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BRIEF COMMUNICATION

DEPENDENCE OF THE INSTANTANEOUS RESPONSE OF IMPEDANCE PROBES ON THE LOCAL DISTRIBUTION OF THE VOID FRACTION IN A PIPE

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Abstract—In a vertical pipe of circular cross-section the instantaneous response of an impedance probe which has its electrodes mounted flush in the tube wall to avoid disturbing the two-phase flow, depends on the void-fraction distribution. Different probe geometries (different widths and numbers of electrodes) and different a.c. supplies were studied to minimize the influence of this parameter. With single-phase a.c. supply the electrodes of intermediate width yield the best results. An increase from two to four electrodes, does not entail any improvement, whatever the kind of electrode connection. With a six-phase a.c. supply, such that a rotating electric field is obtained within six electrodes, the results are better than those obtained with two electrodes of intermediate width supplied with single-phase current.

INTRODUCTION

Even in fully-established two-phase flow, the void fraction is dependent on time. It is characterized by its mean value and fluctuates around this value. When the two-phase mixture consists of a dielectric phase dispersed in a conducting phase, the void fraction can be measured using impedance probes. The signal can be processed in order to obtain its mean value as well as its fluctuations. The mean value depends on the mean void fraction but also on the flow regime (bubbly flow, slug flow . . .). In a pipe of circular cross-section, the influence of the flow regime on the mean time response of probes of various geometries was studied (Abouelwafa *et al.* 1980; Gregory & Mattar 1973; Merilo *et al.* 1977). The fluctuating signal is a function of the void-fraction fluctuations, of the flow regime and, when the electric field is not uniform within the probe, of the distribution of the dispersed phase in the continuous phase. Such is the case in a vertical pipe of circular cross-section when, to avoid disturbing the flow, the electrodes are mounted flush in a dielectric tube wall. To evaluate, along the flow, the changes in amplitudes and the propagation velocity of the disturbances, it is necessary to minimize the influence of the dispersed-phase distribution on the probe response. To our knowledge, this subject was not treated. The purpose of the present work was to perform a quantitative comparison between the sensitivities to the instantaneous void distribution in bubbly flow of the best classical impedance probe (the best classical impedance probe is the measurement device with inserted electrodes, which is the least influenced by the void distribution) and of the rotating field impedance probe (Merilo *et al.* 1977).

THE CLASSICAL IMPEDANCE PROBE

The geometry of the probe is defined by the width and the number of electrodes. If the total width of the electrodes is equal to half circumference of the inside tube wall, the width of each identical electrode is defined as the intermediate width.

The two-electrode probe; influence of the width of the electrode

The electrodes are mounted flush in the inside tube wall of a cylindrical test section, which has an internal diameter of 30 mm and a length of 30 mm. The experiments are

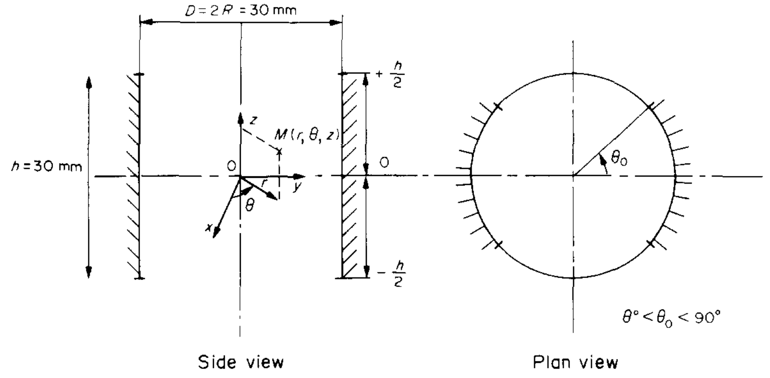

Figure 1. Scheme of a two-electrode probe.

carried out in stagnant water, the mean void-fraction value being close to zero. A void-fraction disturbance is simulated by a non-conductive glass ball the diameter (6 mm) of which is chosen to simulate an amplitude of fluctuation (0.5%) of the same order of magnitude as that of spontaneous fluctuations in actual low-pressure air (or nitrogen)–water flows (Matuszkiewicz *et al.* 1984).

The probe is supplied with 10 kHz alternating current. At this frequency the measured impedance (Z_α) is equal to the two-phase flow resistance. It is divided by the resistance of the single-phase liquid (Z_L) to compensate for changes in the resistivity of the liquid due to variations of its temperature and impurity content. The complement to one of this ratio is the relevant signal. The measurements depend on the width of the electrodes, characterized by the angle θ_0, and on the position of the ball, characterized by its cylindrical coordinates (figure 1). Three different probes ($\theta_0 = 22.5°$, 45°, 85°) have been tested. Defining

$$\mathscr{D}i_{n,\theta_0}(r, z) \triangleq \int_{\theta=0°}^{\theta=90°} |S_{n,\theta_0}(r, \theta, z) - \overline{S_{n,\theta_0}}(r, z)|\,\mathrm{d}\theta,$$

$$\overline{S_{n,\theta_0}}(r, z) = \frac{1}{90}\int_{\theta=0°}^{\theta=90°} S_{n,\theta_0}(r, \theta, z)\,\mathrm{d}\theta$$

and

$$S_{n,\theta_0}(r, \theta, z) = \frac{Z_\alpha}{Z_L} - 1;$$

n = number of electrodes (in this paragraph $n = 2$). The best classical two-electrode impedance probe is defined as the system yielding the minimum value of the dispersion parameter $\mathscr{D}i$.

First, the number of parameters characterizing the localization of the disturbance is reduced from three (r,θ,z) to one (θ) by noting that for all the studied geometries the maximum dispersion of results is observed when the ball moves in the middle cross-section and tangentially to the wall of the pipe. Secondly, the variations of results with the width of the electrodes is shown in figure 2. The maximum is at abscissa $\theta = \theta_0$ and the minimum at abscissa $\theta = 0$ for electrodes with $\theta_0 > 45°$, and at $\theta = 90°$ for electrodes with $\theta_0 < 45°$. For each curve the dispersion parameter defined above can be estimated, it is a minimum for the electrodes corresponding to a 45° angle.

In the middle cross-section the electric field can be considered as two-dimensional and the equipotential lines can be drawn with rheographic paper. The previous results are confirmed; the lines are more evenly distributed (figure 3) for electrodes of intermediate width ($\theta_0 = 45°$, figure 1).

The four-electrode probe

The experiments are conducted with rheographic paper. The distribution of the electric field is a function of two independent parameters: the width of the electrodes and the way

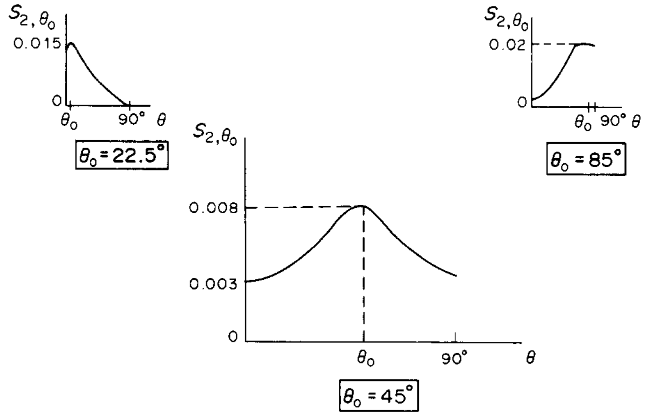

Figure 2. Variation of the response of the probe with the width of the electrode.

they are connected (figure 4). For each type of electrode connection the best results are obtained with an intermediate width ($\theta_0 = 22.5°$). But whatever the connections of the electrodes are, the electric field is not as evenly distributed as with the two-electrode probe ($\theta_0 = 45°$). Increasing the number of electrodes does not improve the performance of the probe.

To conclude, the best classical impedance probe consists of two electrodes of intermediate width.

THE ROTATING ELECTRIC FIELD IMPEDANCE PROBE; COMPARISON WITH THE BEST CLASSICAL IMPEDANCE PROBE

Six electrodes are supplied with sinusoidal currents having the same amplitude but with phases differing by $k\pi/3, 0 < k < 5$. A rotating electric field is thus generated within the probe volume (figure 5).

The electric circuits are shown in figure 6. The absolute values of the amplitudes of the currents, measured in the six resistances R, are summed up. The signal is proportional to the conductance of the two-phase mixture. It is divided by the conductance of water to obtain, as above, a signal independent of the temperature and impurities of the liquid phase.

The measurements were made with rheographic paper. The mean void fraction is equal to zero. The void-fraction fluctuations are simulated by disc-shaped holes in the paper. The tested amplitudes fall in the range (0.1–2%).

The results are presented in figure 7. From the observations of the results for two electrodes, the curves have been drawn only for a fluctuation located at the circumference and at angles $\theta = 0°$ and $\theta = \theta_0$.

Firstly, it can be seen that the signals obtained with a probe having electrodes of intermediate width ($\theta_0 = 15°$) (figure 7b) are less sensitive to the localization of the void fluctuation than those obtained with a probe having large electrodes ($\theta_0 = 25°$) (figure 7c). Secondly, the performances of the rotating-field impedance probe (figure 7b,c) are much better than those of the best classical impedance probe (figure 7a).

CONCLUSION

In a pipe of circular cross-section, the rotating electric field technique yields results which are less sensitive to the void distribution than those obtained with a classical technique. The number of electrodes of the rotating electric field impedance probe could be increased to have measurements less influenced by the void distribution. However, from a technical point of view (smaller electrodes) and an electronic point of view (greater number of phases) it would be more difficult to build such a probe. Thus, presently, a six-electrode

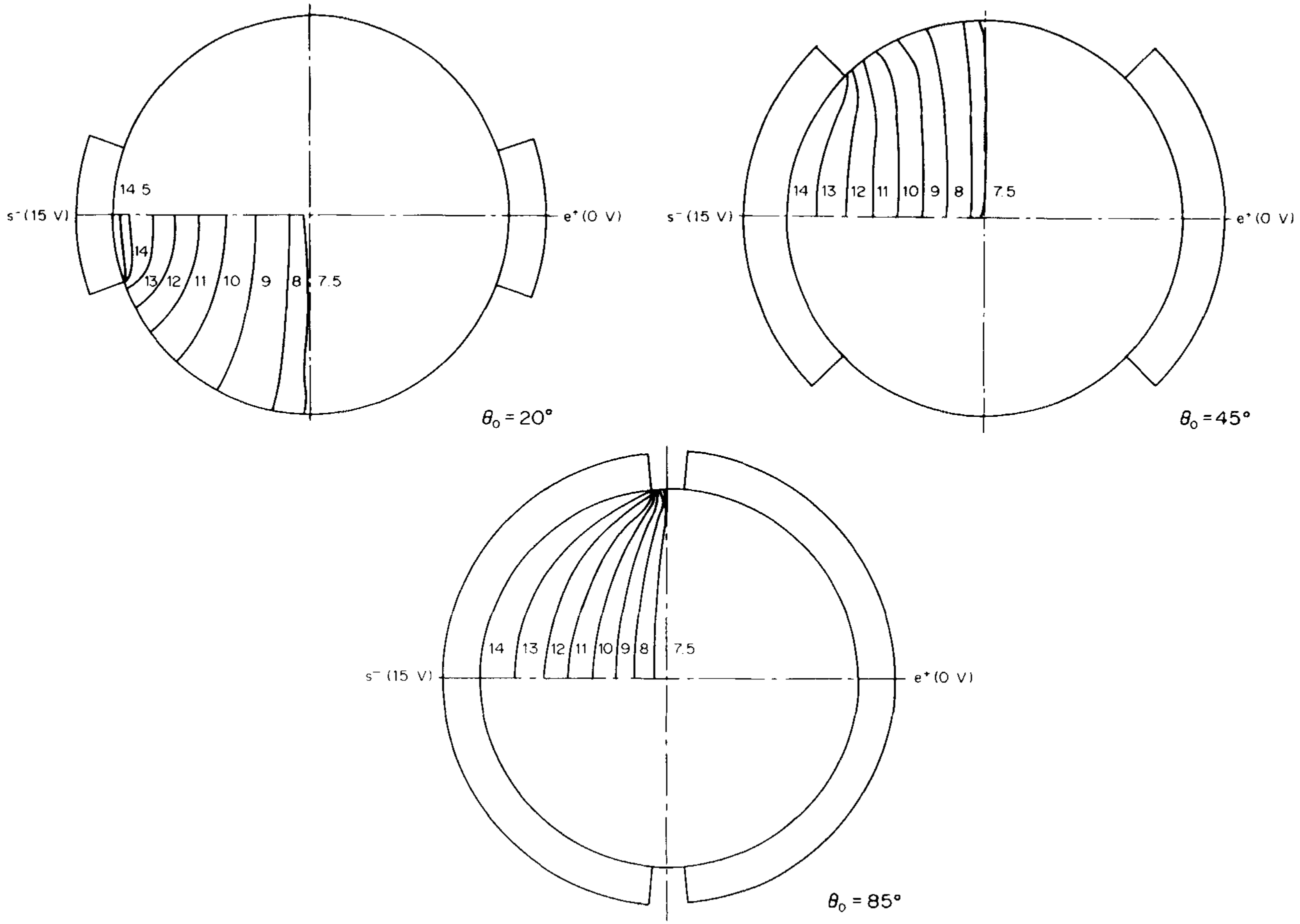

Figure 3. Equipotential lines (two electrodes; supply 15 V).

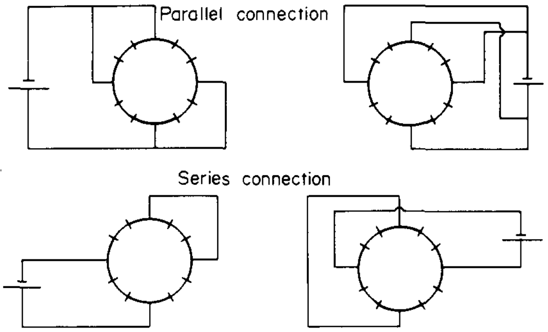

Figure 4. Different kinds of connection of two couples of electrodes.

impedance probe, supplied so as to generate a rotating electric field in the sensor volume, seems to be the impedance probe which, in a pipe of circular cross-section, best meets, the following two constraints:

- —the geometry of the electrodes must not introduce significant disturbances along the flow;
- —the measurement must be, as far as possible, insensitive to the void distribution within the flow.

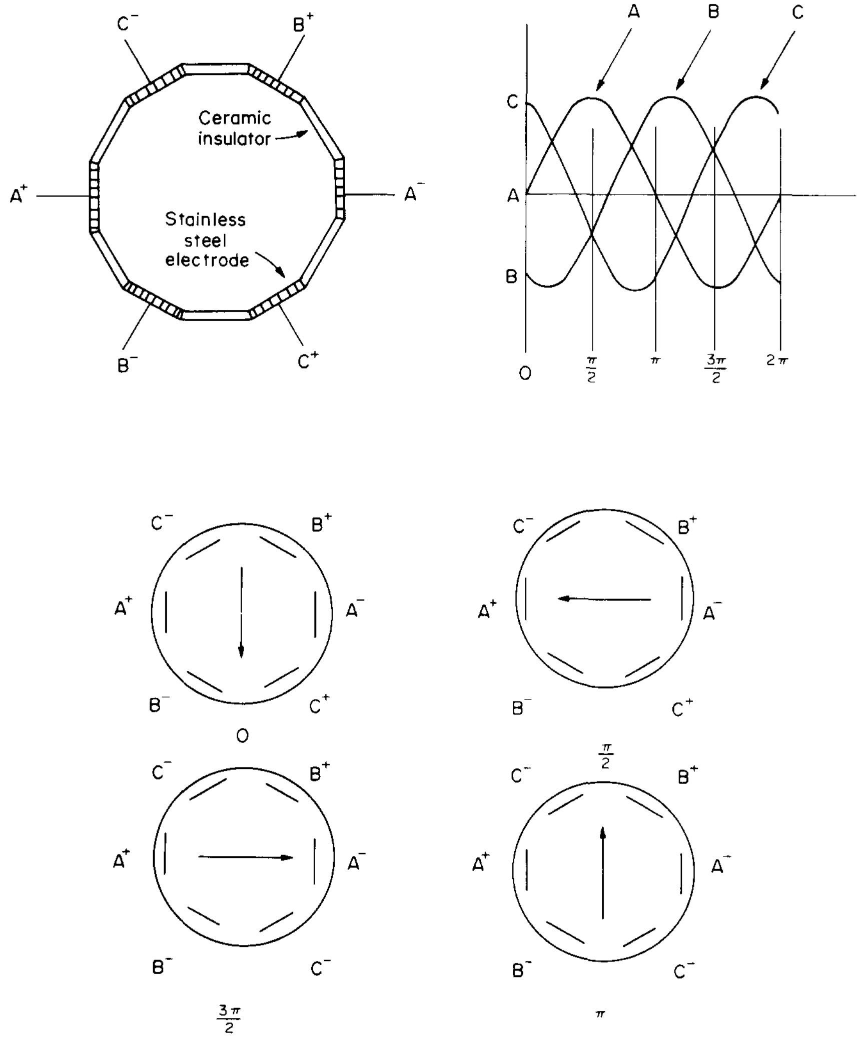

Figure 5. Sensor excitation (Merilo *et al.* 1977).

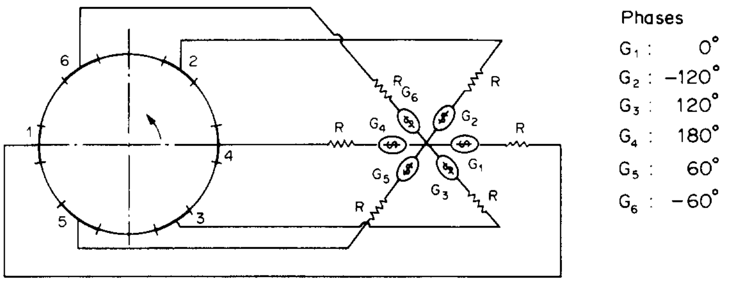

Figure 6. Electric scheme of the rotating electric field technique.

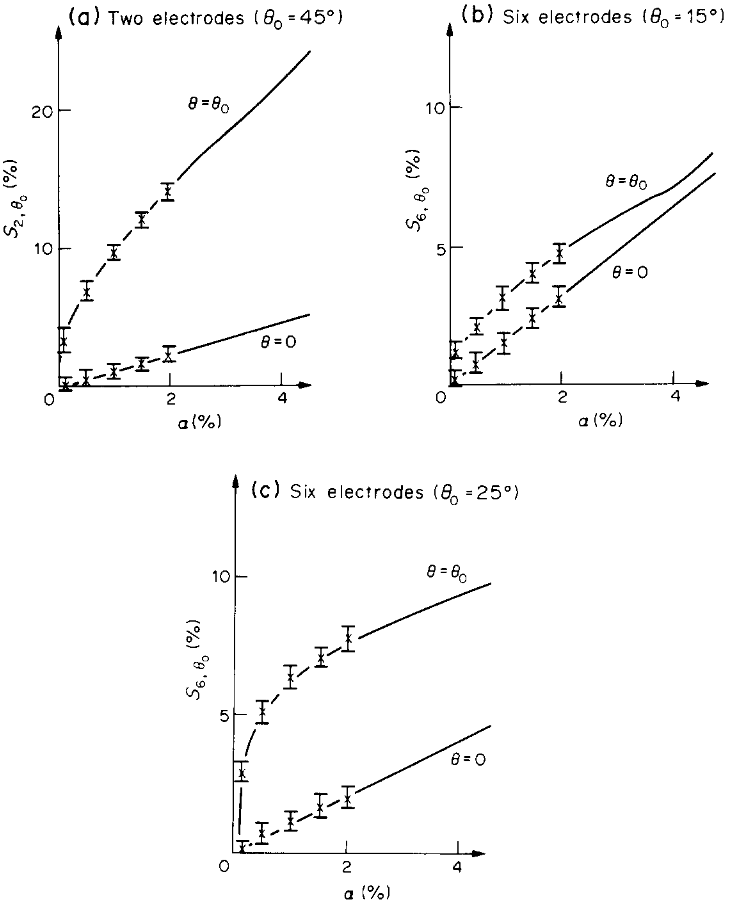

Figure 7

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