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Laboratory Evaluation of an OTT Acoustic Digital Current Meter and a SonTek Laboratory Acoustic Doppler Velocimeter

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Abstract

Recently, an acoustic current meter known as the OTT* acoustic digital current meter (ADC) was introduced as an alternative instrument for streamgaging measurements. The Bureau of Reclamation and the U.S. Geological Survey collaborated on a side-by-side evaluation of the ADC and a SonTek/YSI acoustic Doppler velocimeter (ADV). Measurements were carried out in a laboratory flume to evaluate the performance characteristics of the ADC under a range of flow and boundary conditions. The flume contained a physical model of a mountain river with a diversion dam and variety of bed materials ranging from smooth mortar to a cobble bed. The instruments were installed on a trolley system that allowed them to be easily moved within the flume while maintaining a consistent probe orientation. More than 50 comparison measurements were made in an effort to verify the manufacturer's performance specifications and to evaluate potential boundary disturbance for near-bed and vertical boundary measurements. Data and results from this evaluation are presented and discussed.

Introduction

Whenever a new instrument is introduced to the market it is good practice to perform independent evaluations of its performance and features before investing resources

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and incorporating the new technology into everyday operations. When the OTT acoustic digital current meter (ADC) was introduced in 2007 (Kamminga, et al., 2007), the Bureau of Reclamation and the U.S. Geological Survey collaborated to evaluate the current meter in Reclamation's hydraulics laboratory in Denver, Colorado. Laboratory tests were conducted to compare ADC measurements to a well known velocimeter, SonTek/YSI's laboratory acoustic Doppler velocimeter (ADV) (Kraus et al., 1994). While OTT had the ADC tested in the tow tank at the WL/Delft Hydraulics Laboratory in the Netherlands, we were interested in the ADC's performance in stream-like conditions. A physical model of a mountain stream created in the hydraulics laboratory was used for this evaluation. The laboratory flume was equipped with an instrumentation trolley that was used to deploy and position the instruments in areas of variable roughness, near boundaries, and at locations with highly turbulent flow. During three days of testing, more than 50 data sets were collected. The results of these tests are summarized in this paper.

The OTT ADC

The ADC is a two-dimensional (2-D) acoustic velocimeter that uses two 6 MHz acoustic transducers to measure velocity in two sampling volumes located 10 to 15 cm in front of the sensor (figure 1). The acoustic beams are angled at ± 10º from the longitudinal axis of the transducer body. The ADC uses pulse-coherent processing techniques to compute streamwise water velocity. The ADC contains an absolute pressure sensor that is used to measure the water depth, which allows the user to set the measurement depth without having to read the depth using the wading rod. The ADC has a temperature sensor to compute the actual velocity of sound in water for each measurement.

The manufacturer's specification on velocity measurement uncertainty is ±1% of measured value ±0.25 cm/sec. The ADC's velocity range is -20 to +240 cm/sec.

The Sontek ADV

A laboratory ADV was used to make comparable velocity measurements in one of the two ADC sampling volumes. The 10 MHz ADV was equipped with a 2-D side-looking probe that was oriented to collect streamwise and transverse velocity components in the same plane as the ADC (figure 2). The sampling volume is located 5 cm to the side of the ADV probe. Since we anticipated making comparison measurements in shallow flows, a 2-D side-looking ADV was selected over a 3-D down-looking ADV because it can measure in depths as shallow as 2 cm.

The manufacturer's specification on velocity measurement uncertainty is the same as the ADC (±1 % of measured value ±0.25 cm/sec). The ADV's velocity range is ±250 cm/sec.

Experimental Setup

Since the ADC and ADV use different sensor configurations (monostatic v. bistatic, respectively) and because the sampling volumes for the two instruments are significantly different, it was not possible to measure the same exact sampling volume concurrently with both velocimeters. As a result, we positioned the ADV's sample volume within the ADC's beam 1 sampling volume (figure 1). The ADV's sample volume was located 12.5 cm from the ADC sensor head and on the inside edge of the sample volume. This probe setup should produce similar velocity measurements provided the two sample volumes are located in an area with a uniform horizontal velocity distribution. Unfortunately, the ADC's 1-sec output data do not contain the beam velocities measured within each acoustic beam, so a direct comparison of the ADC beam 1 velocity with the ADV was not possible. In order to verify the uniformity of the horizontal velocity distribution, one test included a horizontal traverse of the ADC sample volume using the ADV.

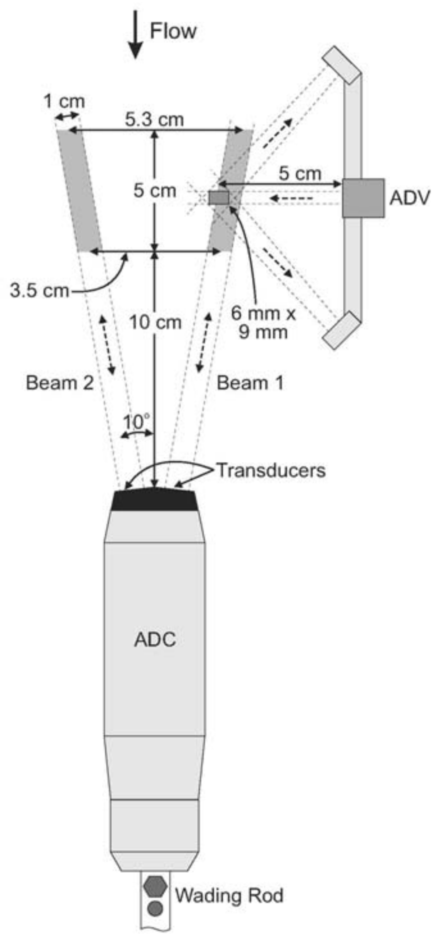

Figure 1. Schematic of the ADC probe and the location of the ADV sampling volume. Note: the ADV sample volume is 5 cm from the ADV probe.

Figure 2. Photograph of ADC and ADV probe configuration in the laboratory flume.

Figure 3. Photograph of the flume used for the ADC-ADV evaluation (looking downstream). Probe locations for the various tests are indicated.

A typical ADC data set was collected for a time period of 210 seconds. The sampling frequency of the ADC is not documented, but a 1 Hz output rate is available, for a sample size of 210. The ADV was configured in burst mode to collect 5000 samples at 25 Hz. Velocities were measured sequentially with one velocimeter powered off to ensure there was no acoustic interference, and with both probes in the water. Several preliminary tests were made to evaluate flow and acoustic disturbance affects from the probe configuration (figures 1 and 2). Two ADC instruments were evaluated to determine any differences between instruments, but the second instrument was not performing within the manufacturer's velocity measurement specification so this comparison was not completed.

Measurement locations were selected to test the ADC's ability to measure in a wide range of flow conditions, including: bed roughness varying from smooth to a cobble bed; a range of velocity magnitudes; near-bed, surface, and bank locations; and in a location with highly three-dimensional flows (figure 3).

An automated laboratory control system was used to deliver uniform, steady flow to the flume. Calibrated Venturi meters were used to measure the volumetric flow rate into the flume. The Venturi meters are regularly calibrated using a weight tank and have an uncertainty of ±0.5 percent.

Evaluation Results

For the 15 tests summarized in table 1, ADC velocities were on average 3.85% higher than ADV-measured velocities. Two of the ADC measurements were lower than comparable ADV measurements. Four measurements fell between the conservative uncertainty range of ±2.0% (figure 4). The reason for this positive bias might be attributed to flow disturbance generated by the ADC probe.

Test no. 30 included an ADV traverse of 9 points within and between the locations of the ADC sample volumes. The ADV measurements confirmed that the velocities were uniformly distributed at this location and flow condition (note: the ADC was removed from the water for these measurements). The average velocity across the ADC sample volume was 0.305 m/sec. Two comparable ADC measurements made before and after the traverse were 0.314 and 0.306 m/sec, respectively.

Vertical velocity profiles were measured by taking velocities at relative depths of 0.2, 0.6, and 0.8D, where D is the total flow depth. In general, the average of these three velocities for each instrument agreed reasonably well. The depth-averaged velocities measured by the ADV were 0.439 (tests 16-18) and 0.808 m/sec (tests 19-21). Comparable depth-averaged ADC velocities were 4.3 and 7.6 percent higher, respectively.

Probe Disturbance - Any probe inserted into flowing water will disturb the flow to some degree. Flow disturbance is also influenced by the probe orientation with respect to the flow attack angle (defined as the angle between the flow direction and the probe's streamwise axis). For this study, we attempted to determine the flow disturbance associated with each velocimeter with minimal attack angle. However, time constraints and the potential for slight changes in probe position with each installation limited the number of flow disturbance measurements collected. ADC flow disturbance was investigated by making measurements with the two probes in place and repeating the measurements with only the ADV in the water. ADV measurements with the ADC in and out of the water for velocities of 0.315 and 0.605 m/sec showed a 3 to 7 percent reduction in ADV-measured streamwise velocity with the ADC probe in the water. For a velocity of 0.959 m/sec, the ADV-only velocity was 4.1 percent faster than with the ADC probe in the water. One explanation for this change may be attributed to changing the ADV velocity range setting from 100 cm/sec to 250 cm/sec (for high velocity tests – nos. 41-50).

A set of three ADC measurements (tests 37-39) with the ADV in and out of the water were within the limits of the ADC's measurement uncertainty of ± 1 percent. Likewise, a review of the ADC's beam 1 and beam 2 backscatter amplitudes for tests with and without the ADV in place did not indicate any side-lobe interference. Based on these results, it was decided that ADC measurements could be made without removing the ADV probe from the water.

Water Temperature - Acoustic velocimetry uses the speed of sound in water to compute velocity from the measured Doppler shift. The speed of sound in water is primarily a function of temperature and salinity. Salinity was set to zero on both instruments because fresh water was used.

A J-type thermocouple was used to collect periodic water temperature measurements in the flume to compare to ADV and ADC measured temperatures. The average thermocouple temperature over the testing period was 17.2° C. The average ADV and ADC measured temperatures were 17.4 and 17.2 ° C, respectively. The ADC temperature was within the manufacturer's specification (±0.5 °C).

Table 1. ADV-ADC velocity comparison data for relative depths varying between 0.2 to 0.8D and with both probes immersed. Vx is defined as the streamwise component of water velocity. Relative depths are taken relative to the total flow depth (D).

Test No.	Relative Depth	ADV Vx- (m/sec)	ADC Vx- (m/sec)	Percent Difference	Comments
8	0.80D	0.557	0.590	5.94	Concrete bed, some cobbles near ADC Beam 1
14	0.80	0.397	0.423	6.35	Repeat 15
16	0.80	0.409	0.422	3.25	Change depth
17	0.60	0.436	0.454	4.12	Change probe depth
18	0.20	0.475	0.500	5.37	Increased channel velocity
19	0.20	0.884	0.928	4.95	Increased channel velocity
20	0.60	0.810	0.853	5.30	Change probe depth
21	0.80	0.728	0.818	12.41	Decreased channel velocity, reduced ADV velocity range from 250 to 100 cm/sec
23	0.80	0.285	0.284	-0.39	Increased flow depth
24	0.60	0.306	0.308	0.65	Change probe depth
25	0.20	0.345	0.360	4.42	Change probe depth
29	0.60	0.308	0.314	1.90	Change probe depth
41	0.60	0.959	0.938	-2.21	New location with rough bed and higher velocity, changed ADV velocity range from 100 to 250 cm/sec
48	0.60	0.648	0.660	1.99	Smooth bed, few cobbles upstream, Low ADC correlation
50	0.55	1.731	1.855	7.13	High velocity in drawdown zone; ADV in same location; very poor data with almost zero SNR and low correlation

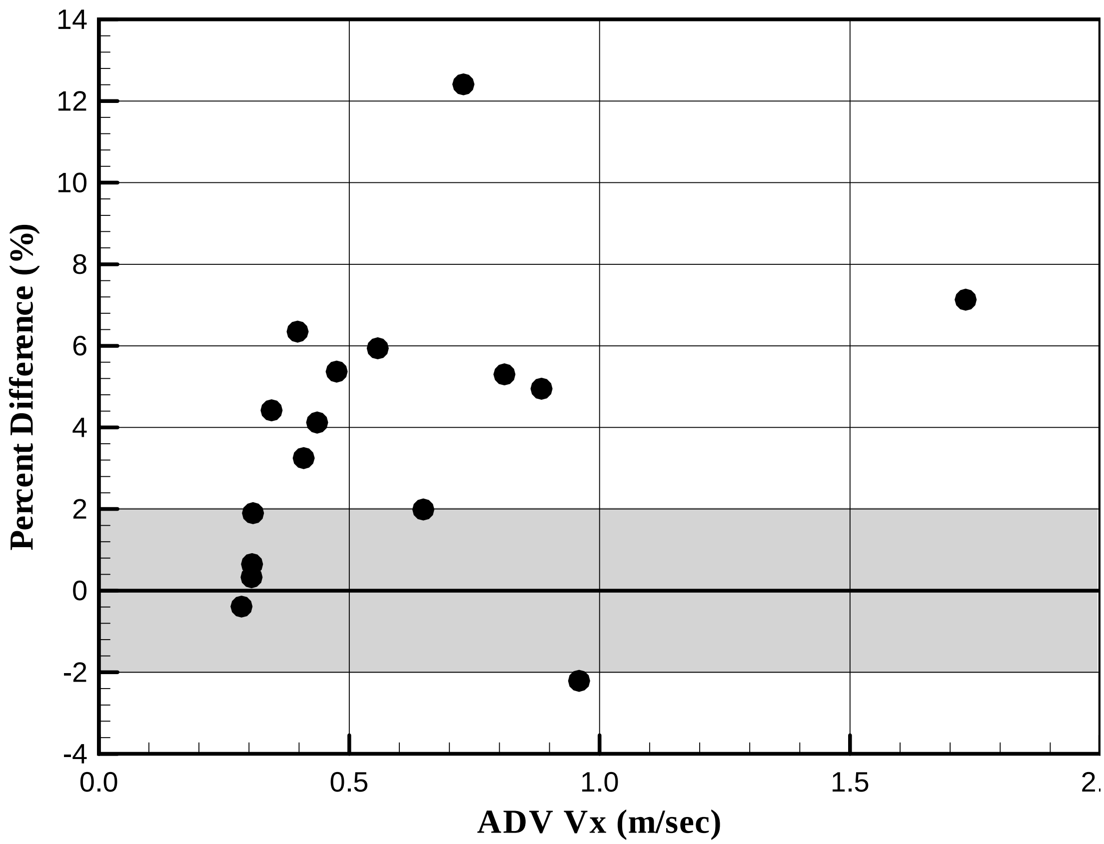

Figure 4. Percent difference between ADC and ADV measured velocities plotted versus ADV streamwise velocity component (Vx). Percent differences outside the ±2 % uncertainty limits (shaded area) are outside the combined manufacturer's specified accuracy limits of ±1%.

Discussion

For the majority of tests, the ADC-measured streamwise velocities were considerably larger than comparable ADV measurements. Attempts to determine if flow disturbance generated by the ADC probe was the source for this bias were not conclusive. Nonintrusive velocity mapping using particle image velocimetry (PIV),laser Doppler velocimetry (LDV), or computational fluid dynamics (CFD) modeling may provide better insight for future investigations.

Tests 37, 38, and 39 at relative depths 0.2, 0.6, 0.8, respectively, were made with only the ADC in the water. The velocities were compared to three similar measurements made with only the ADV in the water. The differences in the streamwise velocities were within the manufacturer's specifications for uncertainty.

Tests to evaluate ADC performance near solid boundaries (i.e. near vertical walls and in shallow water) uncovered some issues with the ADC's internal data screening algorithms. OTT is currently addressing these issues and future testing should be done to complete the evaluation. OTT also plans to publish guidelines on making measurements near boundaries.

The ADC probe appears to create a flow disturbance in its sampling volume that varies with velocity magnitude and presumably with flow attack angle. Like other instruments, it is possible that this disturbance can be corrected via calibration. At this time, it is not known if OTT applies a calibration to correct for the probe's flow disturbance. If such a correction is being applied internally, then this may be the reason the ADC is biased high relative to the ADV when both instruments are in the water. The ADV is not corrected for flow disturbance caused by the ADC and would register a 3 to 7 percent lower velocity due to the ADC flow disturbance based on our measurements

Future Work

This study was designed to evaluate the performance of the OTT ADC for stream like conditions. However, additional questions arose that require further consideration. We propose the following topics for future studies:

- Evaluate the effect of ADC probe flow disturbance in more detail and repeat comparison measurements using a nonintrusive velocity mapping technique.
- Validate manufacturer's recommendations for measurements near vertical boundaries (yet to be released by OTT).
- Determine how close to the bed the ADC can be used to obtain accurate velocity measurements.
- Compare results of this work with field evaluation measurements being collected by the USGS using SonTek's FlowTracker ADV.

References

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