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Development of Three-Ring Conductance Meter on Flexible Printed Circuit Board for Liquid Film Thickness Measurement

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1. Introduction

Understanding the characteristics of liquid film in a two-phase flow is an important part of the analysis on safety and performance of fluid systems. As fluid film-thickness is one of key factors, a lot of researches have been conducted to measure the film-thickness. Electrical methods which based on conductance of fluid film have been widely applied for many years. Recently, Damsohn [1] developed a high speed liquid film sensor that has great time and spatial resolution by applying printed circuit board (PCB) and wire-mesh signal processing unit. However, the conductivity of the fluid can be affected by its temperature change and previous electrical methods have limitations of its applicability where a heat transfer is involved. In order to overcome this limitation, Kim[2] proposed three-ring conductance method which can measure the liquid film thickness independent of the liquid temperature variation. In the present work, the three-ring conductance meter is improved by fabricating it on flexible printed circuit board (FPCB). Since the FPCB can be attached on a curved surface and can tolerate temperature up to 180°C, it is expected to be applied to more diverse experimental conditions of nuclear thermal-hydraulics. This paper introduces the three ring conductance meter on FPCB and a preliminary experimental result in order to show its feasibility for measuring liquid film thickness under temperature varying conditions.

2. Three-ring conductance meter

2.1. Principle of three-ring conductance meter

The three-ring conductance meter consists of three electrodes mounted on a surface as shown in Fig. 1. The currents are developed by induced electrical potential between transmitter (A) and receivers (B, C). As the equal potential difference is induced between path A-B and A-C, the current intensity is determined by the film-thickness and the conductance of fluid. Because of the conductance, the currents are distracted by temperature change. However, the current ratio (I_2/I_1) is independent of the temperature due to the offset of conductivity effect. Therefore, the output current ratio can be used for measuring film-thickness regardless of temperature change.

2.2. Characteristics the liquid film sensor on FPCB

Thanks to the characteristic of a polyimide film which is the substrate of the FPCB, it can be applied to a relatively higher temperature condition (up to 180℃) condition than an ordinary PCB. Furthermore, it has great flexibility that it can be attached to curved surfaces as shown in Fig. 2. The electrodes are formed on FPCB by etching process and creation of bumps cannot be avoided. In the present prototype sensor, its height is 30 μm, which is expected not to cause a significant disturbance on a liquid film.

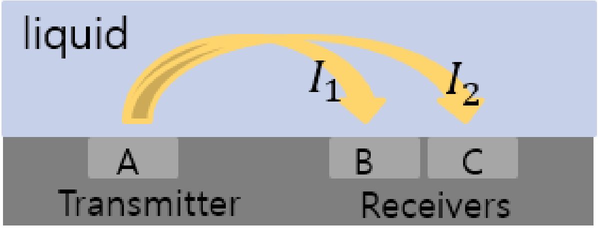

Fig. 1. Current flow between transmitter and receivers of three-ring conductance meter (Kim [3])

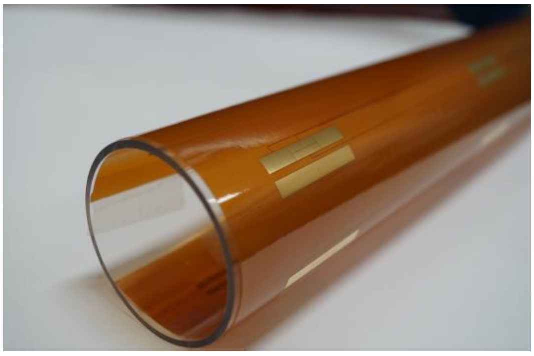

Fig. 2. Shape of three-ring conductance meter on FPCB

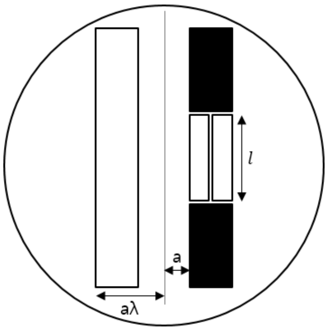

Fig. 3. Schematic diagram of a three-ring conductance meter.

3. Experiment setup

In the present test, for a feasibility of the three-ring conductance sensor on FPCB, a prototype sensor was fabricated as represented in Fig. 3. To prevent the end effect of electrode edges, two ground electrodes were added near the upper and lower edges of the receiving electrodes. For an optimization of sensor geometry, parametric studies were conducted. The geometric parameters are indicated in Table I and the e length l in Fig. 3 was fixed to 10 mm. The gap between receiver B and C should be minimized to approach the electrical field to an ideal situation and the gap between receivers were adjusted to 0.1 mm.

Table I: Geometry types of three-ring conductance meter

Geometry	a (mm)	λ
1	1.0	3
2	1.0	5
3	3.0	3
4	3.0	5

The electrical circuit of the present test is shown in Fig. 4. Inducing AC voltage to transmitter (A) by a function generator, the currents are developed through the water. The output current signals are processed with input voltage signal in lock in amp. And then, the data acquisition system acquires the I_2/I_1 ratio. The frequency of input voltage signal was set to 1 kHz with 0.1V amplitude.

To examine the current ratio with regard to film-thickness and geometry of conductance meter, 4 geometries listed in Table 1 were tested with different film thicknesses. In addition, experiment verifying the independency of liquid temperature was conducted.

4. Experiment results

The current output ratio (I_2/I_1) with regard to film-thickness is presented in Fig. 5. The current ratio becomes larger while increasing the film-thickness, but its increasing inclination gradually decreases with increasing film thickness. This causes deterioration in spatial resolution of the measurement method and therefore, the measurement needs to be performed in the range where the sensor can produce a sufficiently sensitive signal. In the region below 0.8 mm of the film-thickness, the current ratio is not linear with film-thickness, as the current I_2 is too small. Thus, it is needed to find out an optimized design for an interested thickness by adjusting the geometry factors of electrodes (a, λ) so as to measure the film-thickness accurately.

To verify the independency of temperature change, the current output was recorded while controlling the temperature of the water. 1℃ increase of the water temperature usually raises the conductance by 2.5%. Fig. 6 indicates the results of test in varying temperature with a constant film thickness of 3.5 mm and electrodes with geometry 3 (a = 0.3 mm, λ = 3). During the water temperature changed from 20 to 50℃, the I_1 and I_2 output signals increased 47% and 45% respectively. This result implies the single receiver conductance meter is not proper in varying temperature condition. In contrast with current intensity, the current ratio was maintained at an almost constant value with 0.1% maximum error and 0.003 of standard deviation. From this result, it was shown that the three-ring conductance meter is applicable in varying temperature conditions.

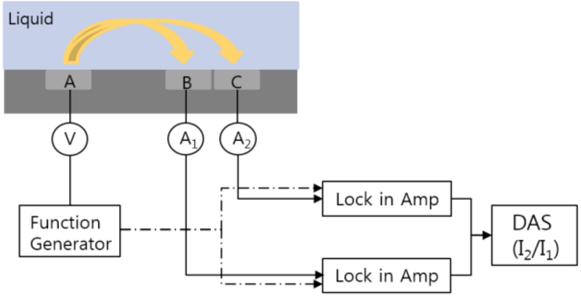

Fig. 4. Schematic of the experimental setup for current ratio measurements.

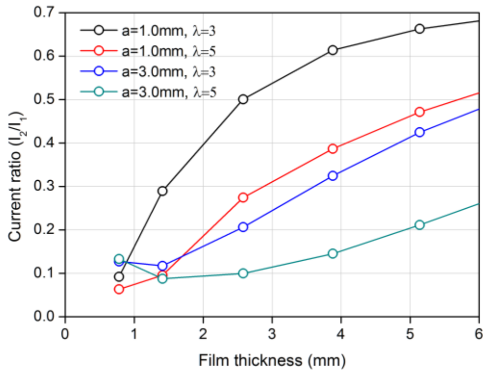

Fig. 5. The current ratio with changing film-thickness and electrodes geometry.

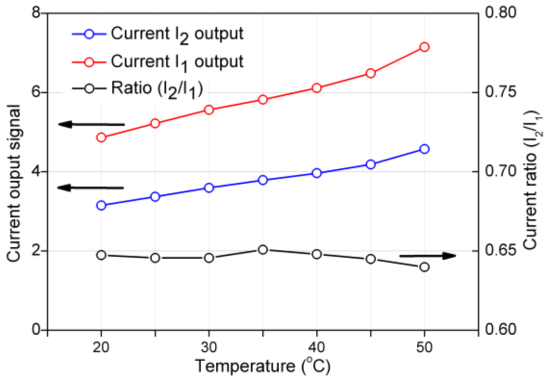

Fig. 6. The current output signal and current ratio with varying temperature.

5. Conclusions

From this experimental research, the availability of three-ring conductance meter fabricated on FPCB for measuring film-thickness by using current output signal was proved. Besides, the necessity of customized electrode design depending on film-thickness was found. Also, it was confirmed that the manufactured three-ring conductance meter can measure the film-thickness regardless of temperature change. In addition to this preliminary experiment, electrical potential analysis is needed to optimize the geometry and space arrangement for extending this research to more applications.

Acknowledgement

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