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A Three-dimensional Current Meter for Estuarine Applications[1]

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ABSTRACT

A current meter that is capable of measuring the high-frequency fluctuations of the three-dimensional velocity vector has been developed. The meter works on a doppler-shift principle. At high velocities, the meter has been shown to have an accuracy of better than 3%.

Introduction. As part of a program to study the turbulent regime of oceanic motions, a current meter[4] that is capable of sensing the high-frequency velocities found in estuaries was developed at the Chesapeake Bay Institute. Besides a rapid response time, the design criteria for the meter were: (i) output data should be true vector averages of the three-dimensional velocity, and (ii) the velocity should be remotely sensed so that the disturbance to the field of flow, at the point of interest, should be minimal.

The idea developed was that of an acoustic doppler-shift current meter.

The Meter.[5] The operation of the meter is conceptually straightforward. Sound is emitted from a transmitter and scattered by particulate matter that is assumed to be moving with the ambient fluid's velocity. The sound, scattered in three independent directions, is recorded, and the doppler-shifts in frequency of the scattered sound relative to the transmitted sound are measured, care being taken to distinguish between an up-doppler-shift and a down-doppler-shift. These frequency shifts give sufficient information to determine the veloc-

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[4] A prototype has been described by Kronengold and Vlasak (1965).

[5] Schematics for the current meter can be obtained from the Chesapeake Bay Institute.

ity vector associated with the water at the intersection of the transmitter's and receivers' beam patterns. Information is fed from the meter to the signal processing equipment through underwater cables.

This type of doppler-shift flowmeter is not fundamentally new. Kronengold and Vlasak (1965) and Vlasak (1968) have described such devices, using acoustic sources and analog processing equipment, for measuring one velocity component. Yeh and Cummins (1964) and Foreman et al. (1965) used an optical source in a similar one-dimensional meter. Fridman et al. (1968) have done the same for a three-dimensional meter. Only the last device senses the full three-dimensional velocity vector, but optical systems of this type have stability problems when used in the field. The acoustic meters, besides sampling a single component of the velocity, have the disadvantage of analogue processing that yields only a mean speed and possibly a spectrum. The signal processing associated with our system yields a time series.

The transmitter of our system consists of a crystal-controlled oscillator which, after appropriate amplification and impedance matching, drives a disc (one-quarter-inch diameter, lead-zirconate-titanate, piezo-electric) at a frequency of approximately 9.965 MHz. The transmitter and all receivers are battery powered. The receivers, located symmetrically about the transmitter and making angles of 45° to it (Fig. 1), detect the scattered sound waves with piezo-electric discs that are similar to that used in the transmitter. The received signal is amplified by a low-Q tuned amplifier and mixed with a sinusoidal signal of approximately 9.985 MHz; then it is low-pass filtered, amplified, and finally fed to the processing equipment.

The intersection pattern of the transmitter and receiver beams is tripodal in shape. When measured it was found to be somewhat less than 2 cm along a leg of the tripod and less than 1 cm across a leg.

Immediately upon reception of the signal above water, an analog tape is written. One channel of the tape contains a timing pulse of 1-m sec duration once every 50 m sec. The outputs of the three receivers, now centered about a frequency of 20 kHz, are fed through band-pass filters into Schmitt triggers. The Schmitt triggers act as wave-shaping devices. The outputs of these trigger circuits are recorded on three other channels of the tape.

The analog tape is passed through a frequency to digital (F-to-D) converter. This system counts the number of cycles of signal on each of the three channels associated with the receivers during each 49-m sec sampling interval and records the counts on magnetic tape.

It was hoped that these counts would provide reliable measures of the doppler-shifts of interest. When the meter was first tested, however, a phenomenon that was designated "drop-out" was observed. Drop-out occurs when the received signal level falls below the no-signal noise level of the receiver. This results in an inability to track the doppler frequency and thus the velocity. There are many possible causes of this phenomenon. Some are eliminated in

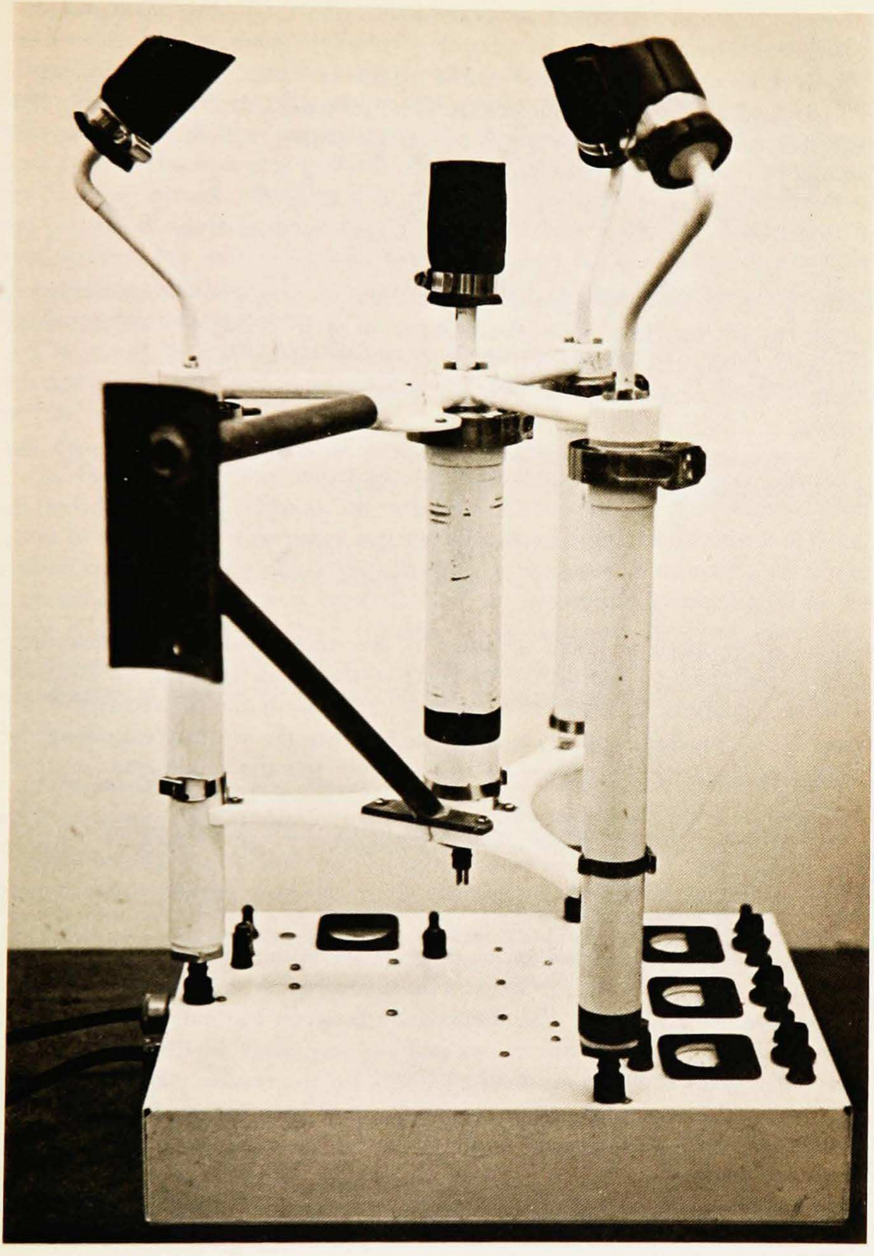

Figure 1. Photograph of the current meter sitting on its battery charger.

the system's design and others are dealt with indirectly during the signal processing.

A clock records, for each receiver and for each sampling interval, the length of time during which drop-out occurs. The estimated doppler frequency for each receiver, for each sampling interval, can then be found by using the formula

$$f_{ij} = \frac{C_{ij}}{(0.049 - d_{ij})},$$

where: f_{ij} is the computed estimate of the output frequency from receiver i during the jth interval; C_{ij} is the number of cycles of signal recorded from receiver i during the jth interval when drop-out did *not* occur; and d_{ij} is the length of time, in seconds, when drop-out occurred at receiver i during the jth interval.

The frequencies are converted to velocities on an IBM 7094 through use of the linear doppler equation (Middleton 1967):

$$u_{ij} = \frac{c(t,s,p) \times (f_{oi} - f_{ij})}{2 \cos 22.5^\circ \times 9.965 \times 10^6},$$

where: c, the speed of sound in water, is determined from the temperature, salinity, and pressure recorded at the depth of the meter by using the equation of Wilson (1960); f_{oi} is the frequency recorded from the ith receiver if the water is not moving; and u_{ij} is the speed,[6] during the jth interval, along the bisector of the angle formed by the ith receiver and the transmitter.

Calibration. The meter was calibrated in the CBI circulating test flume. The flume speed is controllable to within ± 0.05 cm/s or ± 0.5%, whichever is greater, except at very low velocities or at velocities greater than 50 cm/s (Cannon 1969).

With the flume at rest and with a single large stationary scatterer, the meter indicated a mean speed of 0.10 cm/s. The least-count error associated with any one receiver is 0.16 cm/s. The discrepancy between the indicated speed and the true speed is probably due to our inability to exactly determine the difference frequencies between the local oscillators in the receivers and that in the transmitter. These difference frequencies, f_{oi}, had been recorded at two-degree Celsius intervals and were used in the linear doppler equation when the velocities were computed.

All of the other tests were performed with the solid scatterer replaced by polyethylene spheres at a concentration of 5 ppm. In this configuration and

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[6] These speeds are space-time averages. The weighting function in the time domain is zero when drop-out occurs and is unity otherwise. In space, the weighting function is the product of the transmitter and receiver beam patterns.

with the flume at rest (a small residual velocity of approximately 0.5 cm/s always remained), the meter indicated a mean speed of 1.97 cm/s, even after bad points had been corrected by a linear interpolation scheme.[7] At speeds higher than 10 cm/s, however, the meter was always better than 3% accurate. We believe that the change in accuracy of the meter between high and low mean-flow rates is due to a change in the character of the drop-out. At low speeds, the drop-out occurs as long periods of loss of signal preceded by, and followed by, periods of short duration when a single cycle of doppler information is missing from the record. At high speeds, the drop-out occurs in many periods of moderate duration. Our processing scheme can cope effectively with only the latter form of drop-out.

The meter has been used with moderate success in the field when the mean velocity of the fluid was approximately 20 cm/s. The results of this field work will be described in another paper.

Conclusions. A current meter has been developed and tested that is capable of recording the high-frequency turbulent fluctuations of fluid velocity that occur in an estuary. The meter has the advantages over similar meters of being able to sample without disturbing the fluid at the point of sampling, of taking a vector average, and, most important, of simultaneously measuring all of the three components of the fluid velocity. Under adequate sampling conditions, the meter can be made to operate in a satisfactory manner, although it is hoped that future improvements will extend the range of "adequate" sampling conditions.

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[7] Processing of the data begins by computing the sample distribution of the corrected frequencies, f_{ij}. The minimum distance from the modal frequency to the first zero in the distribution is determined. Any sample point lying more than this distance on either side of the modal frequency is replaced by a linear interpolation between the two nearest "good" frequencies that bracket it. If a "bad" point occurs at either end of the time series, the modal frequency is used in the linear interpolation.

REFERENCES

CANNON, GLENN
1969. Observations of motion at intermediate and large scales in a coastal plain estuary. Chesapeake Bay Institute, Techn. Rep., 52; 144 pp.

FOREMAN, JR., J. W., E. W. GEORGE, and R. D. LEWIS
1965. Measurement of localized flow velocities in gases with a Laser Doppler Flowmeter. Appl. Phys. Lett., 7(4): 77–78.

FRIDMAN, J. D., R. M. HUFAKER, R. F. KINNARD
1968. Laser Doppler System measures three-dimensional vector velocity and turbulence. Laser Focus, Nov.: 34–38.

KRONENGOLD, MORTON, and WELDON VLASAK
1965. A Doppler Current Meter. Mar. Sci. Instrum. ISA, *3*: 237–250.

MIDDLETON, DAVID
1967. A statistical theory of reverberation and similar first-order scattered fields. Part I: Waveforms and the general process. IEEE Trans. Inf. Theory, IT-13(3): 372–392.

VLASAK, WELDON
1968. Further development in the Doppler method of water-velocity measurement. IEEE Trans. Geosci. Electron., GE-6(4): 197–204.

WILSON, W. D.
1960. Equation for the speed of sound in water. J. acoust. Soc. Amer., *32*(10): 135.

YEH, Y., and H. L. CUMMINS
1964. Localized fluid flow measurements with an He-Ne Laser Spectrometer. Appl. Phys. Lett., *4*(10): 176–178.