NUREG/CR-0769

BNL-NUREG-50997

RADIO FREQUENCY (R-F) PROBE FOR BUBBLE SIZE AND VELOCITY MEASUREMENTS

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UPTON, NEW YORK 11973

Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Contract No. EY-76-C-02-0016

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R-2

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OFFICE OF NUCLEAR REGULATORY RESEARCH
CONTRACT NO. EY-76-C-02-0016
NRC FIN NO. A-3045

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TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

A radio frequency (r-f) probe that can provide local void fraction and interface velocity measurements in a gas-liquid two-phase flow was developed. The probe response to bubble passage was investigated with single bubble controlled experiments. For fixed geometry, the probe response was dependent on the dielectric constant of the medium surrounding the probe tip, (air or water), and on the frequency of the carrier signal supplied to the probe. Bubble lengths (< 1 cm) and average bubble approach velocities (< 160 cm/sec) were independently measured by two light sources and detectors placed at a known distance from each other and sensing the passage of each bubble. By choosing a sensitive probe tip length of 2.75 - 3 mm, the r-f probe output provided enough information to determine the bubble length and velocity. The results obtained by the two independent methods show reasonable agreement (± 10 percent).

I. INTRODUCTION

Several local probes have been developed to obtain information on the local flow structure of two-phase gas-liquid flows [1,2,3,4] in steady state and transient conditions. Local probes are usually sensitive to some physical property inherent to one of the two-phases, i.e., electrical resistivity, capacitance and index of refraction. These probes yield information on the local time averaged void fraction and the interface velocities. Methods for obtaining these quantities from the raw probe signals were documented in the literature [5]. This report describes the development of a radio frequency (r-f) probe and a calibration technique for determining bubble size and velocity using a simple air-water loop in which well-controlled single Taylor bubble can be generated.

II. THE r-f PROBE

The r-f probe presented in Figs. 1a and 1b consisted of two 0.25 mm diameter insulated wires, with each wire encased in a 1 mm outside diameter stainless steel tube which were electrically connected to a common ground and acted as an electrical shield. The two shielding tubes themselves were encased in a larger stainless steel tube, which acts as a holder and provides rigidity. The sensitive part of the probe, the probe tip, was formed by extending the two insulated wires around 3 mm from the end of the shielding tubes. To prevent water from entering into the stainless steel tubes, each of the end connections were covered with a thin layer of epoxy including the tip of the two insulated wires which were also covered to insulate them from the surrounding media, water or air. When a d-c voltage is applied across one of the wires and the common ground, zero voltage is measured across the second wire and the ground. In operation of the probe, one of the wires is used as an emitter to which a sine wave is applied from a function generator. The second wire is used as a receiving antenna, and its output is fed directly to an oscilloscope or to a magnetic tape recorder after amplification. Similar r-f probes were previously described in the literature [5,6] but a systematic study of the response characteristics was not undertaken. For a given amplitude and frequency of the input sine wave, the probe output signal has the same frequency as the input, but is out of phase with the amplitude, a function of whether the two insulated wires at the tip are immersed in water or in air. The probe is sensitive to the dielectric constant of the media surrounding the tip. The r-f probe was tested both in static air and water and with Taylor bubbles of known length and velocity in a simple test facility described briefly below.

III. THE TEST FACILITY

The test facility used in the study of the r-f probe is shown in Fig. 2 [7]. It consists of a glass tube (0.64 cm I.D. and 83 cm long) connected at upper end to a reservoir open to the atmosphere and at the lower end, through a ball valve, to a pressurized H_2O supply reservoir. The supply reservoir pressure is maintained constant by an air bottle and pressure regulator. Air bubbles are injected at the base of the glass tube by means of a needle valve. Opening the ball valve releases the pressurized water and thus accelerates the liquid column and the single Taylor bubble at the same time. Each air bubble fills the entire tube cross section travels along the glass tube and impinges on the tip of the r-f probe. The average velocity of the bubble along the glass tube is independently measured upstream of the probe tip by means of two sets of light sources (incandescant bulbs) and photo-detectors whose axial position along the glass tube can be varied.

IV. RESULTS

First the static response of the r-f probe in air and fully immersed in water was investigated in the test set-up described above. When a sine wave with an amplitude of 22.7 v (peak-to-peak) was applied to the transmitting antenna (input), the amplitude of the received signal (output) varied with the signal frequency of the input (from 100 Hz to 10^7 Hz) both in air and in water. Figure 3 depicts the variation of the output, (A_{out}) divided by the input (A_{in}), both determined with an oscilloscope, as a function of the input sine wave frequency, when the probe tip is completely immersed in air or in water. Depending on the input frequency, the signal amplitude in water can be higher than the signal in air or vice-versa. The r-f probe seems to act as a band pass filter. For a 500 kHz, 22.7 peak-to-peak sine wave input, the output voltage of the r-f probe was also observed to be dependent on the static immersion depth of the insulated nonshielded portion of the probe tip into the water. The output increased linearly with the immersion depth, reached a maximum and then decreased and leveled off at the all water signal level. An additional fact observed was that the output vs. input curve as presented in Fig. 3 depends on the tube or pipe diameter in which the probe is immersed. Thus before undertaking any application of this probe for a specific geometry, a careful signal optimization with input frequency should be performed.

The probe with a 500 kHz, 22.7 v peak-to-peak sine wave input was also checked during the passage of bubbles with known velocities and lengths. The output of the two light source detector setups were recorded on an FM channel, and the r-f probe output was recorded on a direct record channel, of a Honeywell 9600 tape recorder at a tape speed of 120 in/s (3.05 m/s). The tape was played back at a speed of 7.5 in/s (19 cm/s), and the data recorded with Hewlett Packard 9640A Data Acquisition System and a NEFF multiplexed ADC subsystem at a rate of 50 kHz for 25 seconds, through a built in 1 kHz filter. The stored data for each run was then analyzed and plotted on the Varian printer-plotter.

Figure 4 presents a typical output of the two light source detectors (stations 1 and 2) during the passage of a bubble. Here the voltage output of the detectors connected in series is presented as a function of time. The two large dips in signal display the passage of the bubble through the measuring stations. The two stations were located at 20.2 cm from each other. A measurement of the time of flight of the bubble from stations 1 to 2 provides for calculation of the bubble velocity. Once the average velocity of the bubble is calculated from the measurement of the bubble residence time at each station, one could easily calculate the bubble length. The signal analysis software was developed to allow observation of the total output of 25 sec, or the output at selected time intervals with a minimum time step of 20 μsec. A "zoom" capability was included to allow concentration on the specific parts of a recorded time sequence and examination of the details in the expanded time frames of the selected data. Typical examples are presented in Figs. 5 and 6 which "zooms" in on the details of the signals at stations 1 and 2, which were presented in Fig. 4.

Figure 6 presents the expanded output of the r-f probe during the passage of a bubble. The output decreases from its water level to the air level with the penetration into the bubble and stays almost constant during the passage of the bubble. When the water impinges on the probe tip again, the signal increases, passes through a maximum, decreases, and then levels off at the steady air level. A possible explanation for this maximum was proposed by Fortescue [10]. as being due to the additional capacitance of the water surrounding the insulated unshielded wires. Grounding the water close to the tip by a separate copper wire eliminated this maximum of the probe signal.

In Fig. 7, the bubble velocities determined by the r-f probe are compared with velocities determined from the output of the two light-source detectors. Two penetration time intervals were measured from the r-f probe output (Fig. 6), Δt_1, and Δt_2. By considering a typical characteristic length of the sensitive part of the tip (3 mm and 2.75 mm), a bubble velocity was calculated. The actual dimension of the sensitive part of the tip is around 3 mm (see Fig. 1a). The bubble velocities determined by the two independent methods agree with each other within $\pm$ 10 percent. Thus with an r-f probe, the average bubble velocity can be determined from the passage time of either interface, air-water or water-air, along the insulated wires. This is true irrespective of the amplitude of the signal which may change with fluid state, purity, or test geometry.

The probe output levels for water and air did not change with the bubble velocity in the range considered (up to 160 cm/sec). Figure 8 depicts that the bubble sizes as determined by the two independent methods agree with each other with a maximum deviation of ± 10 percent. The bubble lengths recorded by the r-f probe are 10 percent higher at the low bubble velocities around 30 cm/sec. This fact may be due to surface tension effects during the penetration which become important at these low bubble velocities.

In summary, the r-f probe investigated has a relatively simple construction, and once tuned properly to the test geometry seems to provide information on bubble sizes and velocities. More work is needed to check the response of the probe in two-phase pipe flow conditions.

ACKNOWLEDGEMENT

This research was sponsored by the U. S. Nuclear Regulatory Commission.

The authors wish to thank Ms. Nancy Schneider for her efforts in the preparation and typing of the manuscript.

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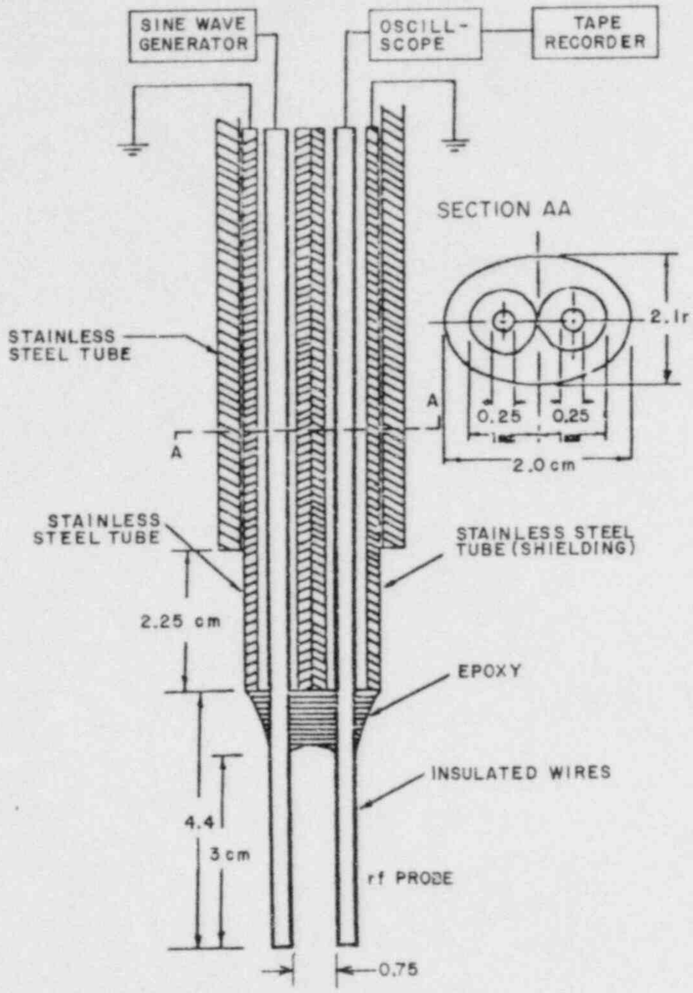

Figure 1a. Schematic representation of the r-f probe.

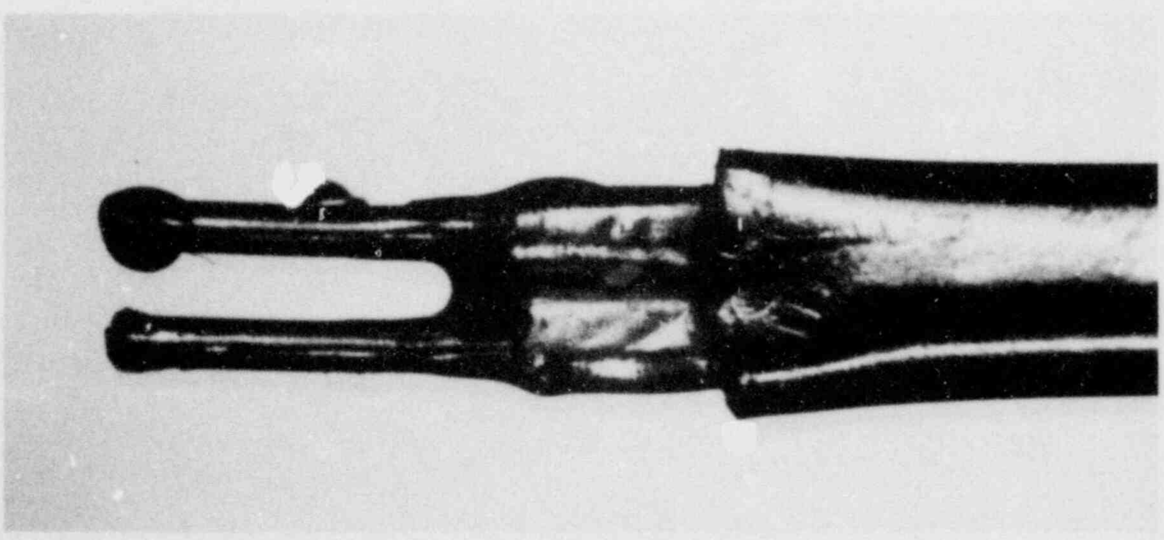

Figure 1b. r-f probe.

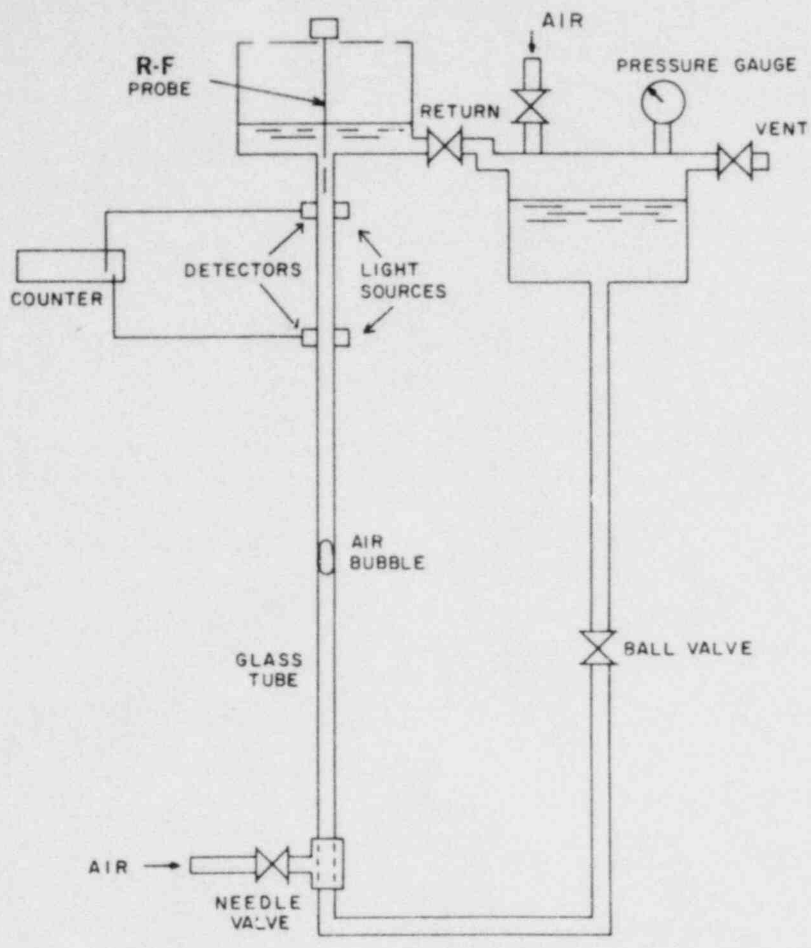

Figure 2. Schematic of calibration loop.

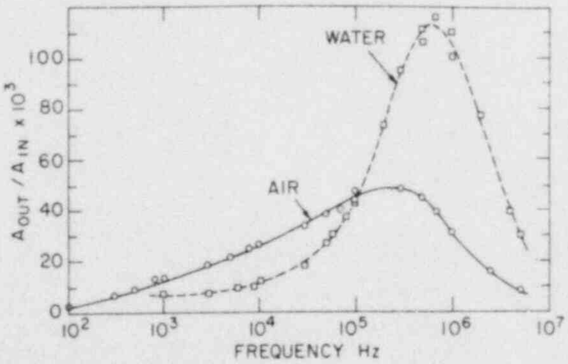

Figure 3. Ratio of r-f probe output to input voltage level as a function of input sine wave frequency, for the probe tip in air and in water.

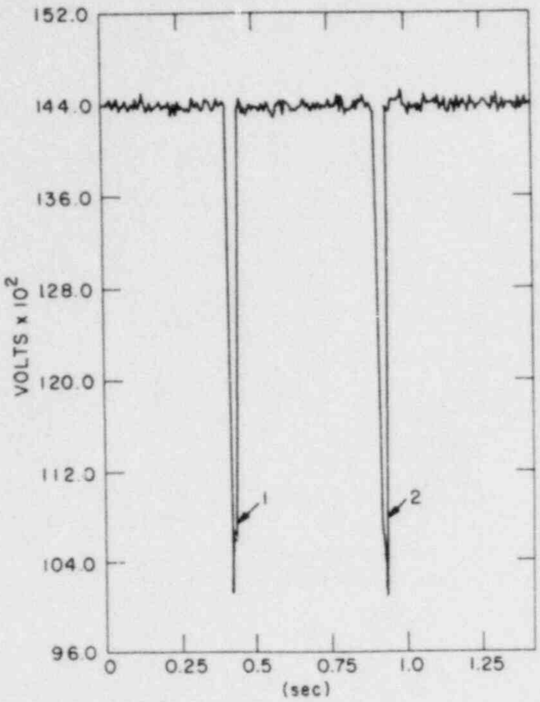

Figure 4. Output of the two light sources and detectors during the passage of a bubble.

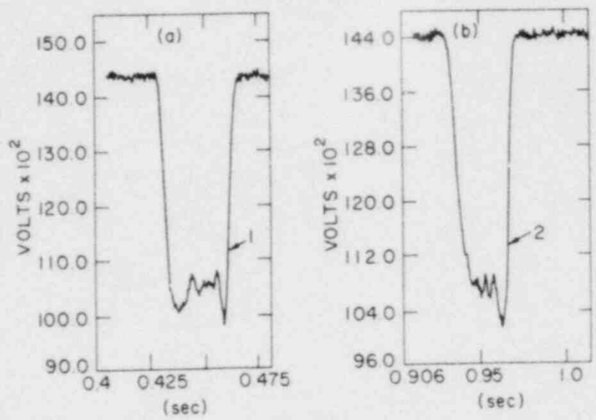

Figure 5. a. Expanded output of detector 1; b. expanded output of detector 2.

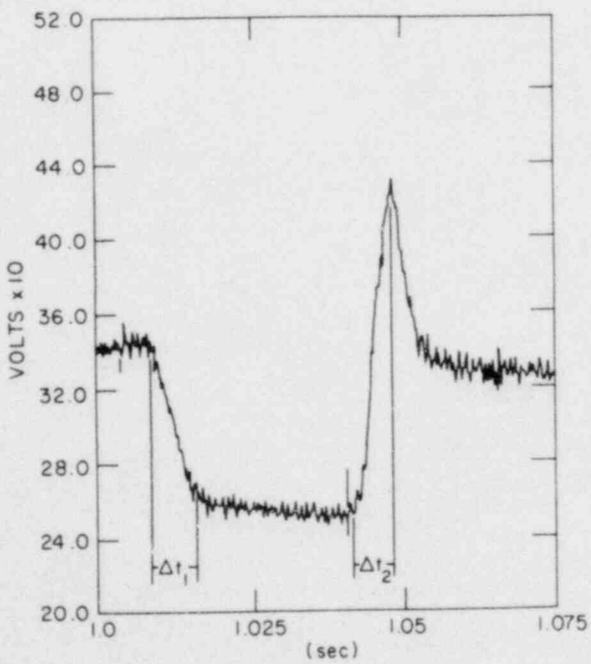

Figure 6. Expanded output of the r-f probe during passage of the bubble.

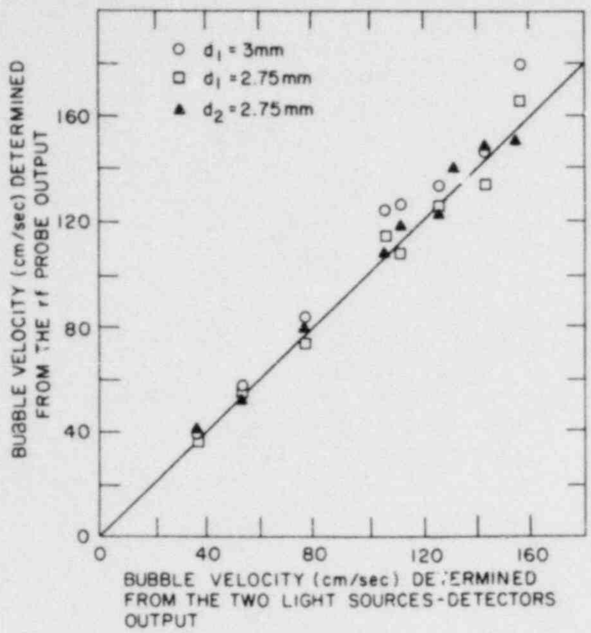

Figure 7. Comparison of bubble velocity as determined by two independent methods, i.e., r-f probe and two light sources and detectors.

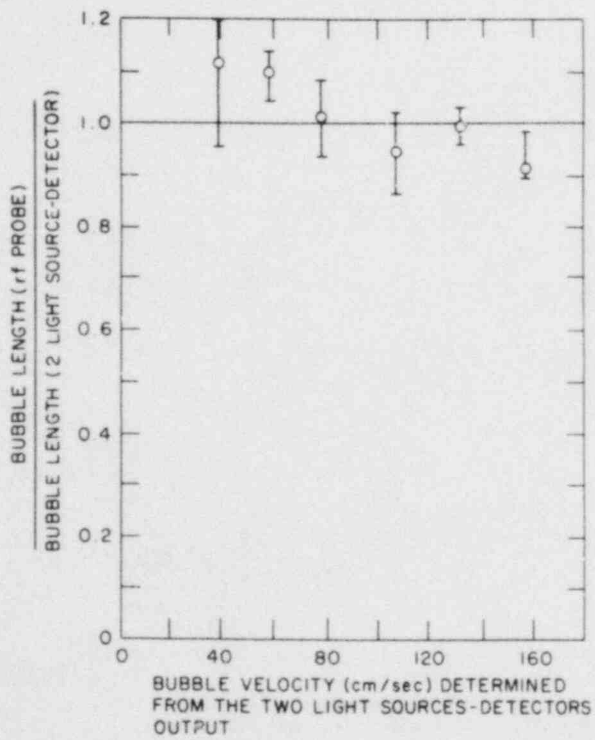

Figure 8. Ratio of bubble length as determined by the r-f probe and the two light source detectors as a function of bubble velocity.