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LABORATORY AND FIELD EVALUATIONS OF ACOUSTIC VELOCITY METERS AT DAVIS AND PARKER DAMS

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13. ABSTRACT *(Maximum 200 words)*

This project was conducted at the Bureau of Reclamation's Water Resources Research Laboratory to evaluate 27 acoustic flowmeters used at Hoover, Davis, and Parker Dams on the lower Colorado River. Penstock flow measurement errors of 1 percent or less are needed to improve the water management program for the lower Colorado River system. A study combining field surveys and laboratory testing was conducted to evaluate and enhance the performance of the chordal-path acoustic flowmeters installed at Hoover, Davis, and Parker Dams. Hydraulic models were tested to identify velocity distributions for the least favorable flowmeter installations at Davis and Parker Dams.

This report describes the use of LDA (Laser Doppler Anemometry) to determine velocity distributions in hydraulic models of penstocks at Davis and Parker Dams. The report also describes the use of an automated LDA traversing system and commercial software for data collection and analysis, respectively. Field surveys of the 27 acoustic flowmeter installations included system hardware and configuration reviews, along with a field monitoring program which provided prototype velocity measurements along the chordal paths. Field survey data were valuable in identifying sources of error and supporting conclusions obtained from the hydraulic model studies.

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Denver, Colorado

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ACKNOWLEDGMENTS

The study was performed in cooperation with Reclamation's Lower Colorado Regional Office. The study was managed by Albert Marquez from the Regional Office, who also collected the necessary field data. Brent Mefford, Technical Specialist, provided technical support throughout this study. Jim Nystrom, Alden Research Laboratory, provided the peer review.

Photographs were taken by Wayne Lambert; Dwight Oswandel and Lee Elgin assisted with data collection and instrumentation design, respectively.

U.S. Department of the Interior
Mission Statement

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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PEER REVIEW

Dr. James Nystrom from ARL (Alden Research Laboratory) in Holden, Massachusetts, was contracted to perform a peer review of this hydraulic model study. Dr. Nystrom provides technical and administrative supervision of ARL's flow measurement calibration facilities. Dr. Nystrom has also been responsible for field performance measurements of over 60 hydro turbines and 20 large pumps, applying various standard methods of flow measurement. His prior duties at ARL included applied research using hydraulic models to investigate thermal discharges in lakes and evaluation of pump intake structures.

The peer review included two WRRL (Water Resources Research Laboratory) site visits to evaluate the hydraulic models and to discuss the study. The peer review emphasized a review of the technical approach and other procedures used to develop project results. The peer review did not include a complete check of calculations, tests, and methods, but did include verification that methods and procedures employed during the study were valid. The final product of the peer review was a technical review of this report.

PURPOSE

This study was conducted to provide the Lower Colorado Regional Office with an examination and evaluation of existing closed-conduit AVM (acoustic velocity meters) installations used to measure flow through Hoover, Davis, and Parker Dams. The purpose was to determine the level of error in existing AVM installations and recommend improvements which would reduce the flow measurement errors.

INTRODUCTION

The material for this report was part of a study requested by Reclamation's (Bureau of Reclamation) Lower Colorado Regional Office. The purpose of the study was to improve flow measurement at the major dams along the Lower Colorado River, namely Hoover, Davis, and Parker Dams. This study is only one of many being conducted in support of the LCRAS (Lower Colorado River Accounting System) program. LCRAS is a water management computer program which will allow Reclamation to better use water resources in the Lower Colorado River basin. LCRAS will be used to estimate water consumption by tracking consumptive use by: crops and phreatophytes, reservoir evaporation, municipal and industrial users, and ground-water recharge.

To improve the accuracy of flow measurement in the turbine penstocks at Hoover, Davis, and Parker Dams, a two-stage study was initiated. The first stage evaluated the existing flow measurement system, which consists of AVMs (acoustic velocity meters) with four or eight acoustic paths. A field survey was conducted to determine if all 27 AVM installations conformed to ANSI/ASME standards and ASME's Performance Test Code for hydraulic turbines. The second stage determined if the AVM installations were performing to manufacturer's specified accuracies of ±0.5% of true discharge. A published error analysis by the AVM manufacturer (Lowell and Hirschfeld, 1979) does not adequately address the error related to the integration of an asymmetrical velocity distribution. To verify the flowmeters' integration techniques when applied to an asymmetrical velocity distribution, physical models were used to determine penstock velocity distributions at AVM measurement sections. Model study results were used to establish overall uncertainty bounds on discharge measurements and to develop modifications to reduce the discharge errors.

MODEL STUDY CONCLUSIONS

Davis Penstock No. 5

An asymmetrical velocity distribution was identified for Davis penstock No. 5 for all discharges tested. A combined bend just upstream from the AVM measurement cross section creates a secondary current which results in a reduced velocity along the inside of the bend. Data analysis showed that for this asymmetrical velocity distribution, velocities measured along the four acoustic paths are considerably different depending on path orientation; discharge measurement errors as large as 2% were measured.

An analysis to determine the optimum path orientation showed the existing condition, horizontal acoustic paths, is optimum. For the prototype path orientation, errors in Gaussian quadrature integration of asymmetric velocity distributions for tests No. 2 through 4 were found to be -0.31, -0.44, and -0.75%, respectively. Therefore, considering the likelihood of other error components (errors associated with path length or cross sectional area measurements) the prototype AVM installation at Davis penstock No. 5 should perform within an accuracy range of ±0.5 to 1.0% Model study tests did not address the error associated with transverse velocity components (cross flows).

Integration error estimates for penstocks No. 1 through 4 are probably worse than those for No. 5 because of the proximity to the upstream combined bend.

Parker Penstock No. 1

A nearly symmetrical velocity distribution was identified for Parker penstock No. 1 for all discharges tested. A combined bend upstream from the AVM measurement cross section creates a slightly skewed velocity distribution. Data analysis showed that for this particular velocity distribution, velocities measured along the four acoustic paths are very similar and average path velocities are essentially independent of path orientation.

An analysis to determine the optimum path orientation showed the existing condition, horizontal acoustic paths, is accurate to 0.2 and 0.4% for tests No. 5 and 6, respectively. The optimum position for the smallest discharge measurement error results when acoustic paths are rotated 30° clockwise (looking downstream). The errors in this optimum position were about 0.1%.

Errors in Gaussian quadrature integration of the velocity distributions for tests No. 5 and 6 were found to be -0.18 and -0.46%, respectively. Therefore, the prototype AVM installation on Parker penstock No. 1 should perform to the manufacturer's specified accuracy of ±0.50%, provided other errors related to AVM installation and set-up are also within manufacturer's specifications. Model study tests did not address the error associated with transverse velocity components (cross flows).

Integration errors for penstocks No. 2 through 4 are probably smaller than those for penstock No. 1 because more straight pipe is located downstream from the combined bend.

FIELD STUDY CONCLUSIONS

AVM installations at Davis and Parker Dams are nonstandard because they do not meet the ANSI/ASME standard concerning the required length of straight pipe upstream and downstream from the AVM measurement section.

AVM installations at Davis and Parker Dams do not meet the requirement in ASME PTC 18, which states: "the intersection of crossed acoustic planes shall be in the same plane as the upstream bend to minimize the effects of the cross flow components on the accuracy of the measurement."

Cross flow errors were measured at Davis penstock No. 5 and Parker penstock No. 1 to be ±0.54 and ±1.9%, respectively. These errors are compensated for by using crossed acoustic planes. Therefore, all penstocks with single plane AVMs are likely to have cross flow errors.

Crossed plane AVMs are recommended on all penstocks at Davis and Parker Dams, except for Parker penstock No. 4. Path velocity data from Parker penstock No. 3 indicate minimal cross flow error. Parker penstock No. 4 has better flow conditions than penstock No. 3, so crossed plane AVMs are not necessary for accurate discharge measurements.

The as-built error analysis for single plane and cross plane AVM installations at Davis Penstock No. 5 and Parker Penstock No. 1 is summarized in table 1. Similar probable errors can be expected for the other AVMs at Davis and Parker Dams. The probable error is reported because it is unlikely that the worst case errors would occur simultaneously for all eight path lengths, eight path angles, and in the area measurements.

Table 1. - As-built error summary for single plane and cross plane acoustic velocity meters at Davis Penstock No. 5 and Parker Penstock No. 1. The total probable error was calculated as the square root of the sum of the individual errors squared.

Error Source	Typical Value	Typical Uncertainty	Worst Case Error (%) Davis No. 5	Worst Case Error (%) Parker No. 1
Path length*	23 ft	±1/16 inch	0.02	0.02
Path angle*	45°	± 20 sec	0.01	0.01
Area*	380 ft^2	±0.1%	0.11	0.09
Dimensional changes caused by temp./pressure**	-	Unknown	-	-
Transducer installation**	-	±0.15%	0.15	0.15
Electronics and timing**	-	Estimated	0.10	0.10
Cross flow*	-	Varies	0.54	1.90
Average velocity profile integration†	-	Varies	0.38	0.32
Total probable error for single plane AVM			0.69	1.94
Total probable error for cross plane AVM (i.e., no cross flow error)			0.44	0.38

* from field study
** based on manufacturer's experience
† from model study

BASIC AVM OPERATION AND THEORY

Operation and theory of acoustic velocity meters are thoroughly described in ANSI/ASME standard MFC-5M-1985. The following section will provide a brief overview of transit-time acoustic velocity meters.

Transit-Time Acoustic Velocity Meters

Transit-time acoustic velocity meters are based on the principle that the transit time of an acoustic signal along a known path is altered by the fluid velocity. An acoustic signal sent upstream travels slower than a signal traveling downstream. By accurately measuring the transit times of signals sent in both directions along a diagonal path, the average path velocity can be calculated. Then, using the known path length and path angle, with respect to the direction of flow, the average axial velocity can be computed (fig. 1).

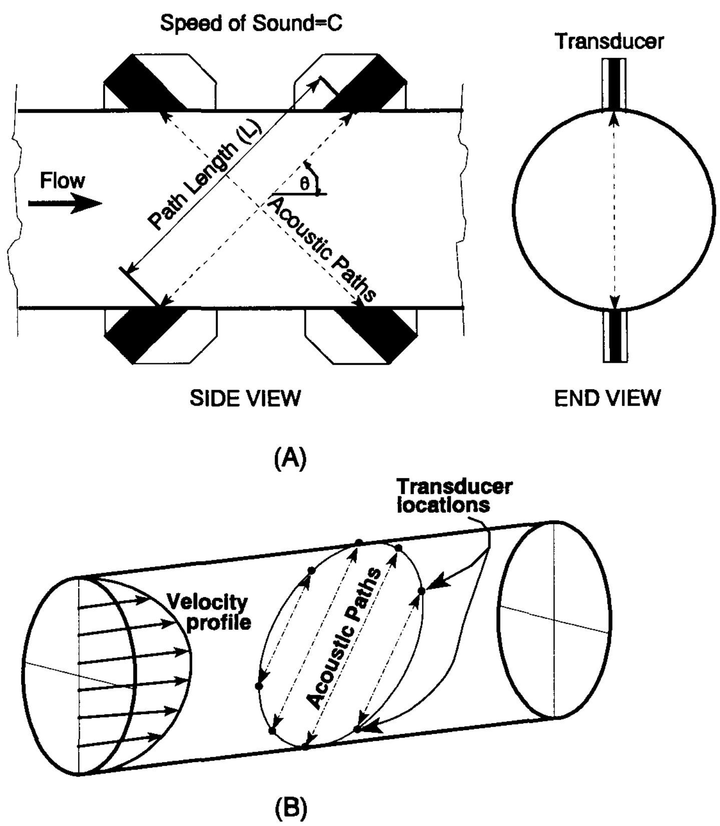


Figure 1. - Transit-time acoustic flowmeters. (a) crossed, diametral path configuration and (b) single plane chordal path configuration.

Theory

Discharge measurements are based on average axial velocity in a full-flowing pipe. Discharge can be calculated using this velocity and the cross sectional area of the measurement section. If no transverse flow components (cross flow) exist in the pipe, the difference in transit times of acoustic signals traveling in opposite directions through the water can be related to axial water velocity (fig. 1a). In the downstream direction, the axial velocity component along the acoustic path, $V_{ax}\cos\theta$, adds to the speed of sound, C, to give effective speed of the acoustic pulse, $C + V_{ax}\cos\theta$. In the upstream direction, velocity delays arrival of the pulse, resulting in an effective pulse speed of $C - V_{ax}\cos\theta$. Taking the difference in upstream and downstream travel times eliminates C from the calculations and results in a relationship with Δt. Using transit times, acoustic path length, L, and path angle, θ, the average axial velocity component along the acoustic path can be obtained from an equation which is derived as follows:

$$t_{up} = \frac{L}{C - V_{ax}\cos\theta}$$

$$t_{dn} = \frac{L}{C + V_{ax}\cos\theta}$$

Taking the difference between the reciprocals of the transit times results in

$$\frac{1}{t_{dn}} - \frac{1}{t_{up}} = \frac{2V_{ax}\cos\theta}{L}$$

solving for V_{ax}

$$V_{ax} = \frac{L}{2\cos\theta}\left(\frac{1}{t_{dn}} - \frac{1}{t_{up}}\right) \equiv \frac{L}{2\cos\theta}\,\frac{\Delta t}{t_{up}\,t_{dn}}$$

where:

V_{ax}	=	average axial velocity component
t_{up}	=	upstream travel time of the acoustic signal
t_{dn}	=	downstream travel time of the acoustic signal
Δt	=	difference in upstream and downstream travel times
θ	=	angle between the acoustic path and the pipe's longitudinal axis
L	=	acoustic path length between the transducer faces

AVM transducers are placed in pairs on opposite walls inside the pipe, one transducer downstream from the other. Chordal path meters usually have four transducer pairs, each pair defining an acoustic path, and they are oriented at a fixed angle, θ, usually between 45° and 65° to the pipe axis (fig. 1b). Path angles vary depending on the available space and accuracy requirements. The AVM processing electronics consist of a transceiver and a processor. The transceiver sends and receives signals, first in the upstream direction then in the downstream direction. The difference in travel time in the two directions is a measure of the axial flow velocity component projected along the acoustic path. To determine the average axial velocity for the full pipe cross section (to this point the AVM has only measured velocity along the chordal paths), the velocity distribution is assumed to fit a Gaussian distribution. To determine the discharge, the velocity distribution must be integrated over the entire cross sectional area. The processor uses the measured chordal path velocities to compute this integral using the Gaussian quadrature method as shown in equation 2.

The processor converts transit time differences into velocities and integrates them in a direction perpendicular to the acoustic plane using Gaussian quadrature (eq 2) to calculate discharge.

$$Q = \int_{-R}^{+R} V(y)\ L(y)\ \tan\theta\ dy \approx SD \sum_{i=1}^{n} W_i\ V_i\ L_i\ \tan\theta_i \qquad (2)$$

where:

Q = discharge, ft^3/s
n = number of acoustic paths
V_i = velocity calculated along path i, ft/s (V_i=V_{ax}cosθ)
L_i = path length for path i, ft
θ_i = angle between path and pipe axis for path i, degrees
W_i = Gaussian weighting factors, for 4-path meters
W_1 = W_4 = 0.1739
W_2 = W_3 = 0.3261
D = pipe inside diameter, ft (D = $L_i$sinθ)
S = integration correction factor for a circular cross section

The Gaussian quadrature method requires positioning of acoustic paths at exact locations. For paths one and four, relative distance from the conduit center to the path (y/R) is ±0.809. For paths two and three, relative distance from the conduit center to the path (y/R) is ±0.309.

THE MODELS

Velocity distributions in penstocks at Davis and Parker Dams were determined using 1:22.96 scale hydraulic models. The 22-ft-diameter penstocks were modeled using an 11.5-in-diameter clear plastic pipe. The penstock intake and the bends were also constructed of clear plastic (fig. 2).

A 150-hp variable speed pump supplied water to the model. Venturi meters in the water supply system measured flow rate to the model. Accurate flow measurements were made over a wide range of discharges using several venturi meters (6-, 8-, and 12-in). The model head box was 6 ft wide, 8 ft long, and 8 ft high. A gravel baffle installed in the head box distributed inflows with negligible approach velocity. The upstream model boundary was the trashrack structure. The penstock inlet transitions were mounted to the head box and the penstock terminated at the tail water box. The tail water box was 6 ft square and 7 ft high. The downstream model boundary was the entrance to the turbine scroll case. Orifice plates were used to establish flow rates through the penstock and were located 4 pipe diameters downstream from the AVM measurement section. Likewise, orifice plates were used to create a head loss similar to the loss across the turbine. The penstock length was extended by 4 ft so the orifice plate would not influence velocity distribution measurements.

Water surface elevations in the head and tail water boxes were measured to the nearest 0.001 ft using a point gauge mounted in a stilling well.

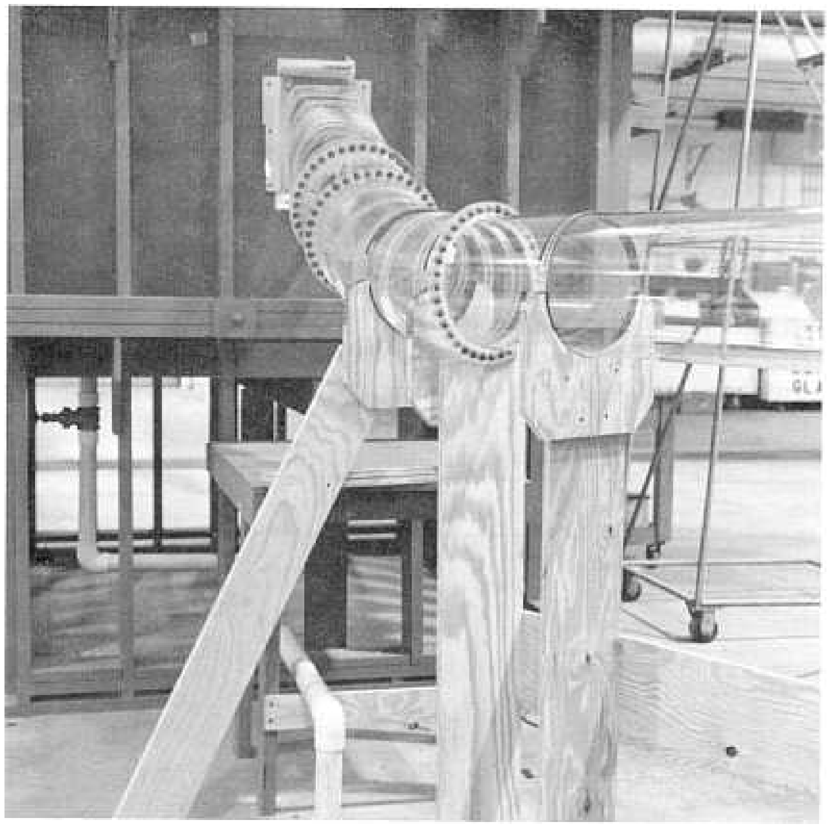


Figure 2. - Photograph of the Davis penstock No. 5 hydraulic model.

Model/Prototype Similitude

The Davis and Parker penstock models were designed to a 1:22.96 geometric scale using Froude law relationships to ensure dynamic similarity. The 1:22.96 scale penstock models have the following scaling relations:

Length ratio	L_r = 1:22.96
Area ratio	$A_r = L_r^2$ = $(1:22.96)^2$ = 1:527.0
Velocity ratio	$V_r = L_r^{1/2}$= $(1:22.96)^{1/2}$ = 1:4.79
Discharge ratio	$Q_r = L_r^{5/2}$= $(1:22.96)^{5/2}$ = 1:2525.0

This model study is based upon Froude number (**F**) criteria for establishing dynamic similitude, which means the primary forces controlling the hydraulics are the inertial and gravitational forces. This model study is not based upon Reynolds number (**R**) criteria. Reynolds number criteria are used when the primary forces controlling the hydraulics are the inertial and viscous forces. To quantify the impact of Reynolds number on the model velocity distribution, a test with an exaggerated Reynolds number was performed.

Ideally, the **R** in the model penstock will equal the **R** in the prototype penstock. For this model study, a 1:22.96 scale requires a velocity of 275 ft/sec to achieve the **R** requirement. Developing velocities of that magnitude in the laboratory was not possible. However, approximate similitudes for high $\mathbb{R}$'s can be reached because the viscous effect on the hydraulics becomes insignificant or is independent of the $\mathbb{R}$. To verify this assumption, a velocity distribution was measured at an artificially high Reynolds number ($\mathbb{R}$=1.1 x 10^7) and compared to the model velocity distributions for normal operating conditions. Results and discussion from this comparison are included in the **Results** section of this report.

Boundary roughness was addressed when designing the hydraulic model. However, with a 22-ft-diameter penstock, relative roughness (ε/D) is very small and is considered hydraulically smooth. Likewise, the acrylic plastic pipe used for the model penstock was also hydraulically smooth. Transition and bend sections were carefully constructed to obtain a model with good kinematic similarity, which ensured accurate development of velocity distributions. A summary of the prototype and model hydraulic parameters appears in table 2.

Table 2. - Summary of prototype and model hydraulic parameters.

Variable	Prototype	Model
Maximum Discharge (ft^3/s)	5000	1.99
Pipe Diameter (ft)	22	0.96
Area (ft^2)	380.1	0.72
Velocity (ft/s)	13.15	2.75
Kinematic Viscosity (ν) (ft^2/s)	1.22×10^{-5}	1.22×10^{-5}
$\mathbb{R}=(VD/\nu)$	2.4×10^7	2.2×10^5
Relative roughness, ε/D (ft/ft)	.0000068 (smooth)	.000005 (smooth)
$\mathbb{R}$ Ratio	$\mathbb{R}_p/\mathbb{R}_p$=1	$\mathbb{R}_p/\mathbb{R}_m$=109

THE INVESTIGATION

The Problem

To establish error bounds on the AVM discharge measurements at Davis and Parker Dams, the velocity distribution for penstocks with nonstandard AVM installations had to be determined. Physical models were constructed in Reclamation's Water Resources Research Laboratory and were used to measure velocity distributions in representative penstocks at Parker and Davis Dams.

Test Procedures

Laboratory tests were made over a range of flow rates and reservoir elevations to cover the normal turbine operating ranges. An automated valve controller maintained a constant inflow. Outflows and reservoir elevations were controlled by the orifice plates and by adjustments in tail water elevation. Once proper flow conditions were established, the velocity distribution was measured using a laser doppler anemometer. Velocity distributions were measured at a cross section located in the middle of the AVM measurement section.

Velocity Measurements

Point velocities were measured using a fiber-optic LDA (laser doppler anemometer) system mounted to an automated single-axis positioning table (fig. 3). An LDA measures fluid velocity by determining the oscillation frequency of light pulses reflected from particles in the fluid as they pass through the LDA's probe volume. A probe volume is created where the two laser beams cross. Velocity data were collected at 12 locations along a radial path, at 24 different angular positions. This procedure resulted in 288 point velocity measurements. Each LDA reading was taken as the mean value of 500 or more instantaneous velocity measurements. Strict signal validation criteria were used to assure data quality. The uncertainty in velocity measurements consisted of a systematic error of ±0.5% of the measured velocity and a random (bias) error of ±0.05% for a 95% confidence level.

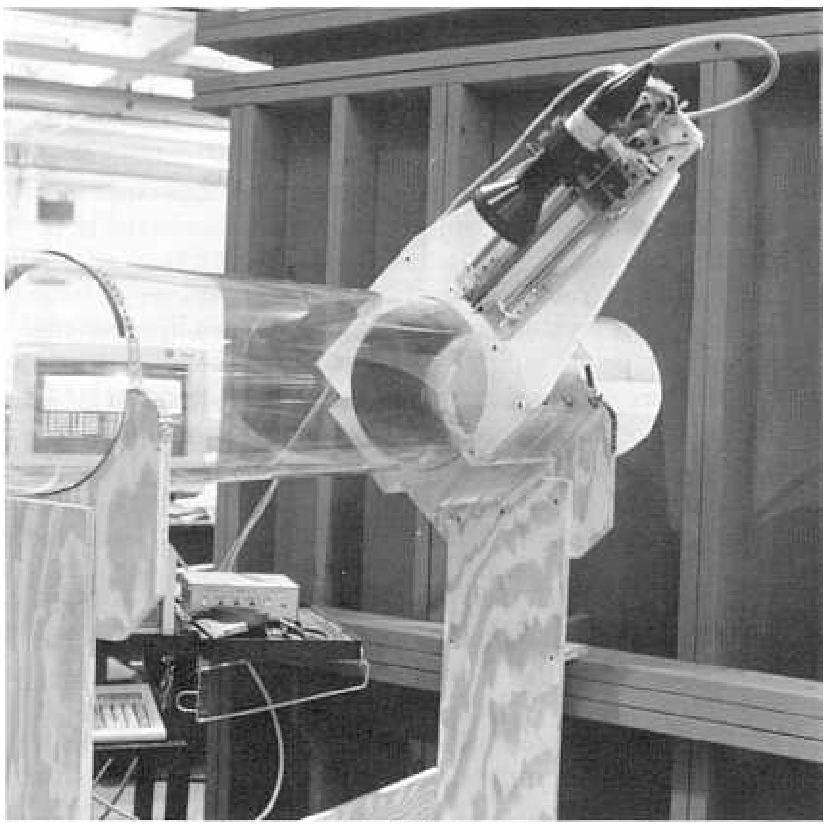


Figure 3. - Photograph of the fiber-optic LDA probe, saddle mount, and single-axis positioning table with stepper motor.

Velocity measurement locations were determined by dividing the pipe area into a center circle and 11 annuli, all of equal area. Velocities were measured at the midpoint of each annulus. These measurements were used in a velocity-area integration method, commonly referred to as the tangential method, to calculate discharge. For the first two tests, measuring velocity at the location nearest the pipe wall was difficult. For these cases, estimates for near-wall velocities were computed using Prandtl's one-seventh power law for a smooth boundary and turbulent flow. This technique usually resulted in a slight improvement in the integrated discharge computations. For subsequent tests, near-wall velocities were successfully measured by making adjustments to the LDA's signal processing algorithms.

Cross Sectional Area Measurements

Cross sectional area measurements are an important component of discharge computations. Therefore, cross sectional area of the AVM measurement sections must be accurately known. For this model study, the outside diameter was measured at twelve different locations using calipers. These calipers were calibrated to standard rods and were capable of measuring to the nearest 0.001 in. The average outside diameters of the Davis and Parker penstock models were 0.998 and 0.997 ft, respectively. To determine the penstock's inside diameter, the average wall thickness was required. Wall thickness was measured at 24 locations around the penstock using an ultrasonic thickness probe. The thickness probe was calibrated to the nearest 0.001 in using standard thickness gauge blocks. The average wall thickness of the Davis and Parker penstock models was 0.021 and 0.020 ft, respectively.

Refraction Through Wall of Penstock

Refraction at optical interfaces changes the laser beam paths, thereby changing the intersection point and angle between beams. Refractive properties of cylindrical surfaces vary depending on whether the velocity component is being measured in the axial, tangential, or radial direction. In this study, we intended to simultaneously measure axial and tangential velocity components (recognizing they would be at two different radial locations) using a two-dimensional LDA system. Unfortunately, two-dimensional LDA processing software requires coincident probe volumes for both laser beam pairs, which is difficult to achieve because refractive properties through a curved surface differ. As a result, only axial velocities were measured. For axial velocity measurement, the optical system was oriented so both laser beams were located in a plane passing through the cylinder axis, and the bisector between the beam angle was positioned at a right angle to the pipe axis. For this case, refraction occurred only in the axial direction, and the refracting surface was perpendicular to the beam angle bisector, as with a flat window. For this orientation, refraction affected only beam intersection location in the radial direction. A calibration was performed to determine the actual beam crossing location for several radii. The calibrated position varied only slightly from the theoretical position. Calibration data were used to develop a relationship between traverse system movement and beam intersection location inside the penstock. A complete discussion on refraction and determining the intersection location is beyond the scope of this report, but can be found in Durst et al. (1976).

Laser Mounting System

To collect velocity data on 24 different angular positions, the LDA probe had to be easily rotated while the laser beams were kept in a plane perpendicular to the pipe's axis. This requirement was achieved by machining a saddle-type mount with a slightly larger outside diameter than the model penstock. A plate and positioning table were attached to the face of the saddle mount. A single-axis positioning table was used to accurately position the LDA probe at the 12 radial positions. The laser probe location was checked each day to assure proper positioning system operation. The positioning table has a manufacturer's specified accuracy of ±0.01 in per ft of travel and ±0.005-in repeatability. The positioning table consisted of a stepper motor system to locate the LDA probe (resolution of 0.005 in per step). The stepper motor was controlled by a personal computer and manufacturer-supplied software. For this application, a heavy duty stepper motor with adequate holding torque (150 in-oz) was necessary to maintain position under the probe's weight.

Discharge Measurements

Flows entering the model were measured using the laboratory's permanent bank of venturi meters. The venturis were calibrated using a weigh tank; the calibrations for the 6-, 8-, and 12-in venturi meters used in this study have an uncertainty of ±0.35, ±0.27, and ±0.36% of weigh tank measured discharge, respectively.

Discharge Computations

Integration of the measured velocity distribution was used to verify the quality of the LDA velocity measurements. Two velocity-area methods were used to calculate the discharge, the tangential method and the log-linear method. A thorough discussion of both methods is presented by Winternitz and Fischl (1957). In general, velocity-area integration of the measured velocity distributions were within an uncertainty of ±1% of the discharges measured with venturi meters (fig. 4). This agreement confirmed the quality of LDA measurements. One exception was the venturi discharge measured for test No. 5. The comparison of both venturi discharge and discharge calculated using tangential and log-linear integrations indicated a 4.7% bias error. The error most likely was caused by a faulty pressure transducer used to measure the pressure differential across the venturi meter. This systematic error does affect the confidence in the velocity data for test No. 5. However, because the tangential and log-linear integrations showed good agreement, the data were deemed acceptable for evaluating the AVM integration method. An uncertainty analysis was performed on the computation of discharge using the tangential integration method. The two components analyzed were the LDA (velocity) measurements and the penstock cross sectional area. This analysis revealed that the uncertainty of discharge measurements for all tests was in the range of ± 0.5%. The primary component of the uncertainty was the systematic error associated with the LDA velocity measurements.

Davis Penstock No. 5

Four model tests were conducted to determine velocity distributions for a wide range of flows (table 3). Test No. 1 was similar to test No. 2 in discharge, but the reservoir elevation was maximum normal pool elevation, 649 ft. Test No. 1 was not used in the AVM analysis because data collection procedures differed from subsequent tests. However, comparisons of velocity profiles from tests No. 1 and 2 showed that reservoir elevation had no measurable effect on velocity distribution. For test No. 1, profiles were measured at upstream and downstream acoustic transducer cross sections to determine if velocity distribution varied spatially. These profiles were similar, which confirmed that no swirling or spatial variation in velocity distribution occurred. As a result, all subsequent velocity profiles were collected at the same cross section in the center of the AVM measurement section.

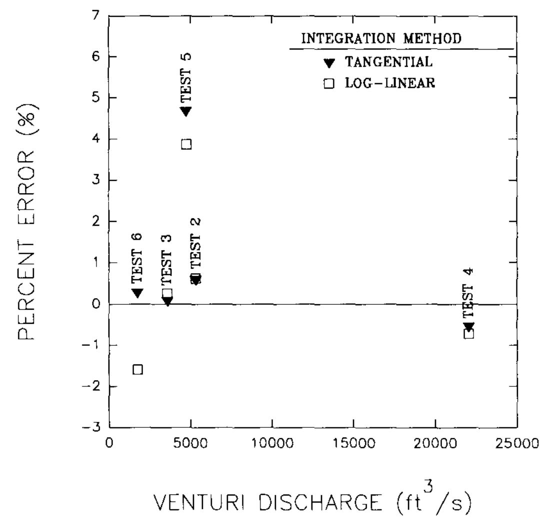


Figure 4. - Comparison of venturi discharges and integrated discharges.

Table 3. - Model test results for Davis Dam penstock No. 5. Flows are reported with an uncertainty estimate for a 95% confidence level.

Test No.	Reservoir El. (ft)	Flow (Venturi) (ft^3/s)	Flow (Tangential) (ft^3/s)	Percent Error*
1	649	5,370 ± 19	N/A	N/A
2	570	5,340 ± 19	5,373 ± 27	0.61
3	570	3,585 ± 13	3,594 ± 18	0.25
4	649	22,080 ± 79	21,962 ± 112	-0.53

* Percent error= $(Q_{tangential}-Q_{venturi})/Q_{venturi}*100$

Parker Penstock No. 1

Two model tests were conducted to determine the velocity distributions for two different discharges (table 4). Tests No. 5 and 6 were conducted at the same reservoir elevation, which was the maximum normal pool elevation, 449 ft. An exaggerated Reynolds number test was not conducted because the Davis penstock tests showed very little influence of Reynolds number on the velocity distribution. All velocity profiles were collected at the same cross section, located in the center of the AVM measurement section.

It should be noted that the venturi discharge measured for test No. 5 was determined to have a bias error of about 4.7% compared to the discharge calculated using tangential integrations. Additional velocity data were collected which matched the original profile shape, but were different in magnitude. This comparison indicated an error in the venturi discharge measurement. The venturi meter was re-calibrated and no calibration changes were identified. Consequently, the error was attributed to a faulty pressure transducer used to measure the pressure differential across the venturi meter, thus resulting in a systematic error in the discharge reading. This error does not affect the overall confidence in the LDA

Table 4. - Model test results for Parker Dam penstock No. 1. Flows are reported with an uncertainty estimate for a 95% confidence level.

Test No.	Reservoir El. (ft)	Flow (Venturi) (ft^3/s)	Flow (Tangential) (ft^3/s)	Percent Error*
5	449	4,736 ± 17	4,958 ± 25	4.69
6	449	1,748 ± 6	1,753 ± 9	0.29

* Percent error= $(Q_{tangential}-Q_{venturi})/Q_{venturi}*100$

velocity data for test No. 5, which were confirmed by redundant velocity measurements. Likewise, a comparison of tangential and log-linear integrations were in close agreement. The percent error between the tangential and log-linear integrations was 0.79%. Consequently, velocity data for test No. 5 were deemed acceptable for evaluating the AVM integration method.

Velocity Distribution Analysis

A computer software package (Amtec Engineering, 1988) was used to develop a numerical model of the velocity distribution which could be easily analyzed for several AVM path configurations. All velocity measurements were normalized using the average velocity calculated using all the LDA data. The pipe's average inside radius was used to normalize lengths. A right-handed coordinate system was used in collecting the data. The positive Z direction is upstream; the positive Y direction is upward; the positive X direction is to the right looking downstream.

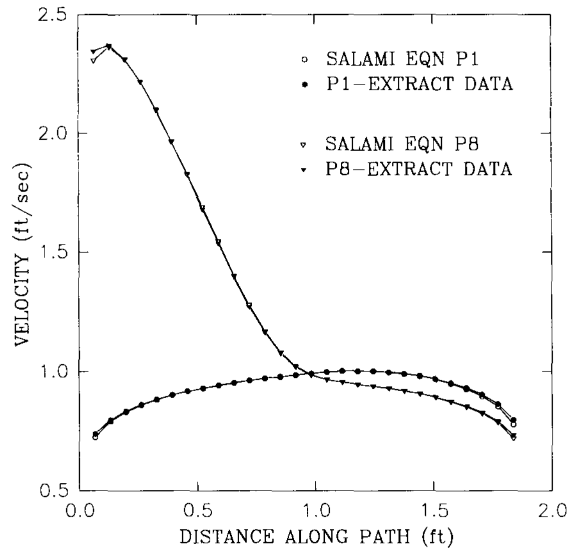


Figure 5. - Comparison of interpolated and computed velocity profiles for velocity functions P1 and P8 as described by Salami (1972).

Velocity distribution numerical models were used to analyze the Chebyshev quadrature method used by the AVM (Accusonic, Model 7410) to compute discharge. The velocity distribution model was used to extract data required to compute discharges using the log-linear method described in ASME PTC 18-1992.

Data were extracted from the velocity distribution model and checked versus model data. Velocity interpolation uncertainties of 0.2 to 0.3% were typical. The small errors can be attributed to errors in interpolation methods used to predict velocities at intermediate locations between measured data points. These errors usually occurred in areas that had a large velocity gradient, like near the pipe wall. In addition, the software was also tested on mathematically derived velocity distributions as described by Salami (1972). This analysis resulted in errors of 0.26% and -0.09% for Salami velocity distribution profiles, equations P1 (eq 3) and P8 (eq 4), respectively. As illustrated on figure 5, the sound agreement between model velocity data and interpolated values indicated that computer models could be used to interpolate velocity profiles with confidence.

$$V_{P1} = (1-r)^{\frac{1}{9}} + mr(1-r)^{\frac{1}{k}} e^{-a\theta} \sin\theta$$ **Salami profile P1 (3)**

$$V_{P8} = (1-r)^{\frac{1}{9}} + mr(1-r)^{\frac{1}{k}} (\theta^2 - 1)(1-\cos\theta)^2$$ **Salami profile P8 (4)**

where:

a, m, and k are constants chosen to create the desired profile shape
r is the radial distance (from 0 to 1)
θ is the rotation of the radius (r) in radians

DAVIS PENSTOCK MODEL

Penstock No. 5 was selected for model testing because it is equipped with a crossed plane, eight-path AVM which provides information on severity of cross flow errors. Of the five penstocks at Davis Dam, only No. 5 has a crossed plane AVM. Penstock No. 5 was selected for crossed plane installation because it is the shortest penstock. Davis penstock No. 5 has 1.7 diameters of straight pipe upstream from the AVM measurement section. Combined bend in penstock No. 5 consisted of 24° vertical and 28° horizontal angles. However, penstock No. 5 also has the longest section of straight pipe upstream from the measurement section (fig. 6). Consequently, penstocks No. 1 through 4 may have velocity distributions which are worse than No. 5.

The Davis Dam penstock model included the following features: 1) trashrack, 2) intake transition, 3) combined bend, 4) penstock up to the turbine scroll case.

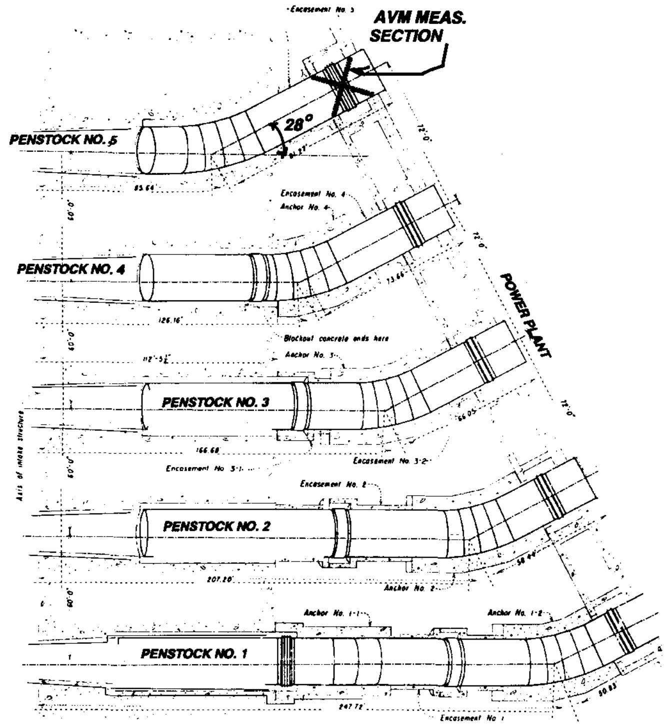
Results

Contour plots of non-dimensional isovels for tests No. 2 through 4 appear on figures 7 through 9, respectively. The figures show four acoustic paths which represent a view looking downstream. Comparison of the plots shows a consistent region of low velocity in the upper left quadrant. These low velocities are caused by the combined (horizontal and vertical curves) bend just upstream from the measurement cross section (fig. 6). This bend causes a secondary current to form, which reduces velocity along the inside of the bend. Conversely, centrifugal forces cause higher velocities along the outside of the bend. These localized variations in velocity distribution make this AVM installation nonstandard. For nonstandard AVM installations, velocities measured along the four acoustic paths will differ depending on path orientation. Likewise, discharge measurements also depend on path orientation.

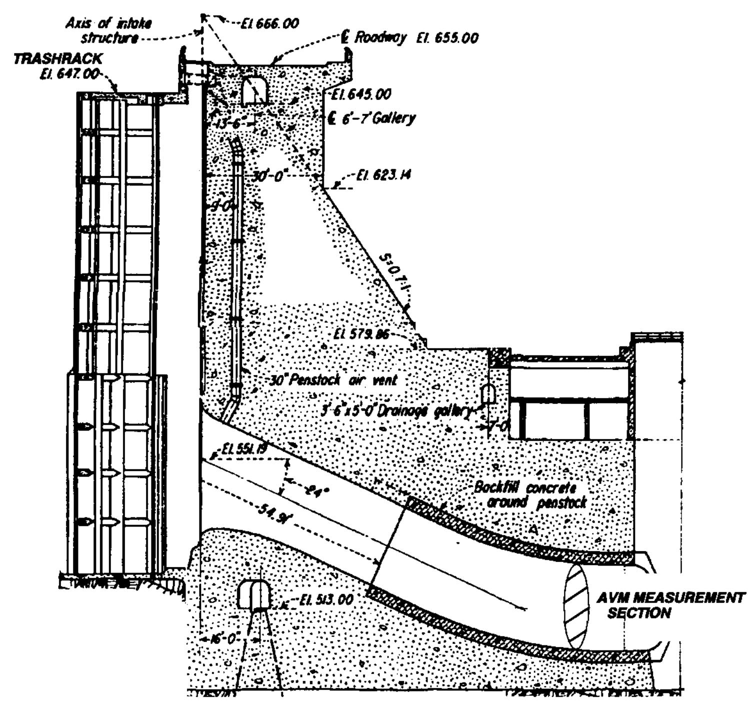
Test No. 4 was conducted at an exaggerated discharge to determine the effects of Reynolds number on the formation of the velocity distribution. The test No. 4 velocity distribution is very similar to tests No. 2 and 3, which indicates an independence of velocity distribution with respect to Reynolds number in the model.

AVM Flow Measurement Simulation

To determine how an asymmetric velocity distribution affects the AVM flow measurement uncertainty, the flow measurement computations performed by the AVM had to be simulated. The Accusonic Model 7410 AVM uses the Chebyshev quadrature method of numerical integration. Simulated discharge computations were accomplished by using a software utility to extract (interpolate) data along each acoustic path from the velocity distribution model. The extracted velocity data were numerically integrated over the acoustic path length to determine the average path velocity. This average path velocity is the same parameter the AVM calculates using transit times and the path angle. Average path velocities were then used in the AVM discharge equation (eq 2) to compute discharge. The AVM discharge computation was then compared to the flow rate computed by integrating the LDA velocity data using the tangential method. The discharge computed using tangential integration was considered to be the standard for all comparisons. The error between the two discharges is an indication of the error associated with the Chebyshev quadrature method of integration for an asymmetric velocity distribution. This analysis was also carried out for the acoustic paths rotated by 15° increments through 90° clockwise and counterclockwise.



PLAN - POWER PENSTOCKS



SECTION - PENSTOCK NO. 5 WITH TRASHRACK

Figure 6. - Plan and section of penstock No. 5 at Davis Dam. The AVM measurement section is shown at the end of the penstock. The combined bend has a 24° vertical and a 28° horizontal angle.

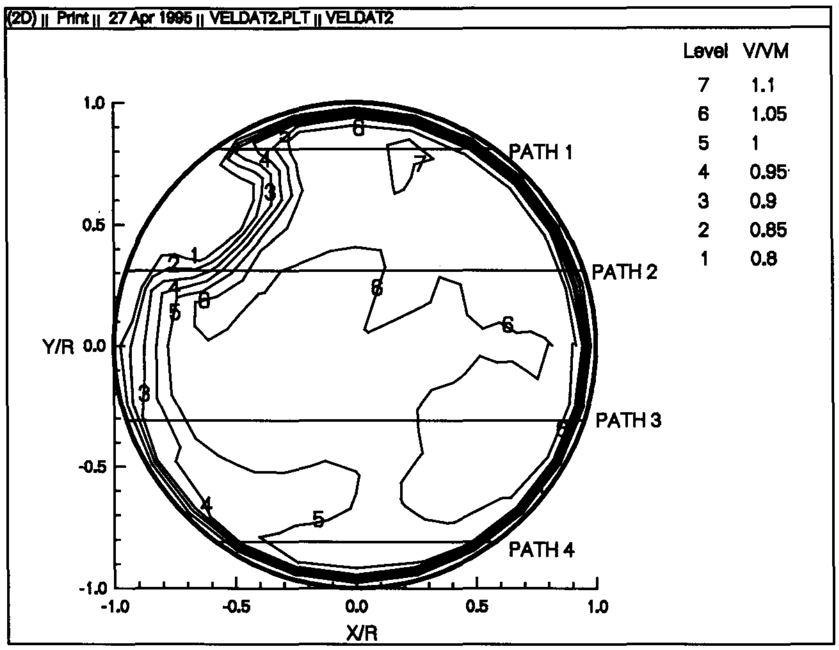


Figure 7. - Test No. 2 non-dimensional velocity distribution (looking downstream) for prototype discharge equal to 5,373 ft^3/s and minimum normal reservoir elevation of 570 ft. The AVM computed discharge was biased -0.31% from the actual flow.

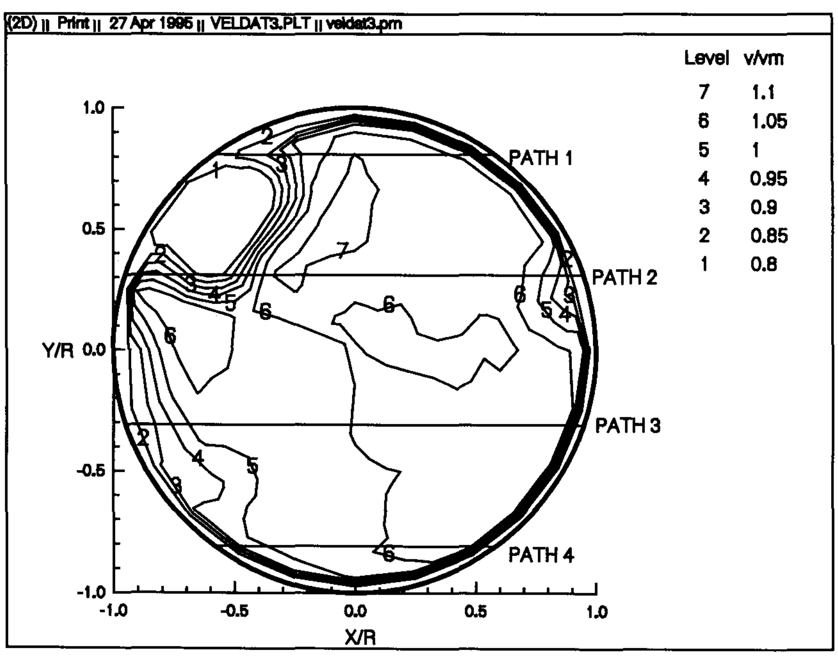


Figure 8. - Test No. 3 non-dimensional velocity distribution (looking downstream) for prototype discharge equal to 3,594 ft^3/s and minimum normal reservoir elevation of 570 ft. The AVM computed discharge was biased -0.44% from the actual flow.

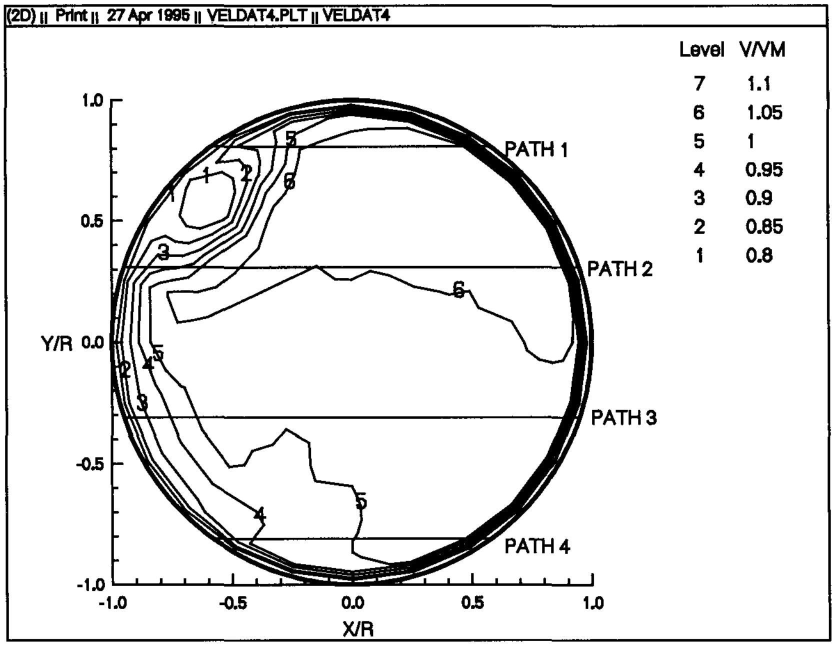


Figure 9. - Test No. 4 non-dimensional velocity distribution (looking downstream) for an exaggerated discharge equal to 21,962 ft³/s and maximum normal reservoir elevation of 649 ft. The AVM computed discharge was biased -0.75% from the actual flow.

Results from this analysis, presented on figure 10, indicate the effect of path orientation on AVM performance. Figure 10 shows that the minimum error occurs near 0° for tests No. 2 through 4, where 0° rotation is the AVM's existing horizontal path position. This analysis indicates that relocating the acoustic paths would not improve system accuracy, with the exception of very similar performance for a 45° clockwise rotation for tests No. 2 through 4.

For the prototype path orientation, discharge measurement errors for tests No. 2 through 4 were -0.31, -0.44, and -0.75%, respectively. These results (table 5) verify the performance of the Gaussian quadrature method for integrating these asymmetric velocity distributions. Therefore, considering the likelihood of other error components (errors associated with path length or cross sectional area measurements) the prototype AVM installation at Davis penstock No. 5 should perform within an accuracy range of ±0.5 to 1.0%.

Table 5. - AVM discharge computations for Davis Dam penstock No. 5. Flows are reported with an uncertainty estimate for a 95% confidence level.

Test No.	Flow-AVM (ft^3/s)	Flow-Tangential (ft^3/s)	Percent Error* (%)
2	5,356 ± 20	5,373 ± 30	-0.31
3	3,578 ± 10	3,594 ± 20	-0.44
4	21,797 ± 80	21,962 ± 110	-0.75

* Percent error = $(Q_{AVM}-Q_{tangential})/Q_{tangential}*100$

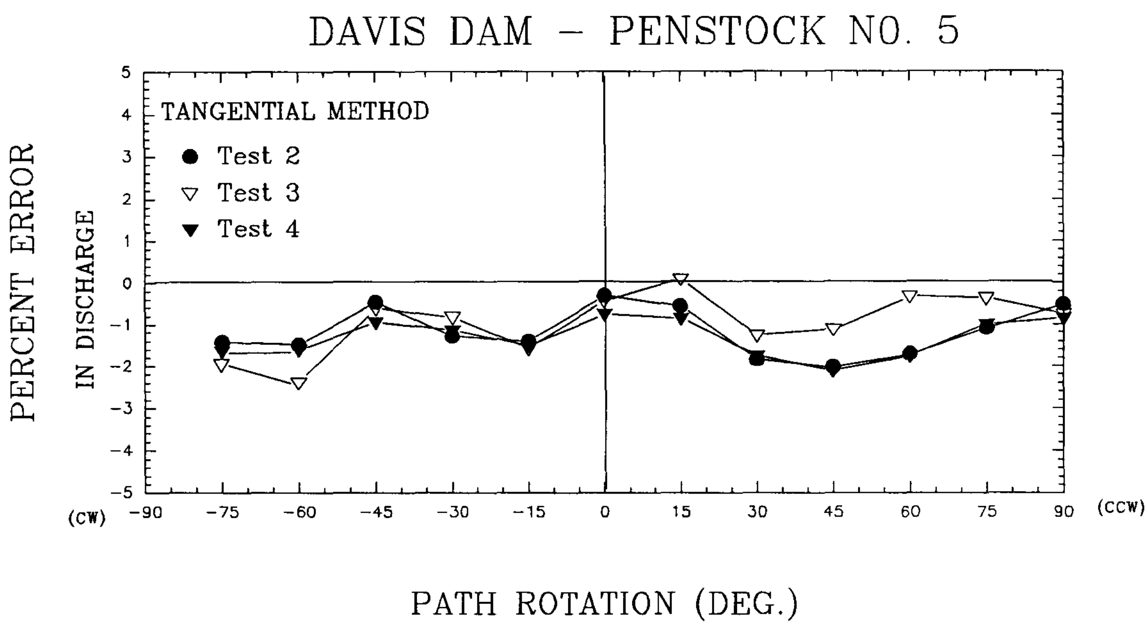


Figure 10. - Percent error in quadrature method discharge computation compared to discharge computations using the tangential integration method. This plot indicates the best transducer configuration is the existing, horizontal acoustic paths.

PARKER PENSTOCK MODEL

Parker penstock No. 1 was selected for model testing because it is the shortest of the four penstocks and has no diameters of straight pipe upstream from the AVM measurement section. In addition, Parker penstocks No. 1 and 3 are equipped with crossed plane, eight-path AVMs which provide information on the severity of cross flow errors. Penstock No. 1 was chosen to be modeled because it has the worst flow conditions. A combined bend in penstock No. 1 is located immediately upstream from the AVM measurement section and consists of a 12.9° vertical and a 4.6° horizontal angle (fig. 11).

The Parker Dam penstock model included the following features: 1) intake transition, 2) gate guides and seat, 3) combined bend, and 4) penstock up to the turbine scroll case.

Results

Contour plots of non-dimensional isovels for tests No. 5 and 6 appear on figures 12 and 13, respectively. Comparison of the two plots shows a consistent and symmetric velocity distribution. The combined bend appears to have a minor influence on velocity distribution near the pipe invert. Velocities measured along the four acoustic paths were very uniform regardless of path orientation. This result indicates that these velocity distributions are undisturbed by the small horizontal and vertical angles which form the combined bend.

To determine how velocity distribution affects flow measurement uncertainty, AVM flow measurement computations had to be simulated. Discharge was computed as described for the Davis penstock model. AVM discharges were compared to flow rate computed using the tangential integration method. The error between the two discharges indicated the error associated with the Chebyshev quadrature method. This analysis was also carried out for the acoustic paths rotated by 15° increments through 90° clockwise and counterclockwise.

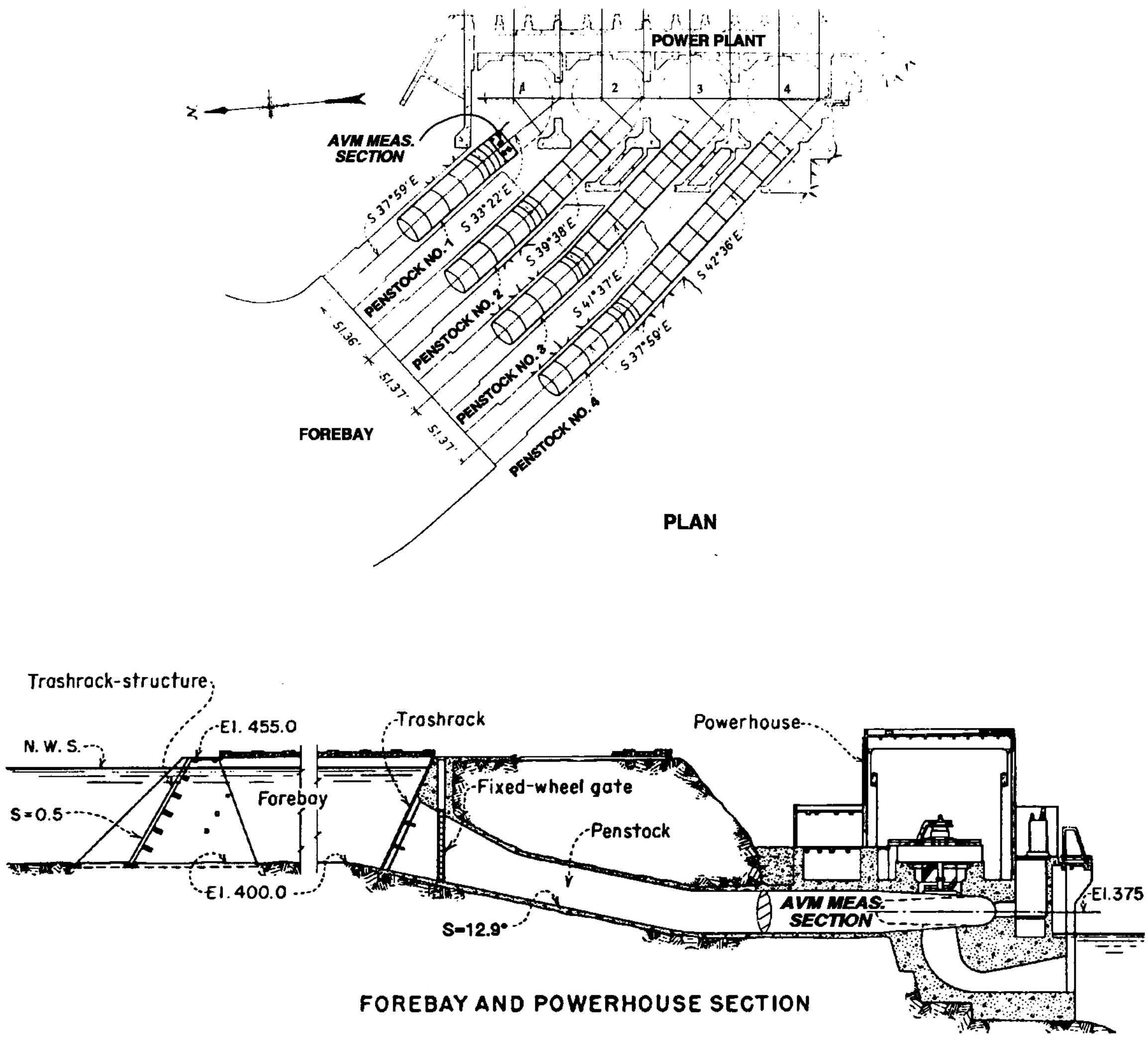


Figure 11. - Plan and section of penstock and powerhouse at Parker Dam. The combined bend is located immediately upstream from the AVM transducer and consists of a 12.9° vertical and a 4.6° horizontal angle.

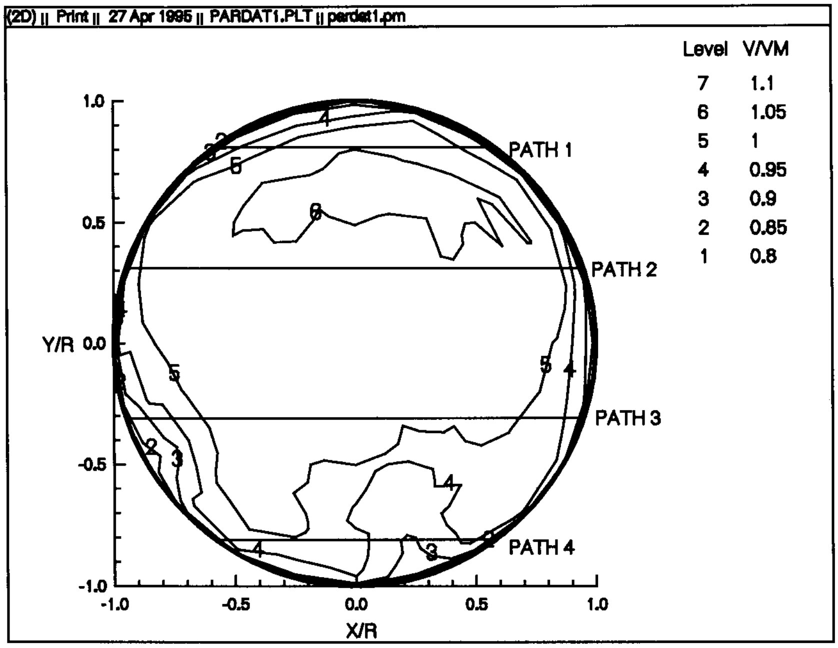


Figure 12. - Non-dimensional velocity distribution for test No. 1, prototype discharge equal to 4,736 ft^3/s and minimum normal reservoir elevation of 449 ft. The AVM computed discharge was biased -0.18% from the actual flow.

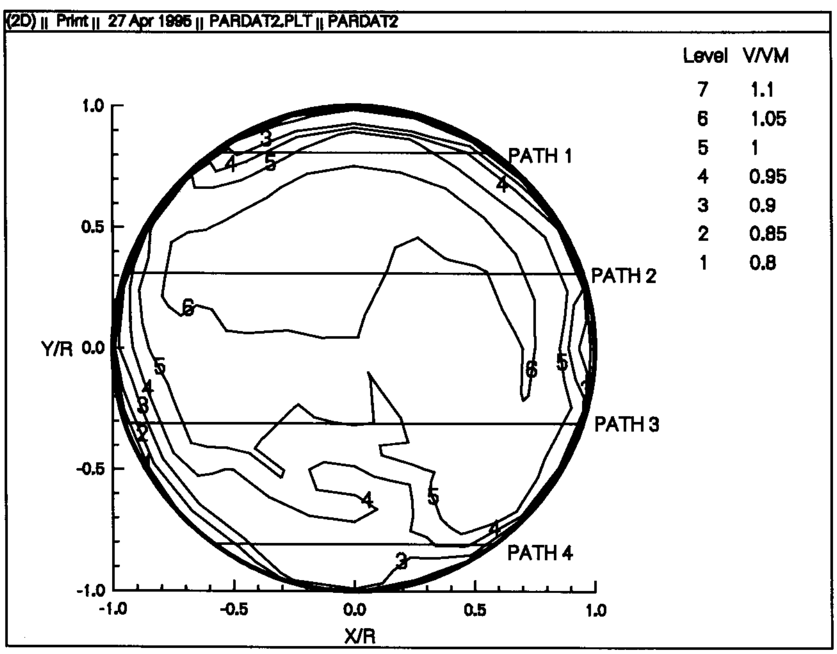


Figure 13. - Non-dimensional velocity distribution for test No. 2, prototype discharge equal to 1,748 ft^3/s and minimum normal reservoir elevation of 449 ft. The AVM computed discharge was biased -0.46% from the actual flow.

Results from this analysis are presented on figure 14, which shows that the minimum error (-0.11%) occurs when the acoustic paths are rotated 30° clockwise for both tests No. 5 and 6. In addition, this figure illustrates a minor influence of path rotation on discharge measurement accuracy. For the prototype path orientation, errors in discharge measurements for tests No. 5 and 6 were found to be -0.18 and -0.46%, respectively. These results (table 6) verify the performance of the Gaussian quadrature method for integrating these particular velocity distributions to within ±0.5%. Therefore, the prototype AVM installation on penstock No. 1 should perform within an accuracy range of ±0.50 if errors related to AVM installation and set-up are also within manufacturer's specifications. The small improvement in discharge measurement accuracy associated with re-installing the acoustic paths at a 30° clockwise orientation falls within the overall uncertainty in the AVM analysis method, which was computed to be ±0.15% for a 95% confidence level. As a result, little statistical basis exists for moving the acoustic transducers from their current position in an effort to achieve manufacturer's specifications of ±0.5% error in discharge.

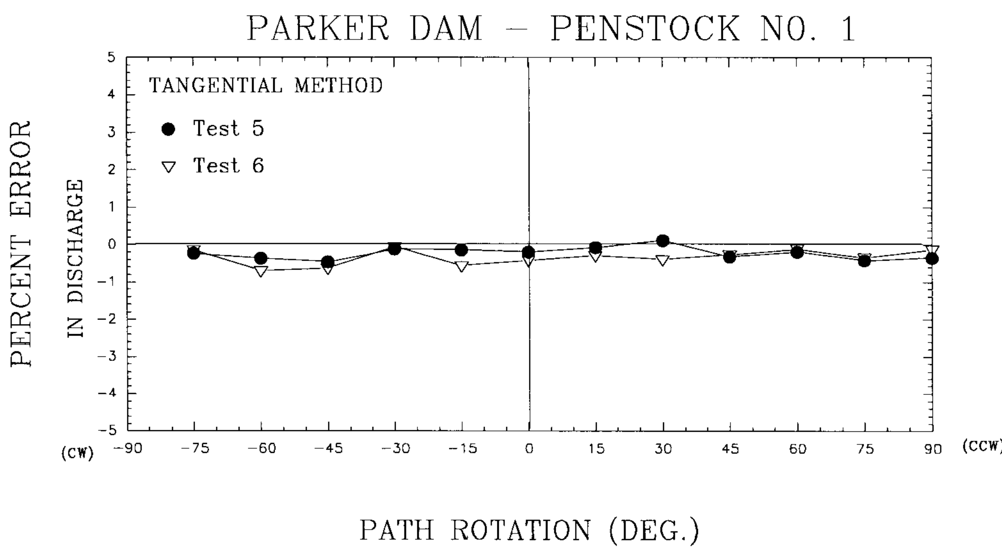


Figure 14. - Percent error in quadrature method discharge computation when compared to discharge computations using the tangential integration method. This plot indicates the best transducer configuration is for a path rotation of 30° clockwise.

Table 6. - AVM discharge computations for Parker Dam penstock No. 1. Flows are reported with an uncertainty estimate for a 95% confidence level.

Test No.	Flow (AVM) (ft^3/s)	Flow (Tangential) (ft^3/s)	Percent Error* (%)
5	4,949 ± 7	4,958 ± 30	-0.18
6	1,745 ± 3	1,753 ± 9	-0.46

* Percent error= $(Q_{AVM}-Q_{tangential})/Q_{tangential}*100$

AVM FIELD EVALUATIONS

National Standards

To determine the accuracy of flow measurement at Hoover, Davis, and Parker Dams, field surveys were conducted in September 1992 to document and review AVM equipment, AVM system parameters, as-built drawings, and perceived system performance. Each of the 27 AVM sites and installations was evaluated using ANSI/ASME Standard MFC-5M-1985, *Measurement of Liquid Flow in Closed Conduits using Transit-Time Ultrasonic Flowmeters.* Likewise, ASME's Performance Test Code for Hydraulic Turbines (ASME PTC 18-1992) was used in evaluations because it is the standard procedure for performing turbine performance tests and is in some instances more stringent than the ANSI/ASME standard.

Standard and Non-Standard Installations

Surveys at Hoover, Davis, and Parker Dams resulted in a large amount of site specific data and personal opinions as to how the AVM systems were performing. Survey information is summarized as follows:

Hoover Dam.—Eighteen AVMs at Hoover Dam were installed over the period of 1989 to 1991. A review of AVM equipment, system parameters, and as-built drawings at Hoover Dam revealed that all AVM installations were according to ANSI/ASME standards and were configured properly. On average, the installations have 30 diameters of straight pipe upstream from the AVM measurement sections and 4 diameters of straight pipe downstream from the AVM measurement sections. The only exception to ASME's PTC 18 is that not all penstocks are equipped with crossed acoustic planes. This exception was incorporated because cross flow information could be obtained from similar penstocks and applied to the penstocks with only one acoustic plane.

Davis Dam.—Five AVMs were installed in 1989. A review of AVM equipment, system parameters, and as-built drawings for Davis Dam revealed that all five AVM installations were nonstandard because of inadequate lengths of straight pipe upstream and downstream from the meter section. Ten and three pipe diameters are the recommended minimum upstream and downstream lengths, respectively, as required in the ASME's PTC-18-1992. The amount of straight pipe upstream from the meter section ranged from ½ to 1½ diameters for each of the five 22-ft-diameter penstocks. However, these lengths could not be increased because of the short penstocks. All AVMs were installed just upstream from the turbine scroll cases to maximize the length of straight pipe upstream. Because of short penstock lengths and bends upstream, cross flows (flows with non-axial velocity components) were anticipated. Crossed plane AVMs are typically used in difficult installations to eliminate cross flow errors. The shortest of the five penstocks was fitted with a crossed path AVM system. It should be noted that ASME's PTC 18 requires installation of two four-path measurement planes, and that the intersection of the two planes shall be located in the plane of the upstream bend. The crossed plane AVM installation on penstock No. 5 at Davis Dam does not meet the above criteria.

Parker Dam.—Four AVMs were installed in 1989. A review of AVM equipment, system parameters, and as-built drawings at Parker Dam revealed that all four AVM installations were nonstandard because of inadequate lengths of straight pipe upstream and downstream from the meter section. The length of straight pipe upstream from the meter section ranged from ½ to 6 pipe diameters for each of the four 22-ft-diameter penstocks. These lengths could not be increased because of the short penstocks. Like Davis, all AVMs were installed just upstream from the turbine scroll cases to maximize the length of straight pipe upstream from the meter section. Two of the four penstocks (No. 1 and 3) were fitted with crossed plane AVM systems. The crossed path AVM installations at Parker do not meet ASME's PTC 18-1992 requirement on acoustic path orientation with respect to the upstream bend.

General Findings

AVM system operators felt their systems were operating satisfactorily. However, interviews indicated that a disparity in knowledge levels existed among AVM system operators. Varying degrees of expertise were evident in system testing and troubleshooting depending on the AVM maintenance history. To alleviate this problem, a training course is recommended for all AVM system operators. Also, an experienced electronics technician is necessary to effectively operate and maintain an AVM system. We also recommend developing a data base to log maintenance and repair data, as well as a system to keep records of system parameters and error logs.

AVM Data Analysis

Individual path velocities and discharge values were collected for the crossed path AVMs at Davis and Parker Dams to determine the errors associated with cross flows. Figure 15a contains a typical sample (~120 measurements taken over 2 minutes) of path velocity data collected from Davis penstocks No. 1 and 2 for a 65% gate opening. Each penstock is equipped with a single plane AVM, so a total of eight path velocities and two discharges (one discharge for each acoustic plane) were measured. Paths No. 1 and 4 are the upper and lowermost acoustic paths. Paths No. 2 and 3 are located in between paths No. 1 and 4.

Davis Dam Acoustic Velocity Meter Evaluation

Field tests were conducted to collect real-time data from the Accusonic Model 7410 acoustic velocity meters. Path velocities and discharge data were collected for a wide range of wicket gate openings. Of the five penstocks at Davis Dam, only No. 5 has a crossed plane AVM. Penstock No. 5 was chosen for the crossed plane installation because it is the shortest penstock. However, it also has the longest section of straight pipe upstream from the measurement section (fig. 6). As a result, penstocks No. 1 through 4 may have velocity distributions which are worse than No. 1.

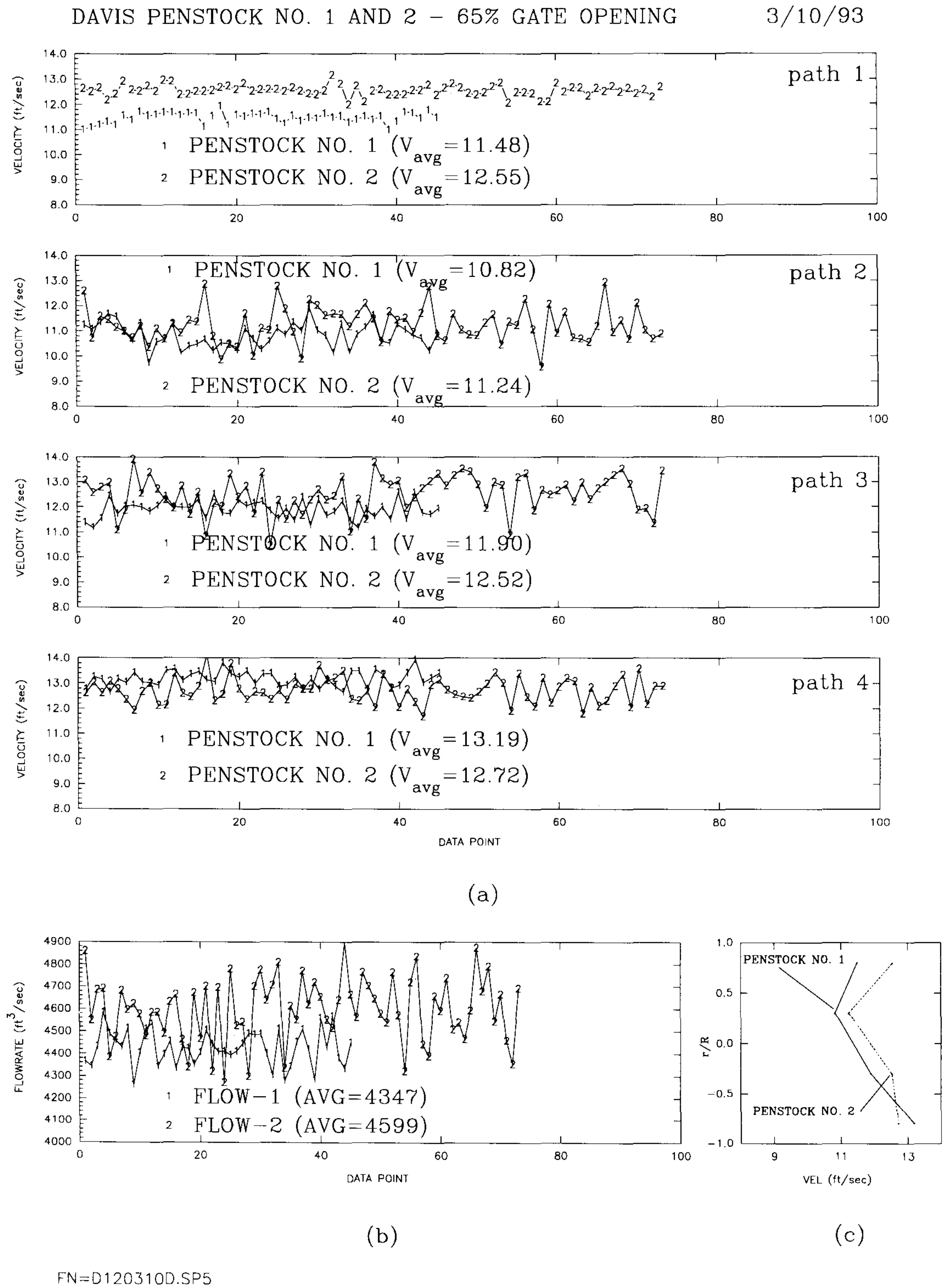


Figure 15. - (a) Instantaneous path velocities for Davis penstocks No. 1 and 2. Single acoustic plane data for each penstock. (b) Instantaneous flow rates for penstocks No. 1 and 2. (c) Average velocity profiles for penstocks No. 1 and 2.

AVM data were analyzed to identify problems with the data collection, AVM set-up, cross flows, and skewed velocity distributions. A summary of the data analysis is as follows:

Penstock No. 1.—This penstock has less than 1 pipe diameter of straight pipe upstream from the AVM measurement section. The combined bend is a vertical curve of 20° and a horizontal curve of 28°. In addition, a 20° vertical bend is located 4 pipe diameters upstream from the combined bend. Analysis of AVM data collected for a 65% wicket gate opening at reservoir elevation of 637 ft resulted in the following observations:

- The velocity profile is skewed; path No. 2 velocities are less than the other three paths (fig. 15a). Skewness is caused by the bends located upstream from the measurement section.

- No diameters of straight pipe upstream from the measurement section and two upstream bends are likely to generate a discharge measurement error because of cross flows.

- This penstock has no crossed acoustic planes. As a result, an estimate of cross flow error could not be established.

- To attain accuracies on the order of ± 0.5%, cross plane measurements must be made on this penstock.

Penstock No. 2.—This penstock has less than 1 pipe diameter of straight pipe located upstream from the AVM measurement section. The combined bend is a vertical curve of 10° and a horizontal curve of 28°. Analysis of AVM data collected for a 65% wicket gate opening at reservoir elevation of 637 ft resulted in the following observations:

- The velocity profile is skewed toward the pipe invert; path No. 2 velocities are less than the other three paths (fig. 15a).

- One pipe diameter of straight pipe upstream from the measurement section and an upstream bend will likely generate a discharge measurement error because of cross flows.

- This penstock has no crossed acoustic planes. As a result, an estimate of cross flow error could not be established.

- To attain accuracies on the order of ± 0.5%, cross plane measurements must be made on this penstock.

Penstock No. 3.—This penstock has about 1 pipe diameter of straight pipe located upstream from the AVM measurement section. The combined bend is a vertical curve of 12.5° and a horizontal curve of 28°. Analysis of AVM data collected for a 65% wicket gate opening at reservoir elevation of 637 ft resulted in the following observations:

- The velocity profile is skewed toward the pipe invert; path No. 2 velocities are less than the other three paths (fig. 16a).

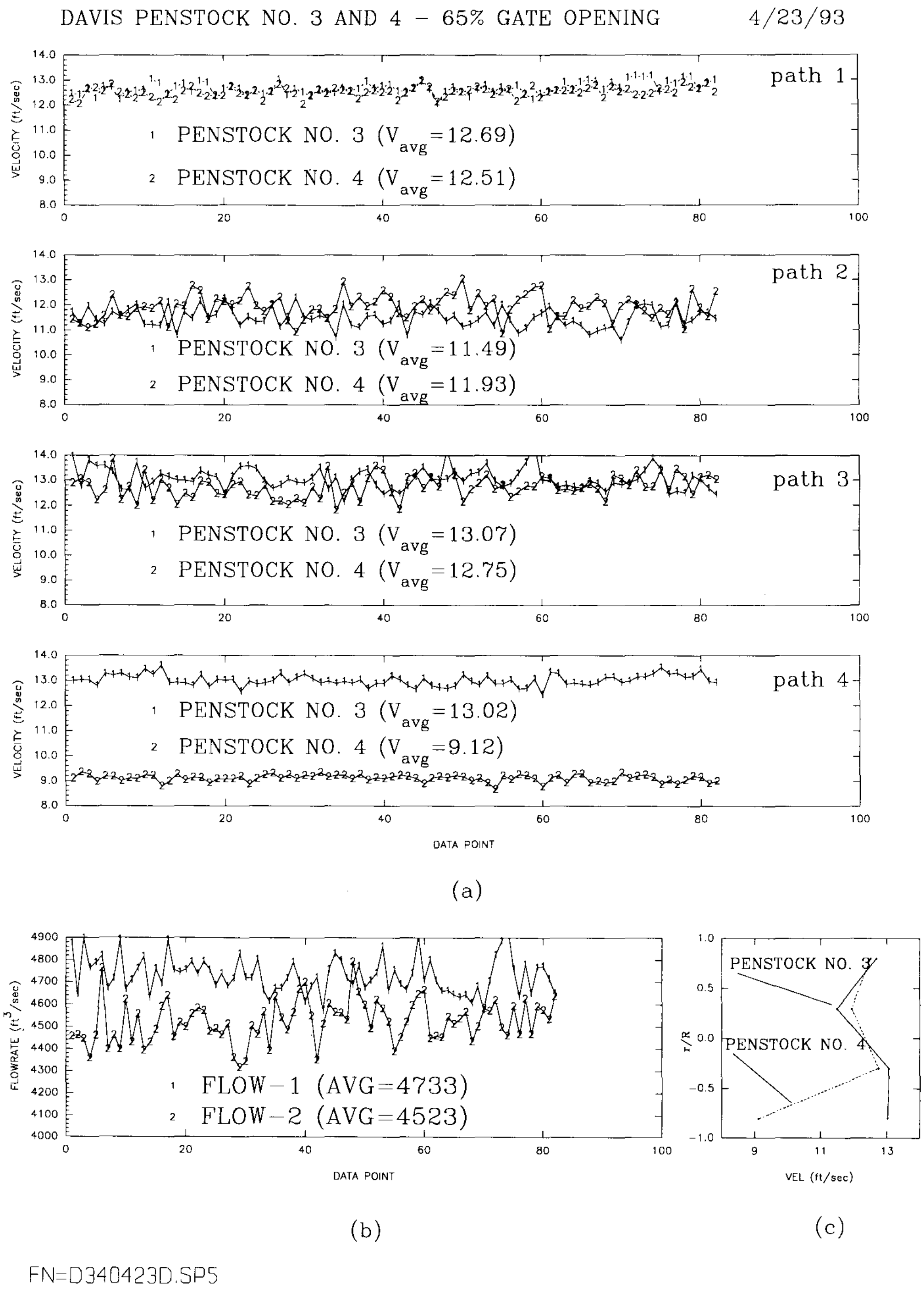


Figure 16. - (a) Instantaneous path velocities for Davis penstocks No. 3 and 4. Single acoustic plane data for each penstock. (b) Instantaneous flow rates for penstocks No. 3 and 4. (c) Average velocity profiles for penstock No. 3 and 4.

- This penstock has no crossed acoustic planes. As a result, an estimate of cross flow error could not be established, but cross flow error probably exists because of the proximity of the upstream bend.

- To attain accuracies on the order of ± 0.5%, cross plane measurements must be made on this penstock.

Penstock No. 4.—This penstock has about 1.5 pipe diameters of straight pipe located upstream from the AVM measurement section. The combined bend is a vertical curve of 16.5° and a horizontal curve of 28°. Analysis of AVM data collected for a 65% wicket gate opening at reservoir elevation of 637 ft resulted in the following observations:

- For several data sets collected on different days, acoustic path No. 4 velocities were consistently 30% lower than path No. 3 velocities. These low velocities are not consistent with path No. 4 velocity measurements on penstock No. 3 or 5 (fig. 16a and 16c). Given the similar geometry of penstocks No. 3 and 5, this radical disturbance in the velocity distribution is improbable unless the penstock is damaged. As a result, this transducer should be evaluated for electrical or installation errors. If this analysis does not identify the problem, the penstock and transducer mount should be inspected for an offset or other source of a flow disturbance.

- This penstock has no crossed acoustic planes. As a result, an estimate of cross flow error could not be established, but because of the proximity of the upstream bend and the very low velocities measured on path No. 4, cross flow probably exists. Therefore, crossed plane measurements should be taken to assure high accuracy (± 0.5%) in AVM discharge measurements.

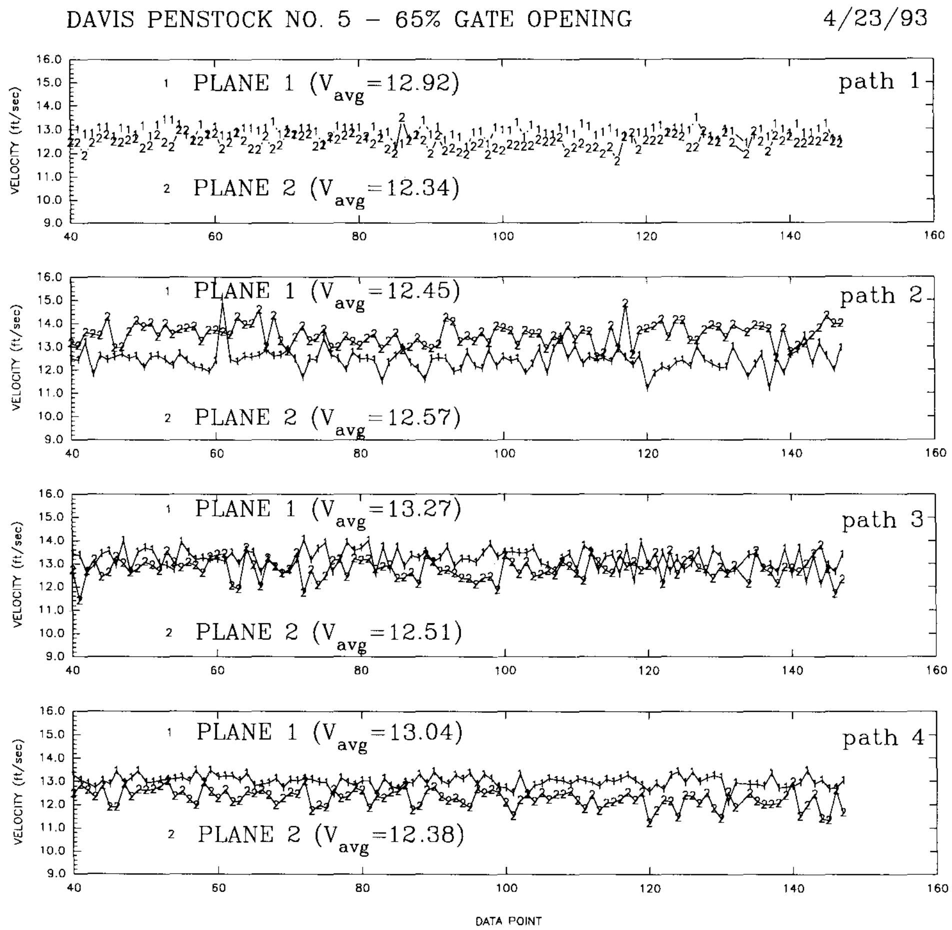
Penstock No. 5.—This penstock has 1.5 diameters of straight pipe located upstream from the measurement section. The combined bend is a vertical curve of 24° and a horizontal curve of 28°. Analysis of AVM data collected for many gate openings (11%, 20%, 30%, 40%, 50%, 60%, and 64%) at reservoir elevation of 630.8 ft resulted in the following observations:

- Velocity data indicate reasonably close agreement between the two acoustic planes (fig. 17a); the average velocity profiles are skewed and have different shapes (fig. 17c), which indicates poor flow conditions caused by the short penstock and combined bend upstream.

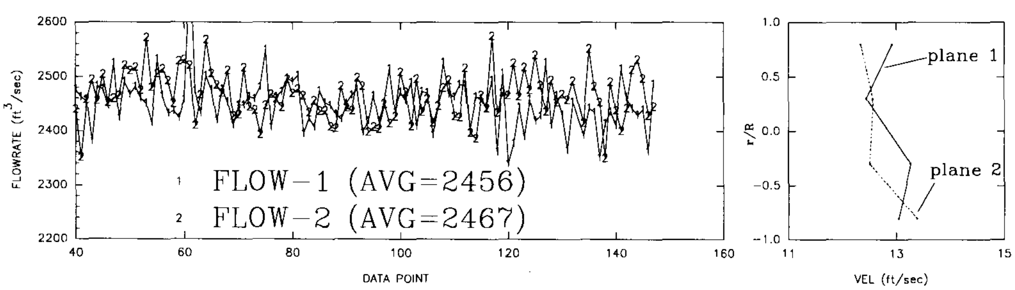
- For all wicket gate openings tested, the two crossed acoustic planes produce discharge measurements which are offset by an average of ±1.07% (table 7), which demonstrates a systematic error in the AVM discharge measurement. This offset is attributed to a cross flow velocity component. As a result, cross plane measurements must be made for this penstock.

- Given the similar geometry of penstocks No. 1 through 4 to penstock No. 5, cross flows are probably also occurring in those penstocks.

- The average of Flow-1 and Flow-2 is a discharge value corrected for cross flow. For the wide range of wicket gate openings tested, Flow-2 values were consistently 1.07% higher than Flow-1 values. Therefore, if one plane of transducers should fail, a correction should be made as follows: increase Flow-1 value by 0.54% if plane No. 2 fails or decrease Flow-2 value by 0.54% if plane No. 1 fails.



(a)



(b)

(c)

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Figure 17. - (a) Instantaneous path velocities for Davis penstock No. 5. (a) Crossed acoustic plane data for this penstock. (b) Instantaneous flow rates for acoustic planes No. 1 and 2. (c) Average velocity profiles for planes No. 1 and 2.

Table 7. - Comparison of cross plane discharge measurements for a range of wicket gate openings in penstock No. 5. Flow-1 and Flow-2 are internally divided by 2 so when summed, they are corrected for cross flow errors in penstock No. 5.

Percent Wicket Gate Opening (%)	AVM Flow-1 (ft^3/s)	AVM Flow-2 (ft^3/s)	Percent Difference (%)
11	427.1	433.8	-1.53
20	726.5	733.1	-0.89
30	1140.2	1159.3	-1.64
40	1418.1	1439.7	-1.50
50	1909.9	1928.4	-0.95
60	2319.9	2322.0	-0.09
64	2467.6	2487.5	-0.80

Parker Dam Acoustic Velocity Meter Evaluation

Field tests were conducted to collect real-time data from the Accusonic Model 7410 acoustic velocity meters. Path velocities (VEL-n) and discharge (FLOW-n) data were collected for a wide range of wicket gate openings (table 8). Of the four penstocks at Parker Dam, penstocks No. 1 and 3 have crossed plane AVMs.

Several AVM data sets were analyzed to identify problems with the data collection, AVM set-up, cross flows, and skewed velocity distributions. A summary of the data analysis follows:

Penstock No. 1.—This penstock has less than 1 pipe diameter of straight pipe located upstream from the AVM measurement section. The combined bend is a vertical curve of 13° and a horizontal curve of 4.6°. Analysis of these AVM data collected for many wicket gate openings (15%, 25%, 35%, 50%, 60%, 70%, and 80%) at reservoir elevation of 446.6 ft resulted in the following observations:

- The velocity profile is skewed; path No. 2 velocities are greater than path No. 3 (fig. 18a). The degree of skewness escalates with increasing gate opening. Skewness is caused by the combined bend located directly upstream from the AVM measurement section.

- The crossed acoustic planes produce discharge measurements which are consistently offset by an average of 3.8% (table 8 and fig. 18b), which indicates the cross flow component in the AVM measurement section is significant for the tested range of wicket gate openings. As a result, cross plane measurements must be made for accurate flow measurement in this penstock.

- Field observations of a vortex near the intake for penstock No. 1 could also be contributing to the development of cross flows. Vortices were not observed in the model.

- The average of Flow-1 and Flow-2 is the discharge value corrected for cross flow. If one plane of transducers should fail, a correction should be made as follows: reduce Flow-1 value by 1.9% if plane No. 2 fails, or increase the Flow-2 value 1.9% if plane No. 1 fails. This correction will give a better estimate of the true discharge.

Table 8. - Comparison of cross plane discharge measurements for a range of wicket gate openings at Parker Dam. Flow-1 and Flow-2 are averaged to correct for cross flow errors in Parker penstock No. 1.

Percent Wicket Gate Opening (%)	AVM Flow-1 (ft^3/s)	AVM Flow-2 (ft^3/s)	Percent Difference (%)
15	846.9	814.8	3.79
25	1458.8	1405.6	3.64
35	2033.5	1954.5	3.88
50	3179.0	3058.0	3.80
60	3974.0	3814.0	4.00
70	4690.0	4510.0	3.84
80	5135.0	4940.0	3.79

Penstock No. 2.-This penstock has about 2 pipe diameters of straight pipe located upstream from the AVM measurement section. The combined bend is a vertical curve of 13° and a horizontal curve of 1.6°. Only one data file was collected for this penstock. Analysis of AVM data collected for a 65% wicket gate opening resulted in the following observations:

- The velocity profile is slightly skewed toward the pipe invert; path No. 1 velocities are less than path No. 4 velocities. Paths No. 2 and 3 velocities were almost identical.

- Considering the cross flow errors in penstock No.1, cross plane measurements must be made on this penstock to confirm accuracies on the order of ±0.5%. Applying a correction to this discharge measurement is difficult, but because this penstock has more pipe diameters of straight pipe located upstream from the AVM measurement section, it is likely to experience less than the ±1.9% error on penstock No. 1.

Penstock No. 3.—This penstock has less than 5 pipe diameters of straight pipe located upstream from the AVM measurement section. The combined bend is a vertical curve of 13° and a horizontal curve of 3.6°. AVM data analysis for many wicket gate openings (15%, 25%, 35%, 50%, 60%, 72%, and 80%) at reservoir elevation 446.6 ft resulted in the following:

- Path velocities are skewed; path No. 1 velocities are less than path No. 4 velocities (fig. 19a). The degree of skewness escalates with increasing wicket gate opening. Skewness is caused by the combined bend located 4.5 pipe diameters upstream.

- The two crossed acoustic planes produce average discharge measurements which are within ±0.12% (table 9), which indicates that the cross flow component in the AVM measurement section is small for all wicket gate openings tested (fig. 19b).

- Average velocity profiles measured on both acoustic planes are very similar, as shown on figure 19c.

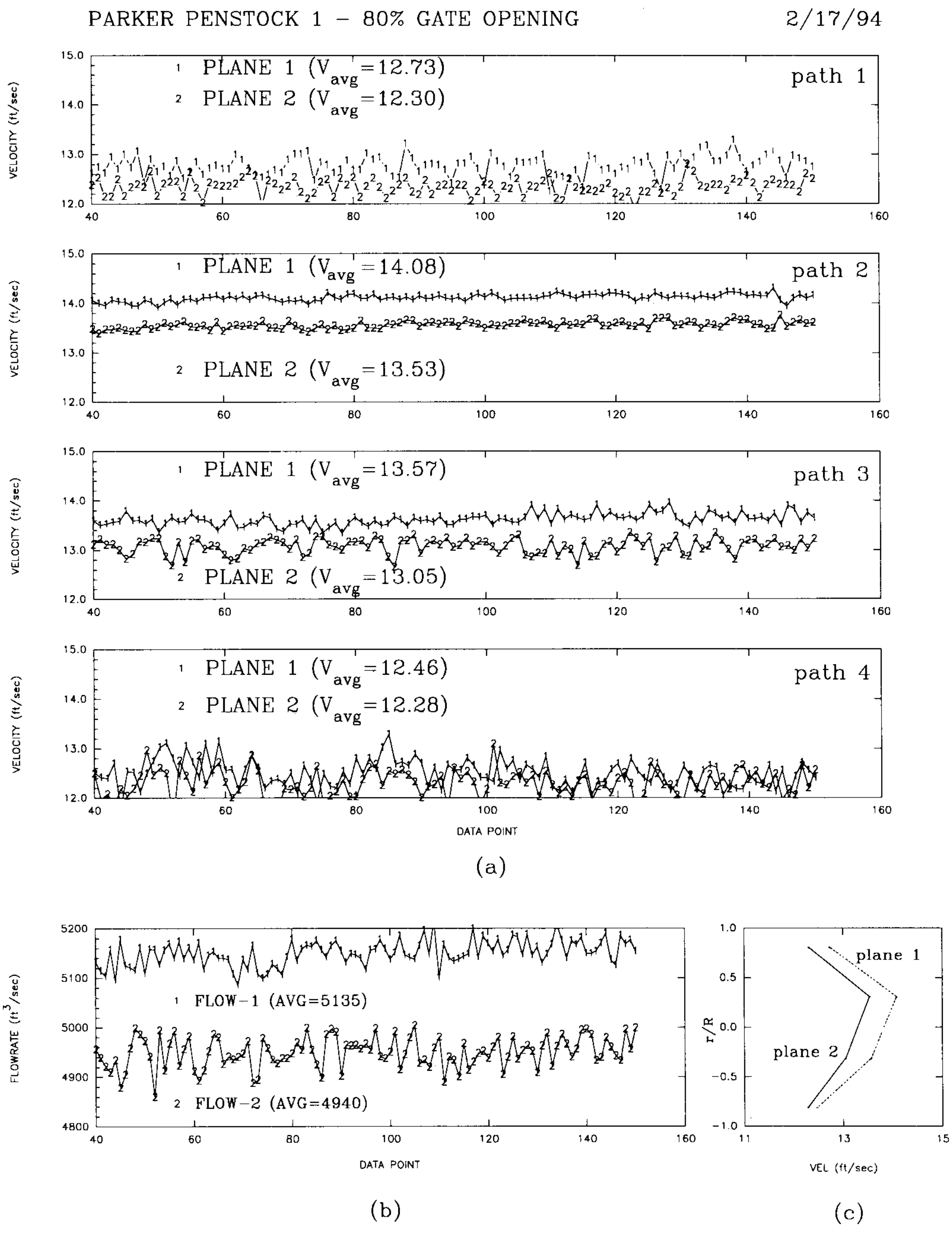


Figure 18. - (a) Instantaneous path velocities for Parker penstock No. 1. Data were collected for crossing acoustic planes. (b) Instantaneous flow rates for planes No. 1 and 2. (c) Average velocity profiles for planes No. 1 and 2.

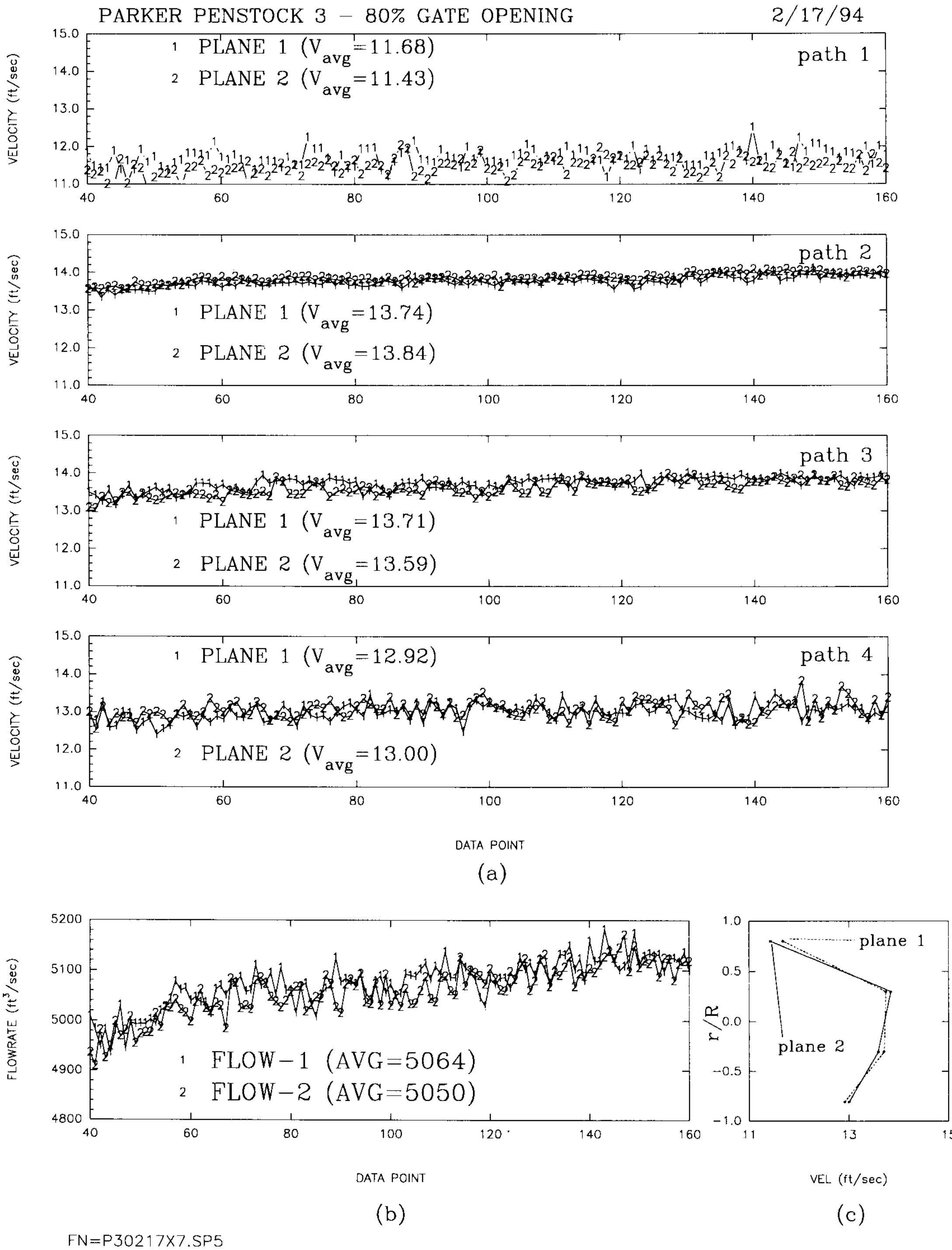


Figure 19. - (a) Instantaneous path velocities for Parker penstock No. 3. Data were collected for crossing acoustic planes. (b) Instantaneous flow rates for planes No. 1 and 2. (c) Average velocity profiles for planes No. 1 and 2.

Table 9. - Comparison of cross plane discharge measurements for a range of wicket gate openings at Parker Dam. Flow-1 and Flow-2 are averaged to correct for cross flow errors in Parker penstock No. 3.

Percent Wicket Gate Opening (%)	AVM Flow-1 (ft^3/s)	AVM Flow-2 (ft^3/s)	Percent Difference (%)
15	779.2	776.3	-0.36
25	1418.6	1420.7	+0.15
35	2004.5	1998.6	-0.30
50	3161.6	3151.2	-0.33
60	3939.6	3930.2	-0.24
72	4717.3	4700.5	-0.36
80	5063.8	5050.0	-0.27

- Based on these data, continuous cross plane measurements are not needed for this penstock. However, an occasional check of the primary plane versus the secondary plane would be wise. Only one plane is necessary for a discharge measurement with the manufacturer's accuracy of ±0.5%. However, it is recommended to always have both planes operating during turbine performance tests.

- The comparison of cross flows at penstocks No. 1 and 3 shows that the amount of straight pipe located upstream from the AVM measurement section is directly related to the severity of cross flows.

Penstock No. 4.—This penstock has 6.4 pipe diameters of straight pipe located upstream from the AVM measurement section. The combined bend is a vertical curve of 13° and a horizontal curve of 4.6°. No data files were collected for this penstock; however, the following comments are based on data collected on penstock No. 3:

- Additional pipe length should create a more uniform velocity distribution than penstock No. 3.

- This penstock has no crossed acoustic planes. However, because very small cross flow errors were measured on penstock No. 3, none probably exist on this installation. As a result, AVM discharge measurement errors should be equal to or less than those measured in penstock No. 3.

COMPARISON OF MODEL AND PROTOTYPE CHORDAL-PATH VELOCITY MEASUREMENTS

A comparison of average chordal-path velocity measurements in the model and prototype penstocks was conducted to verify model/prototype similitude. Model chordal-path velocities were calculated by extracting velocity data along each acoustic path from the velocity distribution model. The path velocities were integrated to determine the average path velocity distribution model. Normalized model path velocities were compared to normalized average path velocities collected from the AVM located on the prototype penstock. Figures 20 and 21 illustrate the comparison of model/prototype data for Davis and Parker penstocks, respectively. Figure 20a shows the comparison for model test No. 2 and figure 20b shows the comparison of model test No. 3. The comparisons of velocity profiles for these two tests are very similar. The differences for paths No. 1 and 4 probably exist because of boundary layer development in the model that does not match the prototype boundary layer. The different boundary layer characteristics are caused by the difference in Reynolds numbers in the model and prototype. Paths No. 2 and 3 are less affected because the longer path length dampens out this small error. In addition, these differences could be caused by disturbances generated by the presence of the prototype AVM transducer. Research by Taylor (1987) revealed that the acoustic transducer causes a distorted velocity profile around the transducer face which affects the travel-time measurement along the acoustic path. This disturbance was not present in the model because the LDA measurements were non-intrusive.

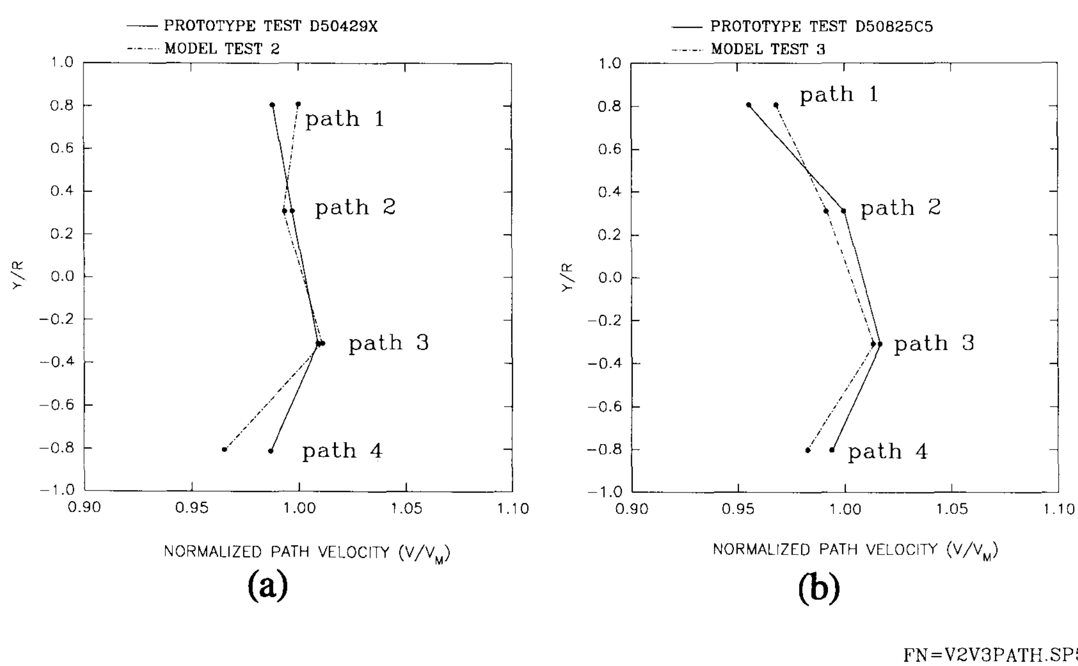
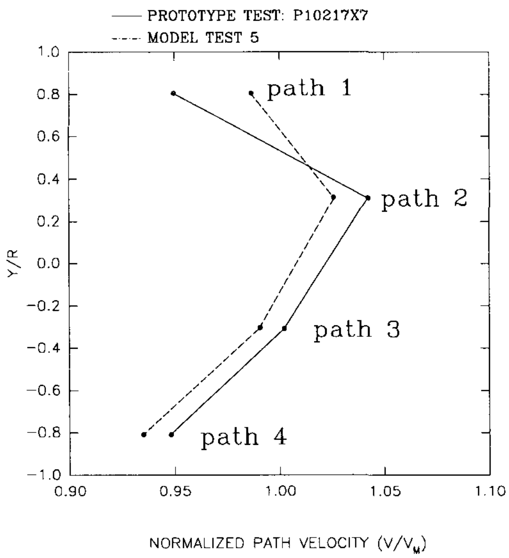


Figure 20. - Model/prototype comparison of normalized acoustic path velocities for Davis penstock No. 5. (a) Test No. 2 velocity distribution (Q=5,340 ft^3/s) and (b) Test No. 3 velocity distribution (Q=3,590 ft^3/s).

Figures 21a and 21b show the comparisons for model tests No. 5 and 6, respectively. The comparisons for these tests are very similar to the Davis penstocks. Overall, the comparison of model/prototype acoustic path velocities is a confirmation of model/prototype similitude.



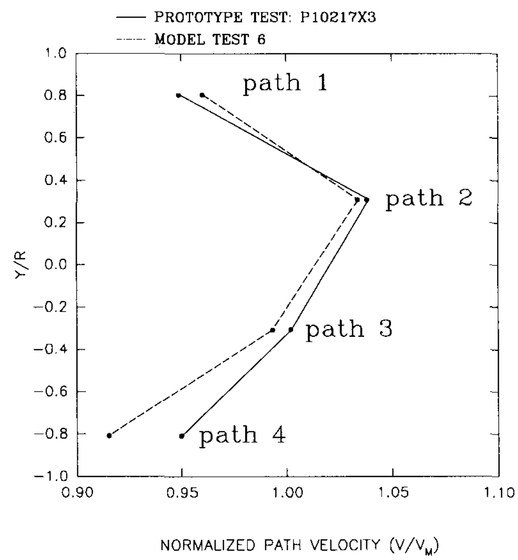


Figure 21. - Model/prototype comparison of normalized acoustic path velocities for Parker penstock No. 1. (a) Test No. 5 velocity distribution (Q=4,930 ft^3/s) and (b) Test No. 6 velocity distribution (Q=1,750 ft^3/s).

FIELD EVALUATION OF A STRAP-ON ACOUSTIC FLOWMETER

A field test of a Controlotron Model 990 portable transit-time flowmeter on Davis penstock No. 5 was conducted at Davis Dam. The field test was requested by Mr. Albert Marquez, civil engineer in the LC (Lower Colorado) Regional Office. This field test supported an effort to improve flow measurement for the LCRAS (Lower Colorado River Accounting System) program. This test was performed as a demonstration of a strap-on meter; the test was not intended to evaluate the chordal-path AVMs.

Initially, 4 hours were spent installing and calibrating the acoustic transducers on the 22-ft-diameter penstock for unit No. 5. We had difficultly establishing an adequate acoustic signal with the transducers (size 5) mounted in reflect mode (both transducers mounted on same side of penstock). This difficulty may have been caused by an expansion joint that may have attenuated the acoustic signal. Likewise, this problem may have been caused by inadequate transducer signal strength. On previous field tests on large pipes, similar problems were noted when using the flowmeter with transducers mounted in reflect mode. As a result, one pair of transducers was mounted in direct mode (on opposite sides of the penstock), which reduced the path length by one-half. Discharge measurements were successful in direct mode and the flowmeter was calibrated to a zero offset value equal to wicket gate leakage, which was measured by the Accusonic flowmeter to be 23 ft^3/s. A second flow measurement path was not established because of time constraints. Input parameters for the Controlotron flowmeter are listed in table 10.

Table 10. - Input parameters for Controlotron 990 flowmeter.

Pipe outside diameter (in)	Pipe material	Pipe wall thickness (in)	Pipe liner material	Liner thickness (in)	Water temperature (°F)
266.0	Steel	1.00	Coal tar	0.063	68

Turbine No. 5 was brought on-line manually in increments of 10% wicket gate opening to a maximum of 64%. During this test, the forebay elevation was 637.3 ft and the afterbay elevation was 502.4 ft. Flow rates were measured with the Accusonic and Controlotron flowmeters for each gate opening; average and standard deviations for each gate opening are listed in table 11. The Accusonic flowmeter is a crossed plane chordal-path flowmeter. The eight chordal paths are configured to correct for any cross flow errors and should produce the most accurate measure of flow rate.

Table 11. - Results of Controlotron strap-on flowmeter testing at Davis Dam unit No. 5.

Gate Opening (%)	Controlotron Flow Rate (ft^3/s)	Accusonic Flow Rate (ft^3/s)	Percent Difference (%)
11	avg= 819.5 stdev= 11.0	avg= 860.4 stdev= 8.2	-5.0
20	avg= 1306.9 stdev= 46.9	avg= 1459.9 stdev= 17.2	-11.7
30	avg= 2167.5 stdev= 36.2	avg= 2299.5 stdev= 28.3	-6.1
40	avg= 2799.9 stdev= 53.7	avg= 2989.7 stdev= 47.7	-6.8
50	avg= 3568.0 stdev= 110.3	avg= 3831.8 stdev= 66.0	-7.4
60	avg= 4492.1 stdev= 152.5	avg= 4635.5 stdev= 62.2	-3.2
64	avg= 4618.5 stdev= 103.3	avg= 4955.1 stdev= 84.4	-7.3

Note: Forebay El. = 637.3 ft, afterbay El. = 502.4 ft.

Strap-On Acoustic Flowmeter Conclusions

On average, the Controlotron flow rates were 6.3% lower than the Accusonic measured discharge. This difference may have several causes:

1. Measuring flow with the acoustic transducers mounted in direct mode does not correct for cross flow errors (streamline direction is not parallel to the measurement section axis). Reflect mode operation, when used, compensates for cross flow errors which have been identified in the field data analyses. Cross flow errors can be either additive, or in this case, subtractive.

2. The coal tar lining thickness was not measured and, according to plant maintenance personnel, was probably greater than 1/16 in thick. In addition, the coal tar lining was applied using rollers and probably had a variable thickness. A thicker liner would result in a small overprediction in flow rate.

3. Another common source of error is in transducer set-up, which was done using the Accusonic transducer locations as a reference. Accusonic transducers were located very accurately using surveying techniques. Consequently, this error was probably minimal, but the Controlotron transducer locations were not verified with survey instruments.

4. The diametral path passes through the low velocity region identified by the model studies (upper left quadrant on fig. 7). This path location is probably the main reason for the underprediction in the discharge measurement. This result illustrates the effect of acoustic path location on the performance of diametral path meters.

Although strap-on acoustic flowmeters cannot claim the installed accuracy of a chordal-path AVM, their cost is significantly less, and they are suitable for many discharge measurement applications. In addition, Taylor (1987) has suggested using strap-on flowmeters to determine the severity of asymmetric velocity distributions. Taylor's procedure may be useful in determining whether a crossed path AVM installation is warranted.

RECOMMENDATIONS FROM FIELD EVALUATIONS

Field Surveys

Some interesting equipment problems were identified during the surveys. At Hoover and Davis Dams, when acoustic transducers were removed for cleaning or when the penstock was dewatered, a large number of transducers failed. Since then, transducer failures have been prevented by keeping transducers submerged in water during maintenance operations. Another common concern was the accuracy of field surveys of path angles and lengths, and cross-sectional areas of the penstocks. These parameters are very difficult to measure accurately and must be determined to a high degree of accuracy. Therefore, operators should be comfortable with the survey accuracy prior to going on-line with an AVM system. This information should be stored for future reference because it is important in setting up the AVM system parameters.

Review of the system parameter lists identified several errors in the system parameters. Errors in path angle and diameters resulted in relatively large systematic errors. Once identified, these errors are easily corrected provided as-built information is available. Another installation had two cables crossed, which resulted in a negative path velocity. Of course, this error leads to a very large error in discharge measurement.

Recommended Installation and Set-Up Procedures

Installation of an AVM requires a layout survey, installation of transducer mounts, and an as-built survey of acoustic path lengths, average cross sectional area, and acoustic path angles. Accurate installation and AVM set-up is critical to assure accurate discharge measurements. ASME's Performance Test Code 18-1992 and ANSI Standard MFC-5M-1985 are good resources for AVM installation, operation, and maintenance guidelines. Field procedures which should be considered are:

- Acoustic signals received at each transducer should be examined using an oscilloscope to look for excessive noise and sufficient amplitude to assure proper signal detection. Signal strength should be examined periodically to check for transducer fouling.

- To check for timing bias errors, the upstream and downstream cables should be reversed and a repeat set of measurements taken. If the two time-averaged discharge values are different, a bias error associated with a timing offset exists. This bias may be caused by unequal cable lengths or delays in the electronic circuitry. PTC 18-1992 recommends measuring the ultrasonic pulse transit-times independently and comparing the transit-times measured by the AVM.

- If cross planes are installed, comparisons of the two velocity profiles and discharge measurements should reveal the presence of cross flow (non-axial) velocity components (fig. 15a and b). Cross flow can be caused by a nearby change in flow direction or by vortices which form near the penstock intake.

- The velocity profile established by the four acoustic path velocities should be studied to determine profile distortion. Likewise, strong fluctuations in instantaneous measurements can indicate non-uniform approach conditions in the AVM measurement section.

- Travel time along each acoustic path is calculated by the flowmeter. The AVM estimates the speed of sound for each measurement, which should correspond to the theoretical speed of sound for the water temperature moving through the penstock. A difference between these two values could be caused by a temperature gradient in the water moving along the acoustic path. This type of problem can occur if the reservoir's thermocline develops at same elevation as the penstock intake structure. A difference in speed of sound could also indicate a survey error.

- Tests should be performed to determine if any long period fluctuations exist, which may affect the average discharge measurement during short period performance evaluations. This type of fluctuation could be generated by a vortex which periodically develops near the intake.

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APPENDIX

Field Survey Forms

ANSI/ASME MFC-5M-1985 Standard Checklists for Parker and Davis Dams

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Parker Dam Site Power Penstock AVM ID P1

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______ Model No. 7410
Year installed 1988 S/N 238 Job # FP-17397

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz Model No. 7630-454 internal mount, two xdcrs/mount

Installation by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☒ Internal
- ☐ Threaded
- ☐ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ______

☐ Intervening material (protective cover) ______ Thickness ______ in.
☒ Cable length varies ft

ACOUSTIC PATH

☐ Diametral ☒ Chordal No. of Paths 8
☒ Crossed Path ☒ Direct ☐ Reflect Is path perpendicular to plane of bend? Yes
Path Angle w/flow path 45° Path length 17.5 & 21.1 ft

☒ As-built drawings: Specification Drawings 231-D-779 and 231-D-780

PIPE DATA

Material Steel Liner matl Coal tar Inside. Diameter 22.021 ft

Wall Thick. 1" Liner Thick. ? Out. Pipe Diameter 22'-2" ft

These distances were difficult to determine from available drawings.

Straight pipe lengths	U/S 10 ft	D/S 10 ft	
Fitting Scroll case	Distance 12 ft d/s	Fitting ______	Distance ______
Fitting Elbow	Distance 11 ft u/s	Fitting ______	Distance ______

Combined bend 13° vertical curve and 4.6° horizontal curve

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______________ Model No. 7410 ____________

Measurement Methods

☒ Unidirectional	☐ Bidirectional
☐ Signal Detection	☐ Noise reduction
☐ Transit-time difference	☐ Frequency difference
☒ Integration tech.	☒ Signal rejection tech.
☐ Signal averaging technique	☐ Automatic Gain Control

Velocity profile correction factor
- ☐ Laboratory Calibration
- ☐ Field Calibration
- ☐ Analytical calculation
- ☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate ________Hz

☒ Excitation: alternates

Are there any known problems with water quality:

☐ Entrained air	☐ Suspended solids	☐ Rapid temperature changes
☐ Pressure changes	☐ Xdcr fouling	**Xdcrs cleaned once per year**

Are there any known problems with:

☐ Electrical noise ☐ Acoustical noise ☐ Secondary flows None

DISPLAY AND OUTPUTS

☒ Discharge, units=CFS	☒ Totalized volume, units=AC-FT
☐ Flow direction	☐ Noise reduction
☒ Digital output	☐ Analog output
☒ Performance Alarms	☐ Telemetry, where to none ______
☒ Data storage: Hard copy of hourly printout	☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow	______________%
Linearity-Max deviation between smooth curve fit and actual flow	______________%
Repeatability-Return to a previous flow after a change in flow	______________%
Stability-Measure of change in accuracy with time	______________%
Resolution-Min change in flow rate required to produce a change in output	______________%
Rangeability-Range of flows which the performance is specified	______________%

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Parker Dam Site Power Penstock AVM ID P2

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______ Model No. 7410
Year installed 1988 S/N 259 Job # FP-17831

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz Model No. 7630-454 internal mount, two xdcrs/mount

Installation by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☒ Internal
- ☐ Threaded
- ☐ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ______

☐ Intervening material (protective cover) ______ Thickness ______ in.
☒ Cable length varies ft

ACOUSTIC PATH
☐ Diametral ☒ Chordal No. of Paths 4
☐ Crossed Path ☒ Direct ☐ Reflect Is path perpendicular to plane of bend? Yes
Path Angle w/flow path 45° Path length 29 & 17.6 ft

☒ As-built drawings: Specification Drawings 231-D-779 and 231-D-780

PIPE DATA

Material Steel Liner matl Coal tar Inside. Diameter 21.9880 ft

Wall Thick. 1" Liner Thick. ? Out. Pipe Diameter 22'-2" ft

These distances were difficult to determine from available drawings.
Straight pipe lengths U/S 140 ft D/S 10 ft
Fitting Scroll case Distance 10 ft d/s Fitting ______ Distance ______
Fitting Combined Bend Distance 140 ft u/s Fitting ______ Distance ______

Combined bend 13° vertical curve and 4.6° horizontal curve

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ____________ Model No. 7410 ____________

Measurement Methods

☒ Unidirectional	☐ Bidirectional
☐ Signal Detection	☐ Noise reduction
☐ Transit-time difference	☐ Frequency difference
☒ Integration tech.	☒ Signal rejection tech.
☐ Signal averaging technique	☐ Automatic Gain Control

Velocity profile correction factor
- ☐ Laboratory Calibration
- ☐ Field Calibration
- ☐ Analytical calculation
- ☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate ________Hz

☒ Excitation: alternates

Are there any known problems with water quality:

☐ Entrained air	☐ Suspended solids	☐ Rapid temperature changes
☐ Pressure changes	☐ Xdcr fouling	Xdcrs cleaned once per year

Are there any known problems with:

☐ Electrical noise ☐ Acoustical noise ☐ Secondary flows None

DISPLAY AND OUTPUTS

☒ Discharge, units=CFS	☒ Totalized volume, units=AC-FT
☐ Flow direction	☐ Noise reduction
☒ Digital output	☐ Analog output
☒ Performance Alarms	☐ Telemetry, where to none ______
☒ Data storage: Hard copy of hourly printout	☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow	______________%
Linearity-Max deviation between smooth curve fit and actual flow	______________%
Repeatability-Return to a previous flow after a change in flow	______________%
Stability-Measure of change in accuracy with time	______________%
Resolution-Min change in flow rate required to produce a change in output	______________%
Rangeability-Range of flows which the performance is specified	______________%

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Parker Dam Site Power Penstock AVM ID P3

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______ Model No. 7410
Year installed 1988 S/N 259 Job # FP-17831

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz Model No. 7630-454 internal mount, two xdcrs/mount

Installation by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☒ Internal
- ☐ Threaded
- ☐ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ______

☐ Intervening material (protective cover) ______ Thickness ______ in.
☒ Cable length varies ft

ACOUSTIC PATH
☐ Diametral ☒ Chordal No. of Paths 8
☒ Crossed Path ☒ Direct ☐ Reflect Is path perpendicular to plane of bend? Yes
Path Angle w/flow path 45° Path length 29 & 17 ft

☒ As-built drawings: Specification Drawings 231-D-779 and 231-D-780

PIPE DATA

Material Steel Liner matl Coal tar Inside. Diameter 21.9920 ft

Wall Thick. 1" Liner Thick. ? Out. Pipe Diameter 22'-2" ft

These distances were difficult to determine from available drawings.
Straight pipe lengths U/S 100 ft D/S 10 ft
Fitting Scroll case Distance 10 ft d/s Fitting ______ Distance ______
Fitting Combined bend Distance 100 ft u/s Fitting ______ Distance ______

Combined bend has a 13° vertical curve and 3.6° horizontal curve.

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ____________ Model No. 7410

Measurement Methods

☒ Unidirectional ☐ Bidirectional
☐ Signal Detection ☐ Noise reduction
☐ Transit-time difference ☐ Frequency difference
☒ Integration tech. ☒ Signal rejection tech.
☐ Signal averaging technique ☐ Automatic Gain Control

Velocity profile correction factor
- ☐ Laboratory Calibration
- ☐ Field Calibration
- ☐ Analytical calculation
- ☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate ________Hz

☒ Excitation: alternates

Are there any known problems with water quality:

☐ Entrained air ☐ Suspended solids ☐ Rapid temperature changes
☐ Pressure changes ☐ Xdcr fouling **Xdcrs cleaned once per year**

Are there any known problems with:

☐ Electrical noise ☐ Acoustical noise ☐ Secondary flows None

DISPLAY AND OUTPUTS

☒ Discharge, units=CFS ☒ Totalized volume, units=AC-FT
☐ Flow direction ☐ Noise reduction
☒ Digital output ☐ Analog output
☒ Performance Alarms ☐ Telemetry, where to none
☒ Data storage: Hard copy of hourly printout ☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow	____________%
Linearity-Max deviation between smooth curve fit and actual flow	____________%
Repeatability-Return to a previous flow after a change in flow	____________%
Stability-Measure of change in accuracy with time	____________%
Resolution-Min change in flow rate required to produce a change in output	____________%
Rangeability-Range of flows which the performance is specified	____________%

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Parker Dam Site Power Penstock AVM ID P4

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______ Model No. 7410
Year installed 1988 S/N 259 Job # FP-17831

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz Model No. 7630-454

Installation by: ☐ Manufacturer ☐ Contractor ☒ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☒ Internal
- ☐ Threaded
- ☐ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ______

☐ Intervening material (protective cover) ______ Thickness ______ in.
☒ Cable length varies ft

ACOUSTIC PATH
☐ Diametral ☒ Chordal No. of Paths 4
☐ Crossed Path ☒ Direct ☐ Reflect Is path perpendicular to plane of bend? Yes
Path Angle w/flow path 45° Path length 17.6 & 29 ft

☒ As-built drawings: SPEC DWG's 231-D-779 & 780

PIPE DATA

Material Steel Liner matl Coal tar Inside. Diameter 21.9880 ft

Wall Thick. 1" Liner Thick. ? Out. Pipe Diameter 22'-2" ft

Straight pipe lengths U/S 140' ft D/S ~10 ft
Fitting Bend Distance 140' v/s Fitting ______ Distance ______
Fitting Scroll Case Distance 10' d/s Fitting ______ Distance ______

Combined bend vert. = 13°, horiz. = 4.6°

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist P4

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ____________ Model No. 7410 ____________

Measurement Methods

☒ Unidirectional ☐ Bidirectional
☐ Signal Detection ☐ Noise reduction
☐ Transit-time difference ☐ Frequency difference
☒ Integration tech. ☒ Signal rejection tech.
☐ Signal averaging technique ☐ Automatic Gain Control

Velocity profile correction factor
☐ Laboratory Calibration
☐ Field Calibration
☐ Analytical calculation
☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate ________Hz

☒ Excitation (simultaneous or alternately)

Are there any known problems with water quality:

☐ Entrained air ☐ Suspended solids ☐ Rapid temperature changes Seasonal 52°-62°F
☐ Pressure changes ☐ Xdcr fouling None

Are there any known problems with:

☐ Electrical noise ☐ Acoustical noise ☐ Secondary flows None

DISPLAY AND OUTPUTS

☒ Discharge, units=CFS ☒ Totalized volume, units=AC-FT
☐ Flow direction ☐ Noise reduction
☒ Digital output ☐ Analog output
☒ Performance Alarms ☐ Telemetry, where to none ______
☒ Data storage: Hard copy ☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow ______________%
Linearity-Max deviation between smooth curve fit and actual flow ______________%
Repeatability-Return to a previous flow after a change in flow ______________%
Stability-Measure of change in accuracy with time ______________%
Resolution-Min change in flow rate required to produce a change in output ______________%
Rangeability-Range of flows which the performance is specified ______________%

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Davis Dam   Site Power Penstock   AVM ID G1

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______   Model No. 7410
Year installed 1989   S/N 241   Job # FP-17739

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz   Model No. 7600

Installation by: ☒ Manufacturer ☐ Contractor ☒ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☐ Internal
- ☐ Threaded
- ☒ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ______

☐ Intervening material (protective cover) ______ Thickness ______ in.
☐ Cable length varies ft

ACOUSTIC PATH

☐ Diametral ☒ Chordal   No. of Paths 4
☐ Crossed Path ☒ Direct ☐ Reflect   Is path perpendicular to plane of bend? No
Path Angle w/flow path 45° & 65°   Path length 17.7 & 23.0 ft

☒ As-built drawings: Specification Drawings 351-D-1104,-1105,-1108

PIPE DATA

Material Steel   Liner matl Coal tar   Inside. Diameter 22.011 ft

Wall Thick. 1"   Liner Thick. ?   Out. Pipe Diameter 22'-2" ft

Straight pipe lengths   U/S 13' ft   D/S ~10' ft
Fitting Scroll case   Distance 10' d/s   Fitting Vertical elbow   Distance 132' u/s
Fitting Bend   Distance 13' u/s   Fitting ______   Distance ______

Combined bend has a 20° vertical curve & 22° horizontal curve

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ____________ Model No. 7410 ____________

Measurement Methods

☒ Unidirectional	☐ Bidirectional
☐ Signal Detection	☐ Noise reduction
☐ Transit-time difference	☐ Frequency difference
☒ Integration tech.	☒ Signal rejection tech.
☐ Signal averaging technique	☐ Automatic Gain Control

Velocity profile correction factor

- ☐ Laboratory Calibration
- ☐ Field Calibration
- ☐ Analytical calculation
- ☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate Unknown ______Hz

☒ Excitation - alternate

Are there any known problems with water quality:

☐ Entrained air	☐ Suspended solids	☐ Rapid temperature changes
☐ Pressure changes	☒ Xdcr fouling: Alkali deposits	

Are there any known problems with:

☒ Electrical noise ☐ Acoustical noise ☒ Secondary flows

From battery charger but this doesn't seem to be a major problem. An asymmetric velocity profile is likely based on model study results

DISPLAY AND OUTPUTS

☒ Discharge, units=ft^3/s	☐ Totalized volume, units=AC-FT
☒ Flow direction	☐ Noise reduction
☒ Digital output	☐ Analog output
☒ Performance Alarms	☐ Telemetry, where to_________
☒ Data storage: Hard copy of hourly data	☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow	______________%
Linearity-Max deviation between smooth curve fit and actual flow	______________%
Repeatability-Return to a previous flow after a change in flow	______________%
Stability-Measure of change in accuracy with time	______________%
Resolution-Min change in flow rate required to produce a change in output	______________%
Rangeability-Range of flows which the performance is specified	______________%

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Davis Dam Site Power Penstock AVM ID G2

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______ Model No. 7410
Year installed 1989 S/N 241 Job # FP-17739

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz Model No. 7600

Installation by: ☒ Manufacturer ☐ Contractor ☒ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☐ Internal
- ☐ Threaded
- ☒ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ______

☐ Intervening material (protective cover) ______ Thickness ______ in.
☐ Cable length varies ft

ACOUSTIC PATH
☐ Diametral ☒ Chordal No. of Paths 4
☐ Crossed Path ☒ Direct ☐ Reflect Is path perpendicular to plane of bend? No
Path Angle w/flow path 45° & 65° Path length 17.7 & 23.0 ft

☒ As-built drawings: Specification Drawings 351-D-1104,-1105,-1108

PIPE DATA

Material Steel Liner matl Coal tar Inside Diameter 22.0086 ft

Wall Thick. 1" Liner Thick. ? Out. Pipe Diameter 22'-2" ft

Straight pipe lengths U/S 27' ft D/S 9' ft
Fitting Scroll case Distance 10 ft d/s Fitting Inlet Distance 240 ft u/s
Fitting Combined Bend Distance 27 ft u/s Fitting ______ Distance ______

Combined bend has a 10° vertical curve & 22° horizontal curve.

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ____________ Model No. 7410 ____________

Measurement Methods

☒ Unidirectional	☐ Bidirectional
☐ Signal Detection	☐ Noise reduction
☐ Transit-time difference	☐ Frequency difference
☒ Integration tech.	☒ Signal rejection tech.
☐ Signal averaging technique	☐ Automatic Gain Control

Velocity profile correction factor

- ☐ Laboratory Calibration
- ☐ Field Calibration
- ☐ Analytical calculation
- ☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate Unknown Hz

☒ Excitation - alternate

Are there any known problems with water quality:

☐ Entrained air	☐ Suspended solids	☐ Rapid temperature changes
☐ Pressure changes	☒ Xdcr fouling: Alkali deposits	

Are there any known problems with:

☒ Electrical noise ☐ Acoustical noise ☒ Secondary flows

From battery charger but this doesn't seem to be a major problem. An asymmetric velocity profile is likely based on model study results

DISPLAY AND OUTPUTS

☒ Discharge, units=ft^3/s	☐ Totalized volume, units=AC-FT
☒ Flow direction	☐ Noise reduction
☒ Digital output	☐ Analog output
☒ Performance Alarms	☐ Telemetry, where to________
☒ Data storage: Hard copy of hourly data	☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow ____________ %
Linearity-Max deviation between smooth curve fit and actual flow ____________ %
Repeatability-Return to a previous flow after a change in flow ____________ %
Stability-Measure of change in accuracy with time ____________ %
Resolution-Min change in flow rate required to produce a change in output ____________ %
Rangeability-Range of flows which the performance is specified ____________ %

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Davis Dam   Site Power Penstock   AVM ID G3

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ____   Model No. 7410
Year installed 1989   S/N 240   Job # FP-17739

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz   Model No. 7600

Installation by: ☒ Manufacturer ☐ Contractor ☒ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☐ Internal
- ☐ Threaded
- ☒ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ____

☐ Intervening material (protective cover) ____   Thickness ____ in.
☐ Cable length varies ft

ACOUSTIC PATH
☐ Diametral ☒ Chordal   No. of Paths 4
☐ Crossed Path ☒ Direct ☐ Reflect   Is path perpendicular to plane of bend? No
Path Angle w/flow path 45° & 65°   Path length 17.9 & 23.0 ft

☒ As-built drawings: Specification Drawings 351-D-1104,-1105,-1108

PIPE DATA

Material Steel   Liner matl Coal tar   Inside. Diameter 22.011 ft

Wall Thick. 1"   Liner Thick. ?   Out. Pipe Diameter 22'-2" ft

Straight pipe lengths U/S 24 ft   D/S 10 ft
Fitting Scroll case   Distance 10 ft d/s   Fitting Inlet   Distance 209' u/s
Fitting Combined Bend   Distance 24 ft u/s   Fitting ____   Distance ____

Combined bend has a 12.5° vertical curve & 22° horizontal curve.

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ____________ Model No. 7410

Measurement Methods

☒ Unidirectional ☐ Bidirectional
☐ Signal Detection ☐ Noise reduction
☐ Transit-time difference ☐ Frequency difference
☒ Integration tech. ☒ Signal rejection tech.
☐ Signal averaging technique ☐ Automatic Gain Control

Velocity profile correction factor
☐ Laboratory Calibration
☐ Field Calibration
☐ Analytical calculation
☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate Unknown _____Hz

☒ Excitation - alternate

Are there any known problems with water quality:

☐ Entrained air ☐ Suspended solids ☐ Rapid temperature changes
☐ Pressure changes ☒ Xdcr fouling: Alkali deposits

Are there any known problems with:

☒ Electrical noise ☐ Acoustical noise ☒ Secondary flows
From battery charger but this doesn't seem to be a major problem. An asymmetric velocity profile is likely based on model study results

DISPLAY AND OUTPUTS

☒ Discharge, units=ft^3/s ☐ Totalized volume, units=AC-FT
☒ Flow direction ☐ Noise reduction
☒ Digital output ☐ Analog output
☒ Performance Alarms ☐ Telemetry, where to________
☒ Data storage: Hard copy of hourly data ☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow _______________%
Linearity-Max deviation between smooth curve fit and actual flow _______________%
Repeatability-Return to a previous flow after a change in flow _______________%
Stability-Measure of change in accuracy with time _______________%
Resolution-Min change in flow rate required to produce a change in output _______________%
Rangeability-Range of flows which the performance is specified _______________%

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Davis Dam   Site Power Penstock   AVM ID G4

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______   Model No. 7410
Year installed 1989   S/N 240   Job # FP-17739

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz   Model No. 7600

Installation by: ☒ Manufacturer ☐ Contractor ☒ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☐ Internal
- ☐ Threaded
- ☒ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ______

☐ Intervening material (protective cover) ______ Thickness ______ in.
☐ Cable length varies ft

ACOUSTIC PATH

☐ Diametral ☒ Chordal   No. of Paths 4
☐ Crossed Path ☒ Direct ☐ Reflect   Is path perpendicular to plane of bend? No
Path Angle w/flow path 45° & 65°   Path length 17.9 & 23.0 ft

☒ As-built drawings: Specification Drawings 351-D-1104,-1105,-1108

PIPE DATA

Material Steel   Liner matl Coal tar   Inside. Diameter 21.9796 ft

Wall Thick. 1"   Liner Thick. ?   Out. Pipe Diameter 22'-2" ft

Straight pipe lengths U/S 30 ft   D/S 10 ft
Fitting Scroll case   Distance 10 ft d/s   Fitting Inlet   Distance 181 ft u/s
Fitting Combined Bend   Distance 30 ft u/s   Fitting ______   Distance ______

Combined bend has a 16.5° vertical curve & 22° horizontal curve

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ____________ Model No. 7410

Measurement Methods

☒ Unidirectional ☐ Bidirectional
☐ Signal Detection ☐ Noise reduction
☐ Transit-time difference ☐ Frequency difference
☒ Integration tech. ☒ Signal rejection tech.
☐ Signal averaging technique ☐ Automatic Gain Control

Velocity profile correction factor
- ☐ Laboratory Calibration
- ☐ Field Calibration
- ☐ Analytical calculation
- ☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate Unknown Hz

☒ Excitation - alternate

Are there any known problems with water quality:

☐ Entrained air ☐ Suspended solids ☐ Rapid temperature changes
☐ Pressure changes ☒ Xdcr fouling: Alkali deposits

Are there any known problems with:

☒ Electrical noise ☐ Acoustical noise ☒ Secondary flows
From battery charger but this doesn't seem to be a major problem. An asymmetric velocity profile is likely based on model study results

DISPLAY AND OUTPUTS

☒ Discharge, units=ft^3/s ☐ Totalized volume, units=AC-FT
☒ Flow direction ☐ Noise reduction
☒ Digital output ☐ Analog output
☒ Performance Alarms ☐ Telemetry, where to_________
☒ Data storage: Hard copy of hourly data ☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow ____________ %
Linearity-Max deviation between smooth curve fit and actual flow ____________ %
Repeatability-Return to a previous flow after a change in flow ____________ %
Stability-Measure of change in accuracy with time ____________ %
Resolution-Min change in flow rate required to produce a change in output ____________ %
Rangeability-Range of flows which the performance is specified ____________ %

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

Location Davis Dam   Site Power Penstock   AVM ID G5

Manufacturer ☒ Accusonic ☐ Stork ☐ Other ______   Model No. 7410
Year installed 1989   S/N 242   Job # FP-17739

SYSTEM TYPE

☐ Non-refractive (acoustic signal crosses liquid/solid interface at 90 deg.)
☒ Refractive system

TRANSDUCER CONSIDERATIONS

Frequency 1 mHz   Model No. 7600

Installation by: ☒ Manufacturer ☐ Contractor ☒ BOR personnel
Surveyed by: ☒ Manufacturer ☐ Contractor ☐ BOR personnel

Transducer mount

☒ Wetted
- ☐ Spool mount
- ☐ Internal
- ☐ Threaded
- ☒ Insert/wet installation
- ☐ Flush mount
- ☒ Protruding mount
- ☐ Recessed (cavity) mount

☐ Non-Wetted
- ☐ Externally
- ☐ Clamp-on
- ☐ Track
  - ☐ Permanent
  - ☐ Portable
  - ☐ Couplant ______

☐ Intervening material (protective cover) ______ Thickness ______ in.
☐ Cable length varies ______ ft

ACOUSTIC PATH

☐ Diametral ☒ Chordal   No. of Paths 8
☒ Crossed Path ☒ Direct ☐ Reflect   Is path perpendicular to plane of bend? No
Path Angle w/flow path 45° & 65°   Path length 17.8 & 23.0 ft

☒ As-built drawings: Specification Drawings 351-D-1104,-1105,-1108

PIPE DATA

Material Steel   Liner matl Coal tar   Inside. Diameter 22.0248 ft

Wall Thick. 1"   Liner Thick. ?   Out. Pipe Diameter 22'-2" ft

Straight pipe lengths U/S 35 ft   D/S 10 ft
Fitting Scroll case   Distance 10 ft d/s   Fitting Inlet   Distance 160' u/s
Fitting Combined Bend   Distance 35 ft u/s   Fitting ______   Distance ______

Combined bend has a 24° vertical curve & 22° horizontal curve

Closed-Conduit Transit-Time Flowmeters

ANSI/ASME MFC-5M-1985 Standard Checklist

SECONDARY DEVICES

Manufacturer ☒ Accusonic ☐ Stork ☐ Other______________ Model No. 7410______________

Measurement Methods

☒ Unidirectional ☐ Bidirectional
☐ Signal Detection ☐ Noise reduction
☐ Transit-time difference ☐ Frequency difference
☒ Integration tech. ☒ Signal rejection tech.
☐ Signal averaging technique ☐ Automatic Gain Control

Velocity profile correction factor
☐ Laboratory Calibration
☐ Field Calibration
☐ Analytical calculation
☒ None

TRANSDUCER OPERATION

Acoustic pulse repetition rate Unknown ____Hz

☒ Excitation - alternate

Are there any known problems with water quality:

☐ Entrained air ☐ Suspended solids ☐ Rapid temperature changes
☐ Pressure changes ☒ Xdcr fouling: Alkali deposits

Are there any known problems with:

☒ Electrical noise ☐ Acoustical noise ☒ Secondary flows
From battery charger but this doesn't seem to be a major problem. An asymmetric velocity profile is likely based on model study results

DISPLAY AND OUTPUTS

☒ Discharge, units=ft^3/s ☐ Totalized volume, units=AC-FT
☒ Flow direction ☐ Noise reduction
☒ Digital output ☐ Analog output
☒ Performance Alarms ☐ Telemetry, where to_________
☒ Data storage: Hard copy of hourly data ☐ Aeration, cavitation

PERFORMANCE PARAMETERS

Accuracy-Max deviation between measured flow and actual flow	______________%
Linearity-Max deviation between smooth curve fit and actual flow	______________%
Repeatability-Return to a previous flow after a change in flow	______________%
Stability-Measure of change in accuracy with time	______________%
Resolution-Min change in flow rate required to produce a change in output	______________%
Rangeability-Range of flows which the performance is specified	______________%

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American Public.