# DEVELOPMENT OF CONDUCTIVITY PROBE AND SIGNAL PROCESSING ALGORITHM FOR MEASURING OF LOCAL TWO-PHASE FLOW PARAMETERS

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**Abstract**: Accurate measurement of local two-phase flow parameters is important for the evaluation of two-phase flow models as well as for the development of closure relations used in the two-fluid model. This paper presents the research development on experiments of two-phase flow hydrodynamic phenomena at Hanoi University of Science and Technology which include a small-scale test rig in vertical round tube configuration as well as the double-sensor conductivity probe for measuring of local two-phase flow parameters such as void fraction, phasic velocity, interfacial area concentration. Also the Signal conditioner, Data Aquisition and System and Signal processing scheme have been developed for the newly designed conductivity probe. Good performance of the measurement system is confirmed by benchmark experiments employing the image analysis method.

**Keywords:** *Two-phase flows, conductivity probe, signal processing scheme*

## 1. INTRODUCTION

The importance of the study of two-phase flow phenomena has increased for both fuel performance and safety analysis of nuclear power plants. One of the most important key issues in the two-phase flow analysis is the existence of multidimensional interfaces between both phases, and the correct behaviour prediction of these interfaces as well as its quantification could make a great contribution on improvements of solving the closure problem in two-fluid model which was adopted in advanced thermal-hydraulics simulation codes. Then, experimental works play a very important role in the development and valiadation of new theoretical models. Up to now, there is not an effective technique and methodology for the multidimensional interface characterization in two-phase flow measurement. However, the use of needle probes as an intrusive method to measure is a well established method and widely used for the investigation of multiphase flows. Different measuring techniques can be employed for the needle probes and among them, the most known techniques are based on conductivity, capacitance or optical measurements. Based on the phase identification, these probes can provide information about void fraction, interfacial area concentration, bubble size, frequency and velocity using simple physical principles. A large number of investigators have reported the application of conductivity probe for the accurate measument of local properties in gas-liquid and steam-water flows [1-5].

A new test facility has recently been constructed at Institute of Nuclear Science and Techniques (INST, VINATOM) to investigate the dynamic behaviors of two-phase air-water flows in vertical-upward channels. This paper present present the development of a miniaturized two-sensor conductivity probe to obtain the time-averaged local two-phase flow parameters of various types of bubbles, which is applicable to a wide range of two-phase flow regimes designed for the test facility constructed at INST. Signal processing algorithm for two-sensor conductivity probe was developed and utilized by using LABVIEW platform embedded with MATLAB script. Also, a small test rig for benchmarking the probe employing the image analysis method was constructed and applied. The results from the benchmark experiment assess both the measurement principle and signal processing scheme of the newly developed two-sensor conductivity probe method.

## 2. TWO-SENSOR CONDUCTIVITY PROBE DESIGN AND FABRICATION

The two-sensor conductivity probe method was adopted to use in this study due to its simplicity, even though the application of probe is limited to relatively large bubbles and large diameter channel [5]. The conductivity probe method is basically based on the difference of electrical resistance between vapor and liquid phases and then the instantaneous measurement of local electrical resistivity around a sensor electrode in the two-phase system is converted to the voltage signal between a sensor tip and ground [Fig. 1]. Each sensor of two-sensor conductivity probe works independently as an identifier of a phase. As the electrical circuit is opened or closed depending on whether the sensor tip is in contact with gas or liquid, the voltage drop across the sensor fluctuates between two reference voltages. For liquid continuous two-phase flow such as bubbly flow, the circuit is closed when the sensor is in liquid [1]. To optimize the design of two-sensor conductivity probe for appropriate uses in the VINATOM test facility with measurement conditions of bubbles as follows: air-water flows; 2÷5 mm in diameter; 0.3÷2 m/s in velocity, the literature survey was carried out thoroughly at first.

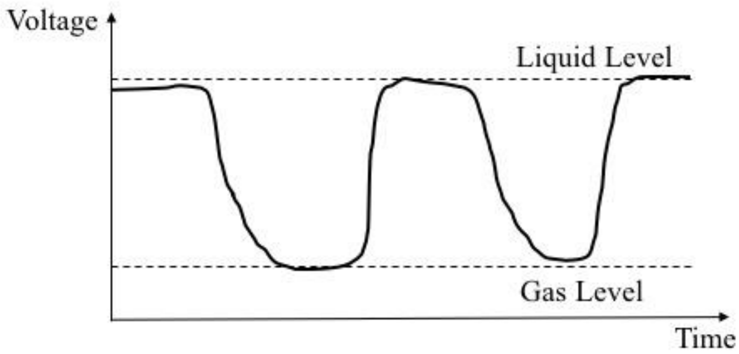


Fig. 1. Voltage signal obtained from conducitvity probe

In fabricating the probe, a wire of thermalcouple (TC) type K (Cromel/Alumel) with its OD of 0.2 mm are employed as the electrodes as well as the stem of sensors as shown in Fig. 2. The sensor tips have to be grinded and sharpened in order to reduce deformation of penetrating bubbles and then coated with thin layer of gold to increase the electrical conductivity of electrodes. For the dielectric coating of the sensors, the sensor tips were exposed and the coating of the epoxy resin with very thin layer was applied to insulate the rest of the sensor, together with the plastic layers which cover TC wires. The other end of electrodes was connected with copper wires and then connected with signal conditioner inputs. These structure were put into a stainless steel tube with ID of 1 mm and a $90^0$ elbow bend and the tips of the two sensors (front- and rear-sensor) were adjusted for typical spacings of 2÷5 mm in the lengthwise direction and were aligned in the axial direction of tube. The next coating step is completed using a commercial strength epoxy layer to form a bond connection between sensors wires and holding tube. Finally, the tube structure was inserted into larger stainless steel tube with OD of 6.35 mm via a plastic connector to conform with the probe holder of VINATOM test facility.

Signal conditioner was developed which consist of a simple electronic circuit with the main objective of impedance matching between the probe and Data Acquisition System. The Silicon N-channel Junction Field Effect Transistor 2N4416 was seleted to use in the signal conditioner design due to its high input impedance and temperature stability. The detailed circuit is shown in Fig. 4. The conductivity probe was connected with Data Acquisition System (DAS) via signal conditioner to convert the analogue voltage into digital signal. The DAS device is DAQ USB-6210 developed by National Instruments with key specifications as 16-bit and 250 kSamples/seconds. The output signals were recorded digitally at sampling frequency between 6 and 10 kHz depending on the flow conditions using LABVIEW software embedded with MATLAB script which was installed in a computer connected with DAQ device through USB port. In vertical-upward air-water flows, the direction of the two sensor points should be made to coincide with the axial flow direction in order to accurately measure the local parameters of two-phase flows. Therefore the axial direction of casing tube contained two-sensor tips should be designed alignment with the flow direction.

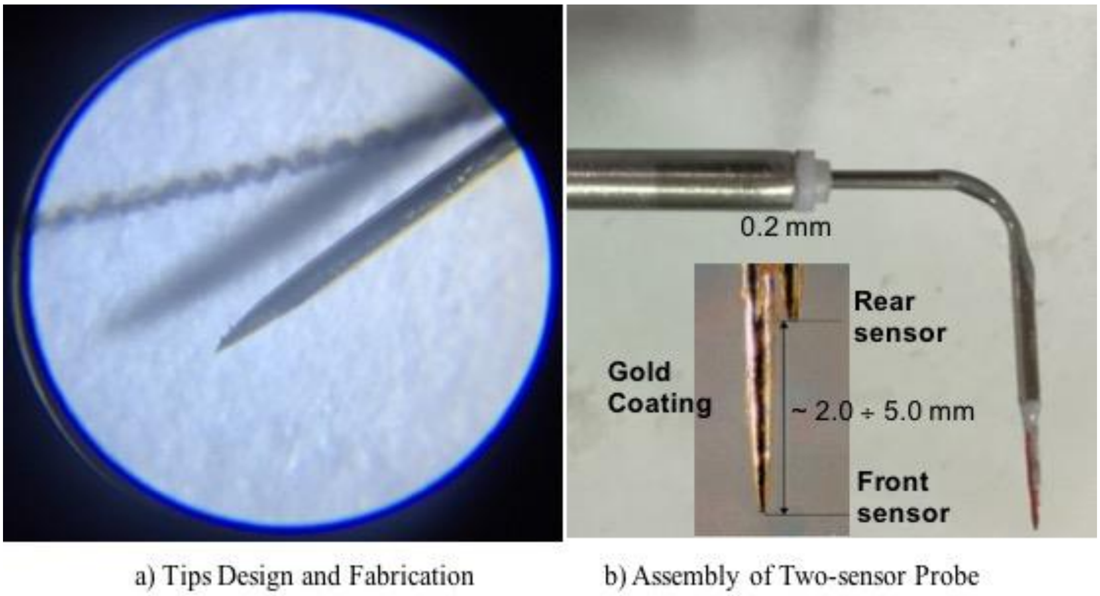


Fig. 3. Conductivity Probe Design and Assembly

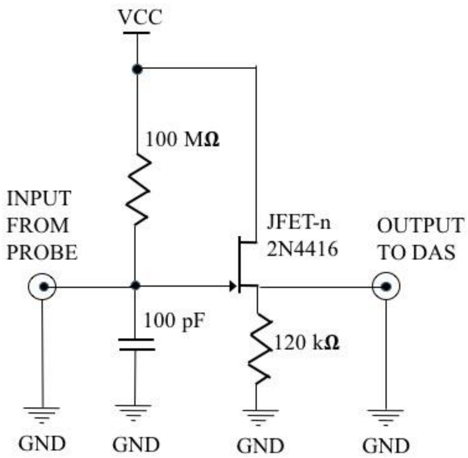


Fig. 4. Electronic Circuit of Signal Conditioner

## 3. SIGNAL PROCESSING ALGORITHM FOR MEASURING OF LOCAL TWO-PHASE FLOW PARAMETERS

To obtain accurate local two-phase flow parameters, it is critical to identify the bubbles appropriately from recorded signals by DAQ system. To accomplish this successfully, the signal processing scheme is constructed in following steps: Signal Reading and Normalization, Make Cut-off Levels, Signal TransRectangle and Filtering, Bubble Statistics Display.

### 3.1. Signal Reading and Normalization

The output signal can be varied by probe fouling and flow conditions, neither the absolute value of the base voltage, nor the voltage drop is fixed. Therefore, all the signals obtained by the probe sensor should be normalized as equation below:

$$V_{\text{norm,i}} = C \times \frac{(V_{\text{i}} - V_{\text{min}})}{(V_{\text{max}} - V_{\text{min}})} \quad (1)$$

where $V_{\text{norm,i}}$ is the normalized voltage of the ith signal, $V_{\text{i}}$ is the ith signal, $V_{\text{max}}$ is the maximum voltage, and $V_{\text{min}}$ is the minimum voltage. In this study, multiplier coefficient was set equal to 1000.

Raw signals were recorded by the DAS system using developed LABVIEW interface mentioned in Section 2, and then loaded and read by signal processing module developed in this Section. The minimum values of normalized signals should indicate the liquid phase level. It can be seen that, however, the fluctuation of these values were observed in every cases of experiments. Kim et al. [4] have considered that any voltage fluctuations within 0.05 V are considered to be noise and should be removed from the raw signals. In this study, we developed an advanced algorithm to determine an adequate level to remove noises and it will be presented in next step.

### 3.2. Make Cut-off Levels

Cut-off levels are very important to determine accurately the square signals which would be finally used for phase indicators [Fig.4]. The algorithm was developed based on the pulse height and slope criteria as proposed by previous investigators [1-4]. However, the advance methodology of Yun et al. [5] was implemented in this study considering that the pulse height produced by individual bubble can be varied for each bubble. Therefore, the cut-off levels for each bubble is different from one case to another, instead of preset cutoff levels for all bubbles as applied previously. The cut-off level is proportional to the pulse height and this value is a necessary condition for phase level transition. The sufficient condition for phase level transition is decided by the slope criteria which is determined by comparing the instantaneous slope and magnitude of the probe voltage with selected slope threshold value.

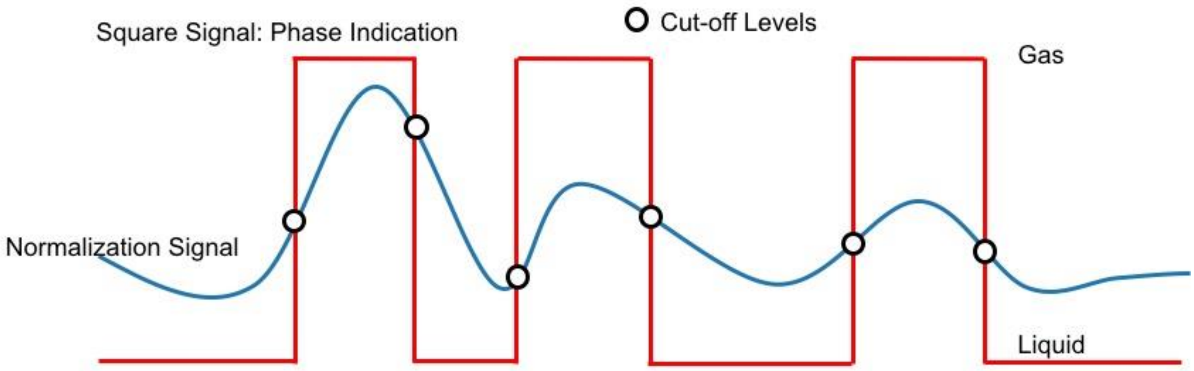


Fig. 4 Determination of Phase Indicators by Cut-off Levels

### 3.3. Signal TransRectangle and Filtering

Once the cut-off levels were determined, the square signals would be generated easily by performing the function Signal TransRectangle in software modules developed by LABVIEW and embedded MATLAB script. However, these square signals must be processed via Filtering module to eliminate the wrong signals produced by Signal TransRectangle module, based on the practical flow conditions.

### 3.4. Bubble Statics Display

The final module is to calculate local two-phase parameters such as void fraction, chord length, bubble velocity, bubble statistics …etc from the square signals of front and rear sensors.

The local void fraction can be obtained from either of the two sensors and calculated by the fraction of total pulse width of square signal, while the total number of squares would give the number of bubbles hitting the tip sensors in a given period of time. The bubble velocity is determined by accurate estimation of residence time of bubble passing through both front and rear sensors.

## 4. BENCHMARK EXPERIMENT WITH IMAGE ANALYSIS METHOD

The benchmark test facility used in the present study was constructed at HUST. Fig. 5 shows a schematic diagram of the vertical upward air-waver test loop. This test loop consists of a test section made of a transparent acrylic rectangular pipe (20mm x 20mm x 400 mm), bubble generator, water supply system, air supply system and a data acquisition system.

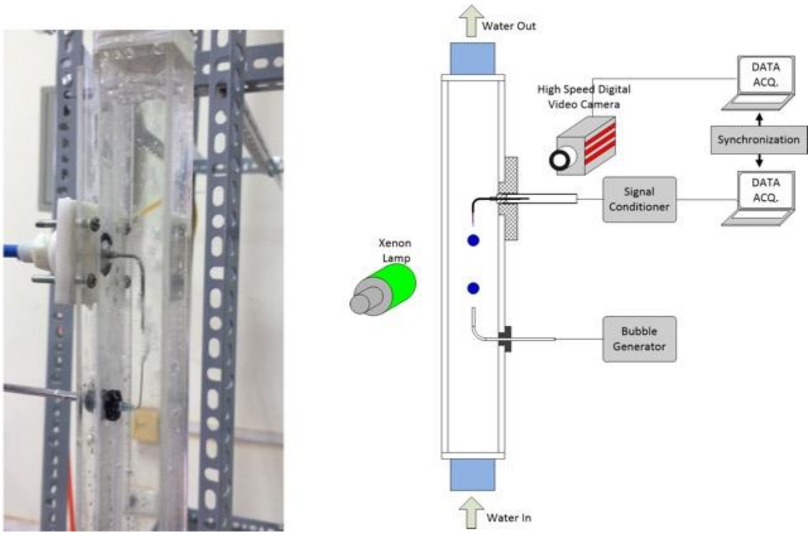


Fig. 5 Benchmark Experiments of Conductivity Probe

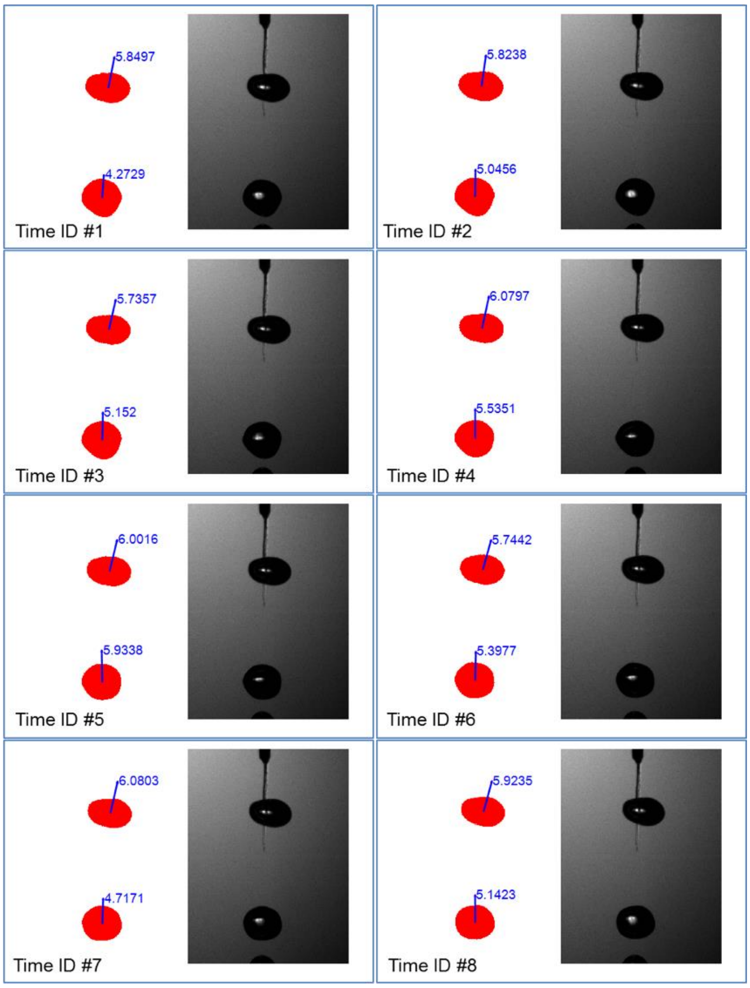


Fig. 6 Imaging Techniques for Bubble Velocity Tracking

A high speed SONY camera were set, based on the expected bubble velocity, to 300 fps and connected to a computer. A xenon lamp, covered with tracing paper, were used to give better image quality; placed just behind the test rig in line with the camera. The captured images was processed with a developed program written in MATLAB to track the bubble boundary and movement of bubble along the channel and produce the estimation of bubble velocity [Fig. 6]. Comparison results between bubble velocities measured by two-sensor conductivity probe and imaging techniques indicate the good performance of signal alorithm as well as the probe itself [Fig. 7].

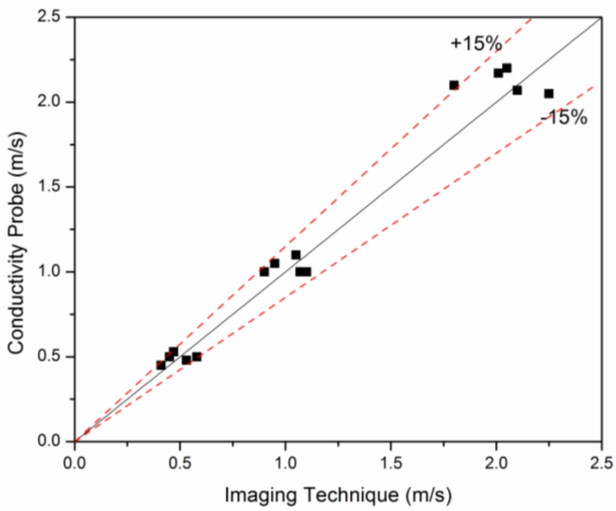

Fig. 7. Comparison results between conductivity probe and imaging technique

## 5. CONCLUSIONS

The paper presented comprehensively the process of conductivity probe design, fabrication and validation. Comparison results have shown the good quality of conductivity probe and they are readily applicable for two-phase flow test facility at VINATOM.

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## ACKNOWLEDGEMENT

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# PHÁT TRIỂN HỆ THIẾT BỊ ĐẦU ĐO ĐỘ DẪN VÀ THUẬT TOÁN XỬ LÝ TÍN HIỆU PHỤC VỤ ĐO ĐẠC CÁC THÔNG SỐ CỤC BỘ DÒNG HAI PHA

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**Tóm tắt:** Đo lường chính xác các giá trị thông số cục bộ dòng hai pha có ý nghĩa cực kỳ quan trọng trong việc đánh giá các mô hình dòng chảy hai pha cũng như phát triển các mối quan hệ vật lý mô tả động học dòng hai pha trong mô hình hai dòng chảy. Bài báo trình bày các kết quả phát triển nghiên cứu thực nghiệm các hiện tượng động học dòng chảy hai pha tại Đại học Bách khoa Hà nội, bao gồm việc xây dựng hệ thực nghiệm cấu hình ống đứng quy mô nhỏ, cũng như chế tạo thiết bị hai đầu đo độ dẫn nhằm đo đạc các thông số cục bộ dòng hai pha như tỉ lệ rỗng pha, vận tốc pha và mật độ diện tích bề mặt pha. Hệ thống tạo dạng tín hiệu, thu thập và thuật toán xử lý dữ liệu đo đạc cũng được phát triển cùng với thiết bị hai đầu đo để hoàn thiện hệ thống đo đạc. Các kết quả thực nghiệm thực nghiệm chuẩn hóa thiết bị đo kết hợp với phương pháp chụp và phân tích hình ảnh đã khẳng định khả năng hoạt động tốt của hệ thực nghiệm và thiết bị đo đạc, sẵn sàng phục vụ cho các nghiên cứu thực nghiệm chuyên sâu về động học dòng hai pha.

**Từ khóa:** *Dòng hai pha, đầu đo độ dẫn, thuật toán xử lý tín hiệu*