JOURNAL OF THE
HYDRAULICS DIVISION

Measuring Water Velocity by Ultrasonic Flowmeter

By Jack C. Schuster[1]

Introduction

The meter uses two ultrasonic transceivers strapped to the outside of a pipe wall or submerged in an open channel (Fig. 1). Pulses of ultrasonic energy from the transmitter propagate through the liquid and across to the receiver. The reception of a pulse triggers the next pulse from the transmitter. A continuous "sing-around" frequency is generated in this manner. After about 2 sec, the direction of propagation is reversed. When transmitted in the downstream direction, the speed of the fluid increases the speed of the ultrasonic pulse, reduces the transmit time, and increases the sing-around frequency. When transmitted upstream, the pulses are opposed by fluid motion and the sing-around frequency is reduced. The measured frequency difference is proportional to fluid velocity. This frequency differencing procedure removes the influence of the value of the sonic velocity in a metered liquid of uniform quality.

The accuracy of discharge measurement of the ultrasonic flowmeter in a 2-ft (0.61 m) diam pipeline was previously studied in the Hydraulics Branch (3). One of the stated advantages of the meter was that, knowing the geometry and coating materials of a steel pipeline, the transducers could be mounted on the outside surface of the pipe to measure the discharge. The thesis study was performed with the transducers mounted on the outside of the pipe in two configurations (Fig. 1).

A conclusion of the study was: "In future installations the ultrasonic flowmeter's transducers should be installed in direct contact with the fluid stream. The largest source of error in installations with the transducers mounted on the outside of the conduit can be in transmitting the sound pulse through the conduit's wall."

The study of the meter, to determine how well the meter could be used for integrating the discharge, was continued in an open channel and is examined

Note.—Discussion open until May 1, 1976. To extend the closing date one month, a written request must be filed with the Editor of Technical Publications, ASCE. This paper is part of the copyrighted Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 101, No. HY12, December, 1975. Manuscript was submitted for review for possible publication on March 31, 1975.

[1]Hydr. Engr., Hydr. Branch, Div. of General Research, Engrg. and Research Center, Bureau of Reclamation, Denver, Colo.

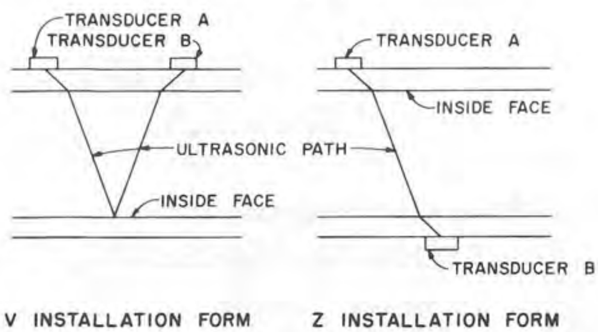

FIG. 1.—Meter Installation Forms

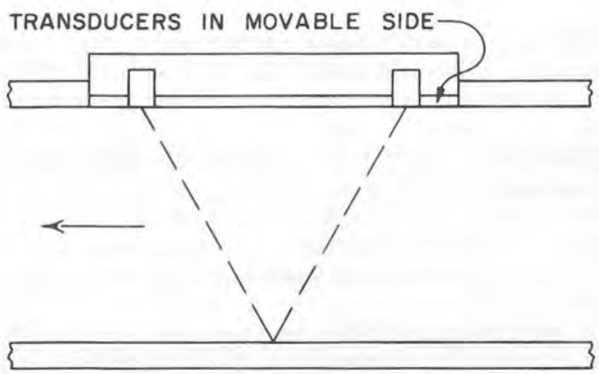

FIG. 2.—V Installation Form for Laboratory

herein. The face of the transducer as suggested in the thesis was placed in contact with the flowing water through a vertically movable side of the channel (Fig. 2).

Laboratory Installation

The ultrasonic flowmeter was installed to measure the velocity in horizontal planes in a 2.5-ft (0.76-m) wide channel (Fig. 3).

The channel, about 55 ft (17 m) long, contained a calming section 40 ft (12 m) upstream from the meter location. One side of the channel, containing the flush-mounted transducers, could be raised or lowered to position the transducers vertically for velocity measurement (Fig. 4).

An 11-thread-per-inch stem and handwheel were used to accurately position the slide with respect to two pointers and elevation scales. Channel flow depths were obtained from a hook gage in a stilling well connected to a pressure tap. The pressure tap was in the floor on the channel longitudinal center line midway between the two transducers. Discharges through the channel were measured by volumetrically calibrated venturi meters.

Although discharge measurement was of primary interest in the pipeline studies,

FIG. 3.—Laboratory Channel Installation of Ultrasonic Flowmeter: (*a*) Transducer Section of Channel

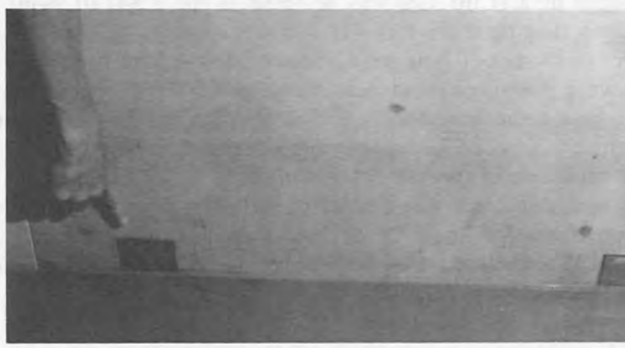

FIG. 4.—Transducer Face Raised above Still Water Surface in Channel

FIG. 5.—Ultrasonic Flowmeter Installation: (*a*) Transducer Section; (*b*) Flowmeter Electronics; (*c*) Integrating Digital Voltmeter; (*d*) Tape Printer

velocity distribution was of primary interest in the channel studies. The meter circuitry was modified in the time between the pipe and channel studies to measure path velocity in place of total discharge. A 4-ma to 20-ma current was previously related to a 0-cfs to 20-cfs (0-m^3/s to 0.57-m^3/s) discharge. The conversion of the meter related in linear form the 4-ma to 20-ma current to a 0-fps to 3-fps (0-m/s to 0.9-m/s) maximum velocity for the channel.

The 0-ma to 20-ma current would normally drive a velocity recorder that was not sufficiently responsive to obtain the desired accuracy in the laboratory measurements. In the laboratory measurements, the current was converted to a 0.4-v to 2.0-v signal by placing a 100-ohm ±0.05% resistor across the meter output terminals. The voltage was desirable because integrating digital voltmeters were available, whereas current meters were not. The data acquisition system was thus assembled to average a voltage related to the velocity of flow (Fig. 5).

Measurement Procedures

An arbitrary depth of 2 ft (61 cm) was selected in the 2.5-ft (0.76-m) deep flume for discharges ranging from 3 cfs–11.4 cfs (0.08 m^3/s–0.33 m^3/s). The mean velocities for this range of flow were about 0.6 fps–2.2 fps (0.18 m/s–0.67 m/s). Velocities were measured from near the floor of the flume to near the water surface by raising the transducers and integrating the flowmeter output voltage. The increments between vertical positions of the transducers were varied dependent on the curvature of the velocity distribution.

The flowmeter operates on a sing-around period with a train of ultrasonic pulses traveling upstream for about 2 sec, and then downstream in the flow for the same period. The difference in frequency caused by the water velocity is used to compute the velocity, V, of the flow (4). Thus

$$V = \left(\frac{l C^2}{2 B f_o^2} \tan\theta\right) \Delta f \quad \text{. . . . . (1)}$$

in which l = length of water path; B = width of channel; C = sound velocity in water; f_o = sing-around frequency in still water; θ = acute angle of sound path with channel center line; Δf = frequency difference upstream to downstream.

A velocity measurement is completed in about 5 sec, allowing 1 sec for switching pulse direction and calculating the velocity.

The upstream-downstream sing-around period is approximately 5 sec. Thus, a register in the flowmeter is updated every 5 sec and the current or voltage represents the average velocity during the period.

The integrating digital voltmeter sampled the output voltage of the flowmeter for time periods that were variable. Times could be varied from 1 sec to large multiples of seconds by using a crystal oscillator. A 100-sec period of integration was selected because of the 5-sec sing-around period. Thus, each 100 sec was an average of approx 20 sing-around periods or samples. Multiples of the 100-sec integration periods were used in measuring the average velocity for each elevation plane of the meter transducers.

Continual records were made manually of the venturi meter manometer differential and the depth of flow from the hook gage. Thus, 25–30 manometer and gage readings were acquired during the velocity traverse. Although the laboratory is not equipped with a constant-head tank, the pumping system is relatively steady. Flows produced by the system should be comparable to those requiring measurement in distribution systems.

Measurement Results

Symmetrical Velocity Distribution

Velocity Traversing.—Preliminary measurements showed a good average of the voltage (velocity) could be obtained normally from ten 100-sec samples. When large variations were noted, the number of samples was increased to 30 or more. Traverses were made for discharges of approx 3 cfs, 5 cfs, 8 cfs, 9 cfs, and 11 cfs (0.08 m^3/s, 0.14 m^3/s, 0.23 m^3/s, 0.26 m^3/s, and 0.31

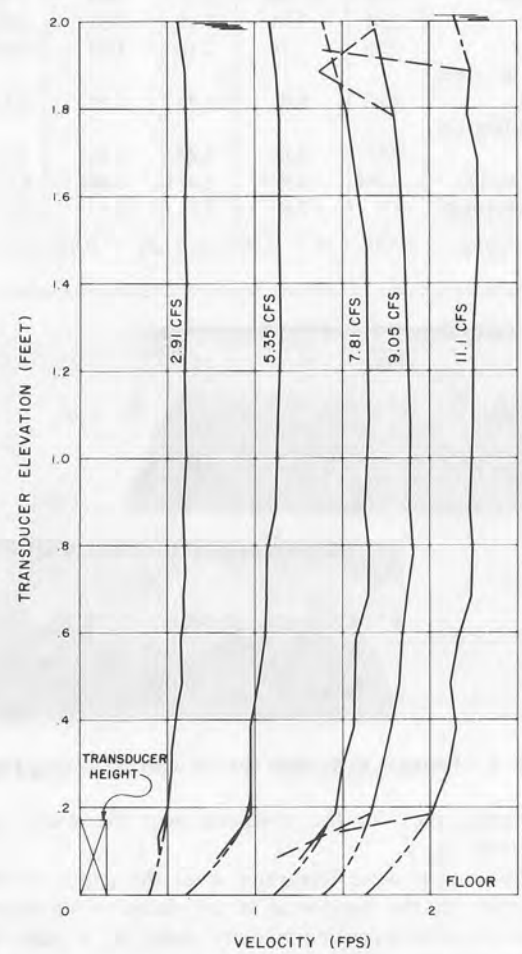

FIG. 6.—Ultrasonic Flowmeter Velocity Profiles (Symmetrical Distribution)

m^3/s). The depth for each discharge was adjusted as closely as possible to 2.0 ft (0.61 m).

Traverse Results.—In general, the velocity distributions evidenced a bluntness of profile (Fig. 6). Detailed studies were made near the floor and water surface in an attempt to define the distribution of velocity. The studies were not particularly successful because of multiple reflections of the ultrasonic pulses from the floor and uneven water surface. Success was better for the small

TABLE 1.—Comparison of Integration Average and Bulk Flow Velocities and Discharges

Data	Measurements					Average
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Water depth, in feet	2.00	2.00	2.03	2.00	2.00	
Ultrasonic, *Qu*	2.91	7.81	11.10	5.35	9.05	
Flowmeter, *Vu*	0.58	1.56	2.18	1.07	1.80	
Volumetric, *Q*, in cubic feet per second	3.02	8.01	11.39	5.55	9.50	
Calibration, *V*, in feet per second	0.60	1.60	2.24	1.11	1.89	
Discharge ratio, *Qu/Q*	0.966	0.975	0.975	0.964	0.952	
Difference, as a percentage	−3.4	−2.5	2.5	3.6	4.8	−3.4

Note: width of flume = 2.510; 1 ft = 0.305 m; 1 cfs = 0.028 m^3/s, 1 fps = 0.305 m/s.

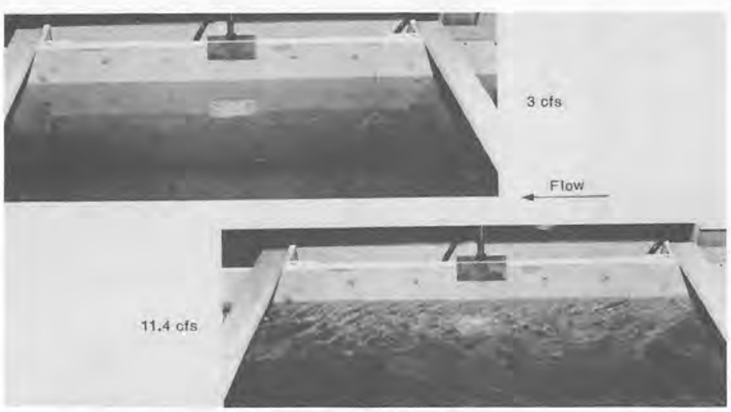

FIG. 7.—Increase in Surface Waves with Increasing Flow

flows than the large ones for the positions near the water surface because of fewer waves (Fig. 7).

The distribution curves were integrated over the depth of the flow to find the average velocity. In the horizontal at the elevation of the transducers the flowmeter measures an average line velocity along the V path. Thus, a vertical integration of the velocity curve should produce the average velocity for the cross section.

The velocity curves were extrapolated near the floor and water surface because difficulties were encountered in measuring close to the upper and lower surfaces. The exact origin of the pulse from the transducer face was not known. Therefore, the vertical center of the narrow [0.172-ft (0.052-m)] side of the transducer (intersection of diagonals) was used as a reference elevation for the velocity measurements. An integration of the curves was made weighting the slight deviations of width in the vertical of the channel cross section. Corrections were made for path length variations in the order of 1/250.

The results showed the flowmeter average velocity to be slightly below that of the bulk flow velocity computed from the venturi meter discharge (Table 1, Fig. 8). There was no apparent regularity to the differences in average velocity between the ultrasonic flowmeter and venturi, except the flowmeter did underregister the venturi discharge by an average of about −3.4%.

A volumetric recalibration of the venturi meters was made over the range of flows used in the ultrasonic flowmeter measurements (Table 2). The average difference between the laboratory standard tables and the volumetric tank was 0.28%. The difference ranged from a maximum of 0.64% at 3 cfs (0.08 m^3/s) to a minimum of 0.02% at 10 cfs (0.28 m^3/s).

Near the conclusion of the tests, the voltage output (corresponding to the 20-ma current) could not be adjusted to the full stated value. In place of 2 v, the range was about 1.984 v–1.990 v on various days of the measurement. Based on this range of voltage, the possible error at full scale, 3 fps (0.9 m/s), would range from 0.8%–0.5%. No difficulty was encountered in adjusting the 0 end of the 0-fps to 3-fps (0-m/s–0.9-m/s) scale. A 0.4-v (4-ma) adjustment at 0 was essentially stable throughout the measurements.

At a 0.6-fps (0.18-m/s) velocity [3 cfs (0.08 m^3/s)] the venturi meter calibration indicated the possibility of a positive difference of 0.6%. An ultrasonic velocity measuring error of 0.1% low ($0.6/3.0 \times 0.5$) might also be possible. The sum of these errors, 0.7%, is much less than −3.4% (Table 1). At a 2-fps (0.61-m/s) velocity [11 cfs (0.31 m^3/s)] the error in the venturi calibration was close to 0, but the ultrasonic velocity indication could have been low by about 0.4%. A −2.52% difference was measured in comparing the ultrasonic and venturi indicated velocities.

An additional source of error in the analysis was in the integration of the velocity distribution curves. The velocity curves were interpolated by straight lines between measured velocities. Extrapolations were made near the channel bottom and water surface by directions indicated from velocities adjacent to these boundaries. Slight modifications of the curves in these areas would produce slight changes in the average velocity computed from the integration. In most positions on the velocity curves, a smooth curve interpolation (least-squares fit or other) would have a balancing effect on the area to produce essentially the same average.

The cause of the slight decrease in velocity between about 0.3 ft and 0.7 ft (0.9 m and 0.21 m) could not be found (Fig. 6). Inspecting and measuring the channel width showed a slight outward dishing of the plastic windows in the channel sidewalls. The maximum deflection occurred at about 1.2 ft (0.37 m), midway from top to bottom. Velocities through this horizontal section of the channel would be slightly lower, but did not coincide with the elevation indicated by the meter. Repetition of the velocity measurements between 0.3

TABLE 2.—Venturi Meter Calibration Check, April 18, 1972

Tests (1)	Discharge (2)	Venturi meter discharge, *Qv* (3)	Calibration tank discharge, *Qc* (4)	Comparison: *Qv/Qc* (5)	Comparison: Deviation, as a percentage (6)	Remarks (7)
I	1	3.003	3.0215	0.9939		8-in. SE
	2	3.020	3.0395	0.9936		Venturi
	3	3.007	3.0234	0.9946		
	Average	3.010	3.0281	0.9940	0.60	
II	1	7.994	8.0081	0.9982		12-in. SE
	2	7.988	8.0065	0.9977		
	3	7.990	8.0074	0.9978		
	Average	7.991	8.0073	0.9980	0.20	
III	1	10.137	10.1410	0.9996		12-in. SE
	2	10.140	10.1007			Water overflow into waste pipe
	3	10.136	10.1380	0.9998		
	Average	10.136	10.1395	0.9997	0.03	Average 1 and 3 only
Average of I, II, and III				0.9972	0.28	

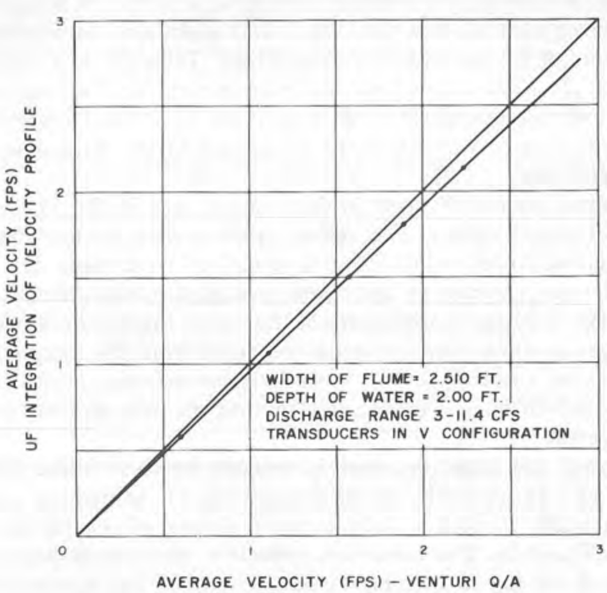

FIG. 8.—Average Velocity-Ultrasonic Flowmeter and Venturi Meter Discharge

ft and 0.7 ft (0.9 m and 0.21 m) confirmed the indentation.

A limited analysis was made of the velocity distribution curves by single and multipoint selection of transducer position. In open channel discharge measurements by current meter, an elevation, 0.6 of the depth below the water surface, is often selected as a point of average velocity. An average velocity is sometimes determined from measurements at 0.2 and 0.8 of the depth, $Q = A(V_{0.2} + V_{0.8})/2$. These methods were applied to the velocity distribution

TABLE 3.—Deviations in Average Velocities Computed by Single and Multipoint Methods

Methods (1)	Number of stations (2)	DEVIATION, AS A PERCENTAGE[a]: Discharge, in cubic feet per second: 3 (3)	8 (4)	11.4 (5)	Average[b] (6)	Remarks (7)
Simple average	1	+5.17	+5.52	+2.70	4.46	$V_{0.6}$
	2	+0.17	+1.35	+1.51	1.01	$(V_{0.2} + V_{0.8})$
	10	+0.02	+0.06	+0.14	0.07	Based on one-tenth depth measurements (0.2-ft)
Gauss	2	+0.85	+1.86	+1.37	1.36	
	3	+0.38	+0.19	+0.64	0.49	
	4	+0.26	−0.26	+0.09	0.20	
	5	+0.03	+0.19	−0.41	0.21	
Chebyshef	2	+0.85	+1.86	+1.37	1.36	
	3	+0.71	+0.71	+1.33	0.92	
	4	+0.47	+1.15	+0.92	0.85	
	5	+0.14	+0.19	+0.14	0.16	
	6	+0.16	+0.32	+0.27	0.25	
	7	+0.09	−0.06	−0.05	0.07	
	8	+0.05	+0.13	−0.32	0.17	
	9	−0.05	+0.26	−0.09	0.13	
	10	+0.21	+0.32	−0.14	0.22	

[a] Percentage of deviation in ratio to integrated average velocity from distribution curve measured by ultrasonic flowmeter.

[b] Average error equal to the average value of the absolute errors for the three discharges.

Note: 1 cfs = 0.028 m^3/s; 1 ft = 0.305 m.

curves of Fig. 6 (Table 3). For 3 cfs, 8 cfs, and 11.4 cfs (0.8 m^3/s, 0.23 m^3/s, and 0.33 m^3/s), the 0.6 depth velocity differed from the average of the integral of the complete traverse by +5.2%, +5.5%, and +2.7%. The values for the average of 0.2 and 0.8 velocities were only slightly higher than the integrated average by +0.2%, +1.35%, and +1.51%. A 10-point equally weighted method of integrating the velocity gave nearly the same averages as the full integration.

Two quadrature methods, Gauss unequal weighting and Chebyshef using equal weighting of the velocities, were applied to the velocity profiles (2). The results showed that a satisfactory average could have been obtained by placing the transducers at three or four elevations by the Gauss Method and five elevations by the Chebyshef Method. Placing transducers at specified elevations or traversing to stop at these elevations apparently would provide a sufficient number of velocities (averaged with time) to compute an average velocity for the cross section.

Unsymmetrical Velocity Distribution

Velocity Distortion.—Optimum locations for installing an ultrasonic flowmeter do not always occur in open channels. Therefore, this study was extended to include an unsymmetrical velocity distribution within the cross section of measurement. The distortion allowed a limited evaluation of the ultrasonic

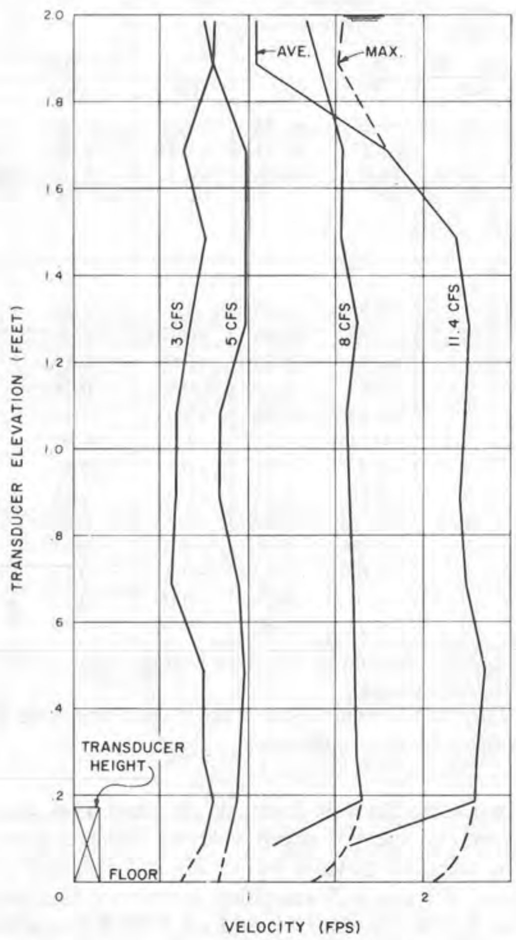

FIG. 9.—Ultrasonic Flowmeter Velocity Profiles (Unsymmetrical Distribution)

TABLE 4.—Discharge and Velocity Comparisons for Ultrasonic Flowmeter Measurements in Unsymmetrical Velocity Distribution

UF (Weighted Arithmetically)			*UF* (Planimeter)			Venturi		
Q, in cubic feet per second (1)	*V*, in feet per second (2)	Percentage (3)	*Q*, in cubic feet per second (4)	*V*, in feet per second (5)	Percentage (6)	*Q*, in cubic feet per second (7)	*V*, in feet per second (8)	Percentage (9)
(*a*) Measurement Number 1								
3.49	0.69	114	3.47	0.69	114	3.05	0.60	100
(*b*) Measurement Number 2								
4.64	0.92	91	4.36	0.87	86	5.05	1.01	100
(*c*) Measurement Number 3								
7.58	1.53	95	7.77	1.55	96	8.06	1.61	100
(*d*) Measurement Number 4								
10.81	2.15	95	10.54	2.10	92	11.4	2.27	100

Note: 1 cfs = 0.028 m^3/s; 1 fps = 0.305 m/s.

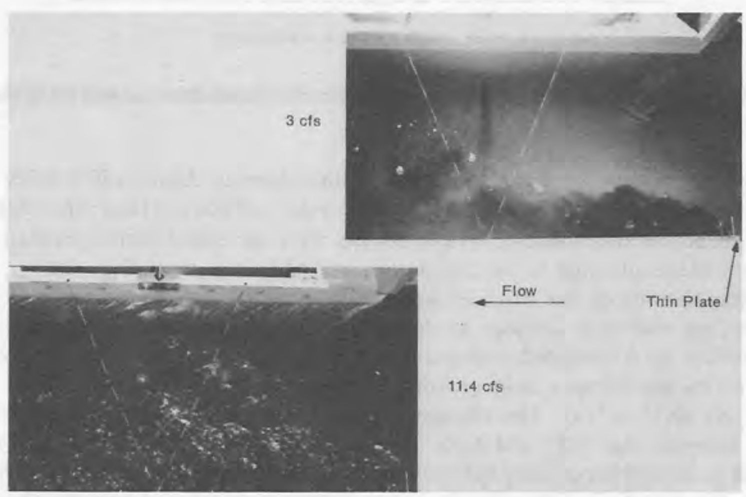

FIG. 10.—Ultrasonic Path and Wake behind Plate Normal to Flow

flowmeter capabilities of averaging nonuniform distribution.

The nonuniform velocity distribution was caused by a vertical thin plate obstruction. The plate was attached to the wall 2.92 ft (0.89 m) upstream from the center line of the transducer pair on the opposite side of the channel. The projection of the plate was 10% of the 2.5-ft (76-cm) wide channel.

Velocity Traversing.—A 100-sec time-averaged measurement of the voltage (velocity) was taken again as a base sample. Velocity variations caused by the unsteady flow downstream from the plate were larger than those occurring for the uniform distribution. A preliminary study indicated that acceptable averages could be obtained from about sixteen 100-sec integrations of the output voltage from the flowmeter. Traverses were made for discharges of about 3 cfs, 5 cfs, 8 cfs, and 11 cfs (0.08 m^3/s, 0.14 m^3/s, 0.23 m^3/s, and 31 m^3/s) at a depth adjusted as close as possible to 2.0 ft (0.61 m).

Traverse Results.—Extreme care was taken in measuring the velocity distribution, but the profile was considerably more irregular than for the symmetrical distribution (Fig. 9). The profiles remain relatively blunt but show gradually

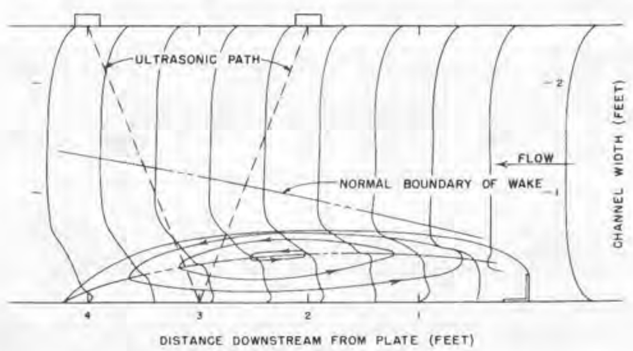

FIG. 11.—Ultrasonic Path and Approximate Velocity Distribution behind Plate Normal to Flow

increasing velocity from top to bottom of the channel. Again, difficulties were encountered in measuring velocities near the water surface and floor, thus defining the distribution was difficult. Wave heights were increased with increased flow as the surface adjusted to the circulation caused by the plate (Fig. 10).

Extrapolations of the profiles were made near the water surface and floor without an elaborate attempt at definition. Average velocities obtained from the profiles by a weighted arithmetic and planimeter integration and by venturi differed by percentages ranging from +14% at 3 cfs (0.08 m^3/s) to about −6% at 11 cfs (0.31 m^3/s). The change from overregistration to underregistration came between the 3-cfs and 4-cfs (0.08-m^3/s and 0.1-m^3/s) discharges (Table 4). The increased irregularity between the symmetrical and unsymmetrical profiles shows the effect of adding the thin-plate obstruction (Figs. 6 and 9). The shift in profile is also evidenced in the change in ratio of the average velocities.

Two-dimensional studies have been made of the wake downstream from a flat plate normal to the flow (1). Detailed experiments in a wind tunnel showed the wake to extend downstream from the plate a distance of nearly nine plate widths [w = 0.5 ft (0.15 m)]. The transverse disturbance of the flow with a free surface would extend over a greater area of the cross section than in two-dimensional flow. In the ultrasonic flowmeter channel, the wake length extended beyond the cross section containing the ultrasonic path (Figs. 10 and 11). The ultrasonic path was in the downstream portion of the wake for the full range of flow [3 cfs-11 cfs (0.08 m^3/s-0.31 m^3/s)]. The two parts of the ultrasonic path apparently averaged adverse velocity gradients and on the two different lines (Fig. 11). The change in distribution in the wake and velocity variance along the path could account for the variation from plus to minus of the ratio of ultrasonic to venturi meter average velocities.

Conclusions

1. The "sing-around" principle of ultrasonic velocity measurement appears suited for discharge measurement and the equipment, in general, performed satisfactorily (Fig. 1).

2. In unsteady flow, the rate of traversing a cross section should be determined by the time required to measure a significant number of 5-sec "sing-around" periods or samples. In the studies of this paper, a minimum of 200 samples (ten 100-second integrations) was normally necessary in the relatively steady flow of the symmetrical distribution for each elevation of the transducers. For the unsymmetrical velocity distribution, a minimum of 320 samples appeared to give an acceptable average velocity.

3. The ultrasonic flowmeter underregistered the velocity in symmetrical channel flow by an average of 3.4% for a discharge range of 3 cfs-11 cfs (0.08 m^3/s-0.31 m^3/s) measured by calibrated venturi meters (Table 1). Larger deviations of +14% at 3 cfs (0.08 m^3/s) ranging to −6% at 11 cfs (0.31 m^3/s) were computed for an unsymmetrical flow (Table 4).

4. An integration of a symmetrical or an unsymmetrical velocity distribution by traversing the flow would produce the optimum discharge measurement. The meter should be placed in a symmetrical velocity distribution or means provided for in-place calibration for unsymmetrical distributions.

5. Accurate average velocities would not be measured in short periods in unsteady flow.

6. The flowmeter appeared capable of measuring the velocity to a distance of about 0.1 ft (0.03 m) of the floor and water surface in a 2.5-ft (0.76-m) square flume. Multiple reflections caused large variances in velocity at lesser distances.

7. Automation of an ultrasonic flowmeter measuring system for traversing would require extrapolation in the computer section to adjust the velocity profile near the water surface and channel bottom for calculating the discharge.

8. The effect of the variance at the boundaries on computing the total flow in relatively deep channels with quiet water surfaces would be minimal.

9. The flowmeter computer should be capable of accepting an input related to depth, and thus, flow area changes for accurately computing discharge.

10. Transducers located at 0.6 of the depth from the surface in the laboratory channel did not measure a satisfactory average velocity.

11. Transducers located at 0.2 and 0.8 depth could possibly produce a

satisfactory average velocity depending on the symmetry of flow and the measurement requirements.

12. Multipoint locations of transducers or measurements by a single pair of transducers moved to elevations defined by Gauss and Chebyshef methods of integration would produce satisfactory average velocities (each velocity time-averaged at elevation).

13. Measurements of the velocity and computing the discharge in unsymmetrical flows or in those having adverse velocity gradients are subject to greater errors.

14. A Z configuration of the transducers in place of the V might reduce the error in measuring the average velocity of flow for the thin plate, because averaging would be in one instead of two ultrasonic paths. The Z configuration or reflective targets could be used in a trapezoidal channel to minimize loss of signal from the sloping sides.

15. No major difficulties were encountered with the electronic circuitry of the meter in the 2-month operating period. Long-term operating characteristics were not available from this study.

16. A 0.5%–0.8% reduction in the full-scale output of the meter was encountered near the end of the study.

17. A stainless steel plate cemented to the face of the epoxy embedding the transducer crystals appeared to retain integrity throughout the study.

18. A transducer smaller than the 2.1-in. by 2.9-in. (50-mm by 70-mm) probably would have improved the resolution of the velocity measurements.

19. An instrument shelter for environment and vandalism control would be necessary for the electronics enclosure [wall space 29 in. (740 mm) high, 22.5 in. (570 mm) wide, and 12 in. (300 mm) deep, with a 23-in. (580-mm) door radius] and for a circular chart recorder, if desired. Analog recording and digital totalizing of the flow could be done on-site or be transmitted by wire or radio to a remote site.

Application

Ultrasonic flowmeters can be applied to measuring small and large flows in open-channel and closed-conduit systems. The accuracy of the measurement depends on positioning the transducers to measure a true average velocity in either open or closed-conduit flow. A measurement of ±2% accuracy may be obtained by applying a correction factor to the velocity measurement from a single pair of transducers in a pipe having a fully developed turbulent velocity distribution. Possibly four pairs of transducers or a traversing pair are required for accurate measurements in a conduit or channel with unsymmetrical distribution. The metering method can be applied to flows varying over a wide range in open channels, to systems designed for a minimum head loss (such as power and pumping plants), to large-capacity turnouts that may require multiple venturi meters to measure the flow range, and to systems having main supplies controlled by automatic or supervisory means. Application of the ultrasonic flowmeter or other meters requiring electrical power should also consider the cost of supplying the power in evaluating the meters.

The ultrasonic method of velocity and flow measurement can be applied to pipes and cross-sectional shapes of natural and artificial channels. The complexity of traversing mechanisms or supports for locating fixed transducers in channels will vary with the shape of the cross section and the required accuracy of the flow measurement.

Ultrasonic flowmeter systems have a basic cost for the electronics and a pair of transducers. Costs of the installations will be governed by the complexity of the shape, the number of transducer pairs, and the scanning equipment needed to produce the required discharge indication or totalization.

An ultrasonic flowmeter could be the only satisfactory means of measurement at some structures (e.g., large channels or conduits, low-head loss requirement), and thus the cost must be justified on the need for the measurement or on the savings of water. Cost comparisons can be made when other devices are available. For example, in a steel pipeline having flow lengths comparable to that required for a venturi meter, a basic ultrasonic flowmeter system should meet the stated accuracy of the manufacturer. Under these conditions at the time of this paper, the cost of the meter was greater than the cost of a standard venturi meter for 24-in. (610-mm) and smaller sizes and less than the cost above this size. Installation costs for the ultrasonic flowmeter should be less than that for a venturi meter in interchangeable sizes, because the attachment of the transducers to the outside of a steel pipe wall or to a metal section of channel recommended by the manufacturer is a relatively simple process. Secure attachment and maintained contact of the transducers should preserve the accuracy of the system.

Appendix.—References

1. Arie, M., "Characteristics of Two-dimensional Flow Behind a Normal Plate in Contact with a Boundary Half Plane," *Memoirs of Faculty of Engineering*, Hokkaido University, Sapporo, Japan, Vol. 10, No. 2 (No. 44), 1956.
2. *Fluid Meters, Their Theory and Application*, 6th ed. The American Society of Mechanical Engineers, New York, N.Y., 1971.
3. Kitchen, M. L., "Ultrasonic Flowmeter for Fluid Measurement," thesis presented to the University of Colorado, at Boulder, Colorado, in 1971, in partial fulfillment of the requirements for the degree of Master of Science.
4. Suzuki, H., et al., "Ultrasonic Method of Flow Measurement in an Open Channel," *Water Power*, May/June, 1970, pp. 213-218.

11806 MEASURING VELOCITY BY ULTRASONIC FLOWMETER

KEY WORDS: Accuracy; Calibrations; **Closed conduit flow; Discharge measurement;** Electronic equipment; Errors; **Flow measurement;** Flowmeters; **Hydraulics; Laboratory tests;** Open channel flow; Pipelines; **Test results;** Transducers; Velocity; **Velocity distribution;** Venturi meters

ABSTRACT: A limited study of a sing-around ultrasonic flowmeter was made in a 2.5-ft (0.76-m) square laboratory channel. Traversing the flow vertically with the meter transducers produced a satisfactory velocity profile. Integration of the profile by manual methods showed an average deviation of -3.4% compared to the bulk flow velocity Q/A measured by a venturi meter in a symmetrical profile for flows ranging from 3 cfs-11.4 cfs (0.08 m^3/s 0.32 m^3/s). Deviations of +14% to -6% were found in an unsymmetrical flow caused by a thin vertical plate having a width 10% of the channel width. General operation of the meter was satisfactory, and the sing-around principle appears satisfactory for discharge measurement.

REFERENCE: Schuster, Jack C., "Measuring Water Velocity by Ultrasonic Flowmeter," *Journal of the Hydraulics Division,* ASCE, Vol. 101, No. HY12, **Proc. Paper 11806**, December, 1975, pp. 1503-1517