SHORT COMMUNICATION

Direction-specific characteristics of a three-component electrodiffusional velocity probe

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Nomenclature

A_i, B_i calibration coefficients
d electrode diameter (mm)
κ coefficient in Equation 3
l electrode length (mm)
u liquid velocity (m s^{-1})
u_e effective velocity (m s^{-1})
U effective velocity for the normal flow orientation (m s^{-1})

I_i probe current for i-oh electrode (A)
I_m probe current for the normal orientation (A)

Greek symbols

α angle between the normal to the electrode and flow direction (degree)
γ angle of the electrode to the probe axis (degree)
θ angle of rotating frame inclination (degree)
φ angle of probe rotation (degree)

1. Introduction

Various types of electrodiffusional wall shear stress and velocity probes have been suggested in the last years. Most attention has been paid to probes consisting of three electrodes which allow detailed information on the velocity field to be obtained. A three-segmented circular wall shear stress probe was developed in [1, 2]. A triple-split velocity probe was suggested in [3]. To study the detailed fine structure of the flow velocity miniature probes are needed to make possible the detection of high-frequency fluctuations without accounting for the probe frequency response. A small sized probe may also be of importance in measurements in gas–liquid flows with small gas bubbles.

A design of a two-component liquid velocity probe which satisfies these requirements was suggested in [4–6]. This was a V-shaped velocity probe similar to an X-type cross hot wire probe [7]. The development of an analogous probe for a three-dimensional flow is presented in this paper.

2. Probe design and measuring equipment

The basic concept was to make the probe as similar as possible to a triple hot wire probe. A sketch of the probe is shown in Fig. 1(a). The procedure for production was as follows. Three thin platinum wires were welded into glass capillaries. The ends of the wires which were not covered by glass served as the probe electrodes. They were cut to a definite length, l, and bent symmetrically to produce the same angle, γ, with respect to the probe axis. A similar probe with two electrodes for two-component measurements was described in [5, 6]. It was shown there that this

type of probe had high angular sensitivity even at low ratios of the electrode length to diameter of 3 to 10. The probe with small l/d, where d is the wire diameter, was also sufficiently mechanically strong and was not deformed in the gas-liquid flow. For these reasons, a ratio l/d of 10 was chosen for the three-component probe. The wire diameter was 50 μm. The angle γ was 54.7° to establish orthogonal probe geometry. In this case the angle between each pair of electrodes was 90° as in the orthogonal triple hot wire probe [8].

To calibrate the probe a special installation was mounted. This consisted of a circulating flow loop. The test section of the installation was a Plexiglas box of size 250 mm × 250 mm × 250 mm. At the bottom of this box a nozzle was mounted through which the liquid was supplied into the box. The liquid level in the box was maintained constant. The liquid temperature was stabilized by a thermostat; the liquid flow rate was measured by a rotameter. The velocity in the nozzle was calculated from the liquid flow rate assuming a uniform velocity profile at the nozzle cut.

To measure the angular response of the probe a traversing mechanism was mounted inside the box (Fig. 2). This consisted of a rotating frame which could change the probe angle of attack with respect to the flow direction. The probe could also rotate around its axis. This traversing mechanism made it possible to calibrate the probe in the whole solid angle up to a definite angle of attack. The probe orientation was indicated by two angles: θ, the angle of frame inclination, and φ, the angle of probe rotation around its axis.

The connecting leads from all three probe electrodes 1, 2 and 3 were connected to a three-channel d.c. amplifier with the same gain on all channels. The output voltages of the amplifiers, proportional to the electrode currents, were either measured by an integrator or processed by a computer.
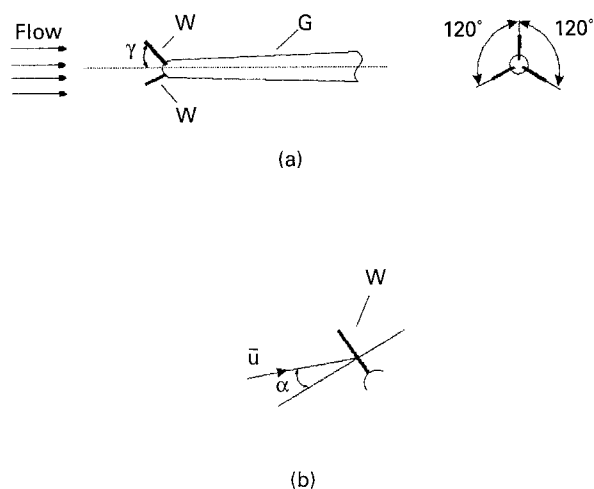
Fig. 1. (a) Three-component probe: (W) platinum wire, (G) glass capillary. (b) Designation of angle α.
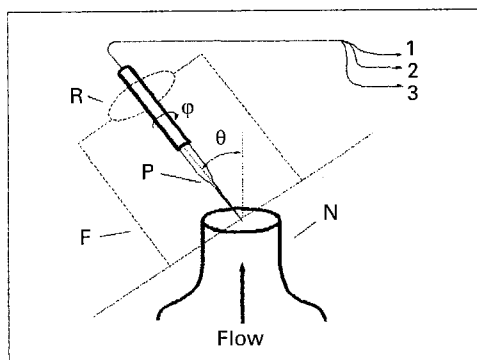

Fig. 2. Calibration setup: (N) nozzle, (F) rotating frame, (R) rotating wheel, (P) probe, (1,2,3) electric leads.

The orientation of each electrode with respect to the flow is characterized by the angle, α, between the flow direction and the normal to the probe electrode. This angle is schematically shown in Fig. 1(b) for one of the electrodes which is in the plane of the paper.

3. Results of probe calibrations

Initially, the calibration of the probe in a normal position ($\theta = 0$) was made. In this case the flow direction was the same as the probe axis. The currents of the corresponding electrodes, I_i, are plotted against square root of the liquid velocity, u. It can be seen from Fig. 3 that the well known King's law [7] is satisfied:

$$I_i = A_i + B_i u^{1/2} \tag{1}$$

for all three electrodes. The difference in probe currents is caused by different electrode lengths.

The effect of flow orientation on the probe readings is shown in Fig. 4. Here the effective velocity, u_e, is introduced similar to that for a hot wire probe [7]:

$$u_e = ((I - A)/B)^2 \tag{2}$$

where I, A and B are taken for the same (no. 3) electrode. Data in Fig. 4 are measured for three values of liquid velocity, u, in the nozzle. α is the angle between
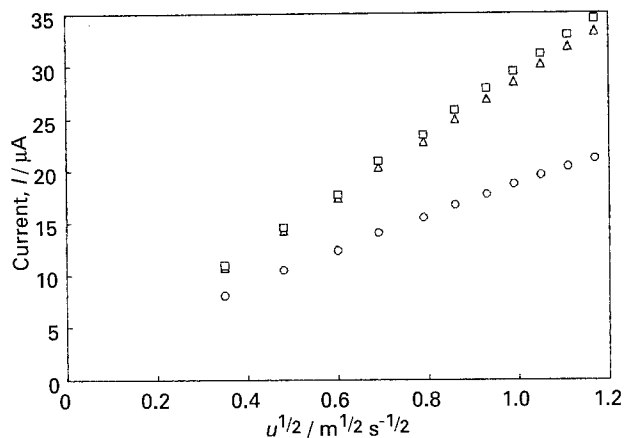

Fig. 3. Probe calibration. Key: ($\circ$) electrode 1, ($\triangle$) electrode 2 and ($\square$) electrode 3.

the normal to the electrode and the flow direction, U is the effective velocity for $\alpha = 0$ (the flow is normal to the electrode). The effect of the flow orientation on the probe readings may be approximated by the relation:

$$u_e = U(\cos^2 \alpha + \kappa \sin^2 \alpha)^{1/2} \tag{3}$$

similar to that for a short hot wire [9]. Relation 3 is shown by solid line in the figure for a κ value of 0.05. Results for the other electrodes of the probe also correlate well with Relation 3 for the same value of κ. It was assumed also that under constant α the probe current was independent of varying θ, φ.

Because the probe geometry is similar to an orthogonal hot-wire probe, techniques of data processing for the latter probe [8] may be applied to resolve the three components of the velocity vector from three probe currents. This type of probe can give unambiguous results, up to an angle θ less than 65°.

The complete calibration of the probe was as follows. For the same value of θ the readings of all three electrodes were recorded for the angle φ from 0 to 360°. Then the procedure was repeated for another value of θ, and so on. If Relation 3 is accepted for all the electrodes, then the readings of the probe for a constant θ and varying φ are presented by the curves shown in Fig. 5. Here I is the probe current, the maximum value of this current, I_m, corresponds to a normal position of the electrode
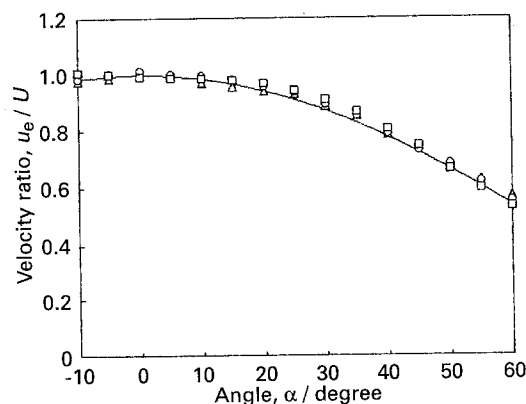

Fig. 4. Angular characteristics for different flow velocities. Solid line: Relation 3. u: ($\triangle$) 1.24, ($\circ$) 0.85 and ($\square$) 0.48 m s^{-1}.
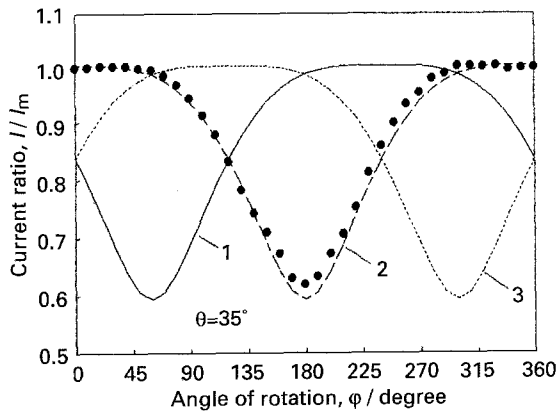
Fig. 5. Calibrations of the probe. Closed points (●) experimental data for electrode 2. (——) electrode 1, (— — —) electrode 2 and (- - - - -) electrode 3.

with respect to the flow ($\alpha = 0$ for this electrode). The numbers on the lines indicate the number of the electrode. The experimental results of the probe calibration are also presented in Fig. 5. It can be seen that Relation 3 describes the angular probe calibration fairly well. Some discrepancy between the calculated and measured curves can be attributed to the nonideal geometrical shape of the probe. This discrepancy can be easily accounted for.

The result shows that a relatively short electrode ($l/d = 10$) is adequately sensitive to the flow orientation. This effect is typical only for the electrodiffusional probe, it is not the case for a hot wire probe. The reason is that in the electrodiffusional method there are no effects similar to heat losses to the prongs in the hot wire technique. Therefore all the electrode surface takes part in the mass transfer process. The possibility of using short

electrodes for flow direction measurements is one of the main advantages of the electrodiffusional method.

4. Conclusions

A three-electrode electrodiffusional velocity probe is suggested for liquid velocity measurements. The results of the probe calibration demonstrate high sensitivity of the probe readings to the flow direction.

The design of the probe makes it possible to manufacture miniature probes for velocity vector measurements both in single-phase and gas–liquid flows.

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