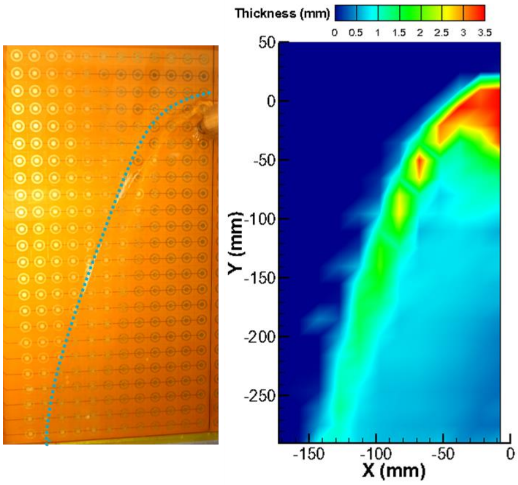


Fig. 13. Liquid film flow and contour of the liquid film thickness (V_{in}=0.63 m/s)

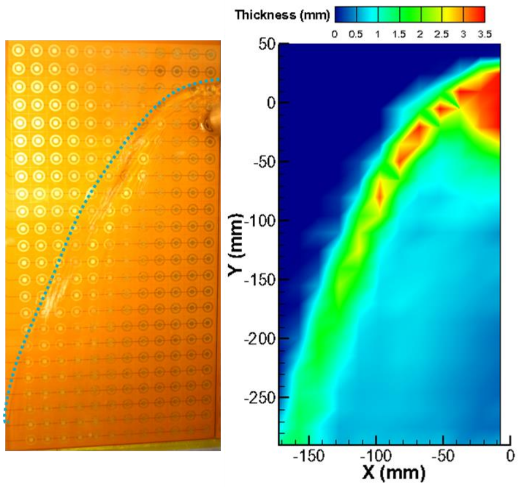


Fig. 14. Liquid film flow and contour of the liquid film thickness (V_{in}=0.87 m/s)

film is distributed around the point (0, 0) since this region is the nearest from the injecting nozzle. Also, hydraulic jump was measured at the boundary of the liquid film. Because of the hydraulic jump, the film boundary is thicker than its surroundings. In addition, the width of parabolic shape become large and overall film thickness also become thicker as increasing the injecting velocity. Meanwhile, around the boundary of the liquid film, very thin liquid film which does not cover the probe entirely was observed. However, the currents measured in this probe are too little to detect from the electrical noise. This result is considered as the electrode geometry was designed for measuring relatively thick film.

4. Conclusions

In this study, three-ring method and parallel circuitry system were coupled to measure the liquid film thickness. And the parallel circuitry system was devised for effective signal processing of three-ring method. In addition, with applying the FPCB sensor on liquid film flow experiment, the flow pattern of downward film flow was observed.

The temperature compensation range was limited to 10℃ in case of using current ratio. In order to improve the temperature varying range, additional impedance analysis and tests for various electrode design are required. Besides coupling this methodology with wire-mesh system is necessary to obtain high time resolution to measure the film thickness instantaneously.

Acknowledgement

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety(KOFONS), granted financial resource from the Nuclear Safety and Security Commission(NSSC), Republic of Korea (No. 1305011).

REFERENCES

[1] M.Damsohn, H. -M. Prasser, High-speed liquid sensor for two-phase flows with high spatial resolution based on electrical conductance, Flow Measurement and Instrumentation, Vol.20, pp.1-14, 2009
[2] M. Hayashi, Temperature-electrical conductivity relation of water for environmental monitoring and geophysical data inversion, Environmental Monitoring and Assessment, pp. 119-128, 2004
[3] J. R. Kim, H. K. Cho, D. J. Euh, Experimental study of the characteristics of three flat probe conductance meter, Transactions of the Korean Society of Mechanical Engineers., pp. 378, Dec 2013.
[4] J. H. Yang, H. K. Cho, D. J. Euh, G. C. Park, Experimental study on two-dimensional film flow with local measurement methods, Nuclear Engineering and Design, Vol. 294, pp. 137-151, 2015

[5] K. B. Lee, J. R. Kim, D. J. Euh, G. C. Park, H. K. Cho, Development of three-ring conductance sensor based on flexible printed circuit board for measuring liquid film thickness in two-phase flow with high resolution, Journal of Sensor Science and Technology, Vol. 25, No. 1, pp. 57-64, 2016
[6] H. –M. Prasser, A. Bottger, J. Zschau, A new electrode-mesh tomography for gas-liquid flows, Flow Measurement and Instrumentation, Vol. 9, pp. 111-119, 1998