FLOW MEASUREMENT TEST AT G. M. SHRUM POWERPLANT WITH ACOUSTIC SCINTILLATION AND ACOUSTIC TIME-OF-TRAVEL METHODS

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1 Introduction

W. A. C. Bennet dam and G. M. Shrum generating station (GMS) are located on the Peace River in northeastern British Columbia, Canada.

Figure 1: W. A. C. Bennet Dam and G. M. Shrum Generating Station

The dam and power plant were built in the early 1970s. The underground powerhouse has 10 Francis units providing a total of 2730 MW. The net head is 161 m and the penstock diameter is 5 m. Recently, B.C. Hydro (BCH) upgraded 5 units with new turbine runners. Only one of the 5 upgraded units was efficiency tested to meet contract requirements, using an Acoustic Time-of-travel (ATT) flow meter in the penstock. The remaining 4 upgraded units were not tested, as their penstocks were not equipped with ATT flow meters, and the cost of installing them now was considered just as prohibitive as it was in the 1970s (dedicated instrumentation would have had to be installed in each penstock of the 10 units in the plant, consequently only 4 units were equipped with the ATT flow meters).

A recent BCH study (Taylor et al, 2011) compared the cost of turbine efficiency testing at multi-unit plants with ATT, current-meter and acoustic scintillation (AS) methods. Because fully instrumented AS frames can be moved from unit to unit at little extra cost (no unit dewatering, no equipment dismantling and reinstallation), the unit efficiency testing cost with AS was indicated to be less than 50% of the testing cost with ATT if the 4 units were tested consecutively. A consecutive testing of all 10 units would result in even more cost reduction. If only the flow measurement costs are considered, the incremental cost of testing additional units with the AS method would be only about 20% of the same testing cost with the ATT method (Taylor et al, Hydropower & Dams, Issue One, 2012).

BCH is therefore considering using AS for measuring flows at GMS units. It would like to test the remaining 4 upgraded units for potential efficiency differences on the same basis, so that measured data could be used to optimize dispatch from the plant (the potential differences could be even larger among the remaining 5 older units). A 0.2% improvement in plant dispatch at GMS is worth approximately $1.1 million per year.

Before deciding whether or not to proceed with a multi-unit testing program using the AS method, BCH carried out a flow comparison test at the upgraded turbine (Unit 4) that had been previously tested for contract acceptance, as it had an ATT system in place. Although experience from other comparison tests had shown that the two methods usually agreed with each other to within 1%, verification that the AS system could perform accurately at the GMS plant was required, as the flow velocities in the intake and penstock were significantly higher than previously encountered with the AS method. Figure 2 shows the locations of the two instruments at Unit 4.

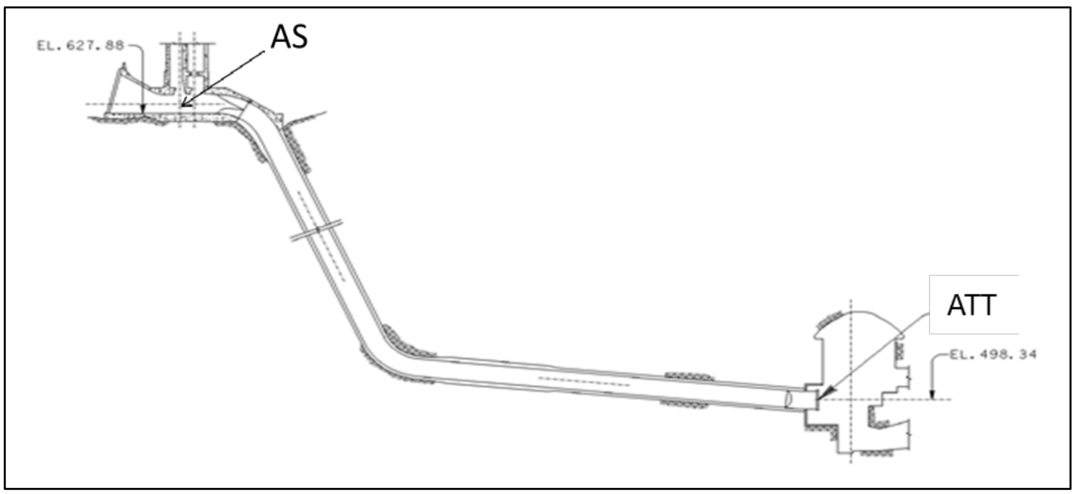

Figure 2: Location of the two methods at Unit 4

2 Acoustic Scintillation Method

The AS method uses a technique called acoustic scintillation drift to measure the flow velocity by utilizing the natural turbulence embedded in the flow (ASL, 2011). Transmitting and receiving transducers are mounted at preselected levels on the opposite sides of a frame inserted in the intake slot and the average velocity is calculated at each of those levels. The discharge through the intake is then computed by integrating the horizontal component of the individual velocities over the cross-sectional area of the intake.

The AS flow meter was installed with 16 fixed acoustic paths mounted on a frame in the maintenance gate slot at Unit 4. Plan and vertical section views of the Unit 4 intake are shown in Figure 3.

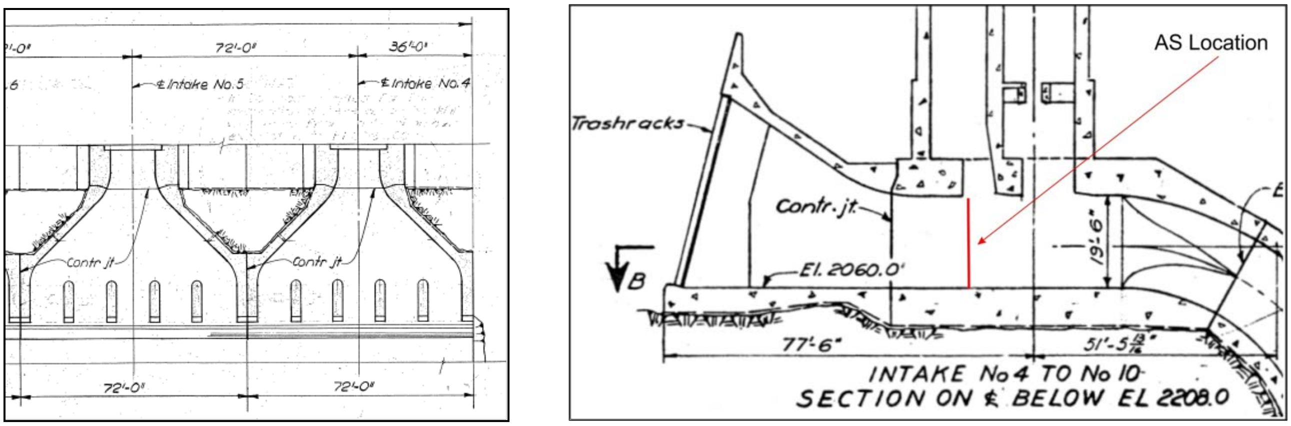

Figure 3: Plan and vertical section of the Unit 4 intake.

The transducers were placed with their faces flush with the sides of the frame so that the full width of the intake was sampled and the transducers were protected from any debris carried along with the flow (Figure 4).

Figure 4 – One side of the AS frame (cross beams holding the two sides together at the top)

The maximum flow velocities at GMS (>7.5 m/s) were beyond the upper limit for the standard configuration of the AS instrument, and therefore the test required modifications to the data collection and processing to maintain accuracy. The sampling rate was increased and the processing to determine time difference was revised.

3 Acoustic Time-of-Travel Method

The ATT system consisted of a Rittmeyer Risonic 2000 flowmeter. The flowmeter transducers were mounted in the penstock just upstream of the spiral case at a location half a pipe diameter downstream of a gradual vertical bend (5°43’). The diameter there is 4.897m. The transducers were installed in 2 planes with 4 horizontal paths each. The paths are oriented at nominally 65° to the penstock axis. Two planes are required to eliminate errors due to non-axial flow in the penstock. Scaling for the flowmeter is based on as-built measurements of path angle, path length, and length of protrusion of the transducers into the flow. The time of travel of a 1 MHz acoustic pulse between two transducer faces is measured in the upstream and downstream directions. The difference in the times of travel is a measure of the axial velocity superimposed on that path. After determining the axial velocity at all four paths in a plane the velocities are integrated vertically into flow using the Gauss Legendre formulation. The calculated flow in each plane is then averaged to determine the flow in the penstock.

4 Test Procedure

The flow comparisons were carried out in conjunction with other engineering tests being performed on the turbine. Repeat measurements were done at three different flows, with nominal power outputs of 185, 230 and 275 MW. Measurements were also made at other flows, when the engineering test program presented opportunities to do so; however repeat measurements could not usually be accommodated.

The comparisons were conducted as a blind test for the AS method. BCH personnel filled the role of Chief of Test and operated the ATT instrument. The AS flows were reported to the Chief of Test, but the ATT data were not shared with the AS team until after the test results were finalized. During the test, the AS team was to be notified if flow discrepancies were present that might indicate an AS malfunction.

The duration of the test at each setting was 20 minutes, during which time data were collected simultaneously on both flowmeters

5 Discharge Computations

The AS flow meter measures the lateral average of the component of velocity normal to the measurement path. The accuracy of the measurement depends on the sampling levels being placed properly to resolve the variation of the horizontal velocity with elevation; 16 paths were used in this case to ensure that any such variations were fully resolved.

The measured points do not extend all the way to the intake roof and floor; as a result, complete evaluation of the integral requires an evaluation of the flow in the zones next to those boundaries. In the field, the AS test team was notified that a discrepancy existed between the two discharge methods, but with no other information. The field results were reviewed after completion of the tests but before the final results were submitted. No changes were made to the measured velocity data, but the values used for the intake geometry and the boundary layer flow estimates were modified as follows:

BCH was able to provide better drawings of the intake at the conclusion of the test, which showed that the roof elevation at the downstream edge of the stoplog slot was 10 cm higher than the upstream edge (Figure 3). The measurement plane is located approximately 13 cm downstream of the upstream edge of the slot and the velocity will not be zero in the measurement plane at the elevation of the upstream edge (5.944 m) since there is no physical boundary in the measurement plane in the roof region and the flow will expand into the open gate slot. It was assumed that the expansion of the flow into the slot would initially follow a steeper trajectory than the straight line joining the upstream and downstream roof edges, and therefore the roof elevation was increased by 2.5 cm (to 5.970 m) to account for this expansion of the flow into the gate slot. Re-computing with the roof elevation adjustment resulted in increasing the AS flows by 0.4%.

The boundary layer forms had been initially set to the same shape and thickness as had been used at the 2009 comparisons at Kootenay Canal (Almquist et al, 2011), however during the review it was realized that the very strong horizontal contraction of the intake (5:1) and the resulting high acceleration of the flow would significantly reduce the boundary layer thickness. The boundary layer recalculations were based on the method of calculation of general two-dimensional boundary layers presented by Schlichting (1958) and applied to aerofoil boundary layers, with the displacement thickness converted to a physical boundary layer thickness using a velocity distribution (Taylor et al, 2016). Re-computing the discharges with the modified boundary layers increased the AS flows by 0.8%.

With the 0.4% increase from the adjustment to the roof elevation the total AS flow has increased by 1.2%.

6 Flow Comparisons

Table 1 shows the discharges from each instrument for all of the measurement conditions, while Figure 5 shows the results for the three settings at which repeat runs were made.

Test	Nominal MW	AS Flow cumecs	ATT Flow cumecs	% Difference (AS-ATT)/ATT*100
1	70	59.6	60.2	-1.0
2	93	73.5	74.0	-0.7
3	165	112.0	113.0	-0.9
4	186	122.0	123.2	-1.0
5	210	137.2	138.3	-0.8
6	230	149.2	150.4	-0.8
7	275	175.8	178.1	-1.3
8	185	122.0	123.0	-0.8
9	230	148.2	149.4	-0.8
10	190	124.4	125.4	-0.8
11	276	176.6	178.5	-1.1
12	276	176.6	178.5	-1.1
13	276	176.5	178.4	-1.1
14	230	148.8	149.7	-0.6
15	185	122.0	122.8	-0.7
16	185	122.4	122.8	-0.3
Average Difference, %				**-0.9**
Standard Deviation of Difference, %				**0.2**

Table 1: Comparison of discharges for AS and ATT instruments, all conditions

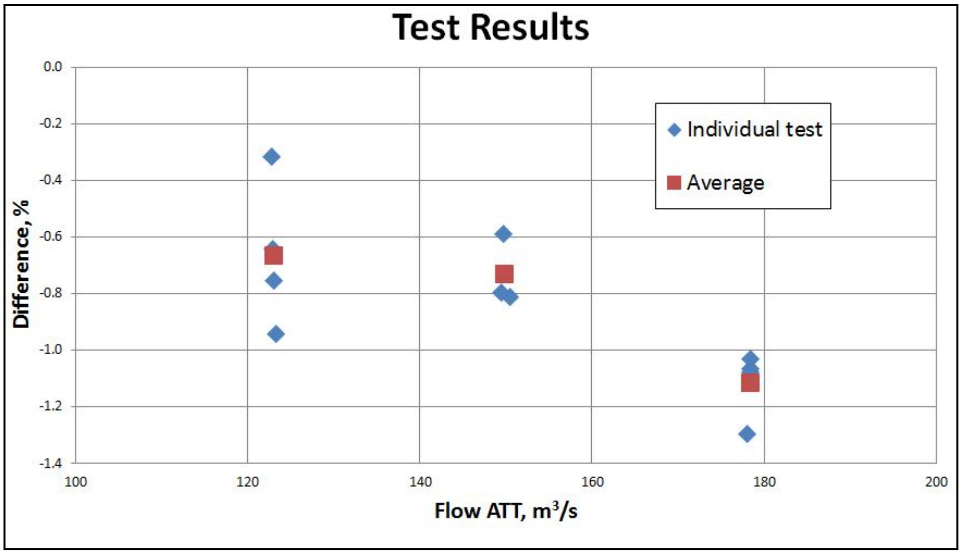

Figure 5: Average and individual differences between AS and ATT flows at each repeat setting.

The difference between the average discharges at each repeat setting is nearly constant at -0.7% for the two lower settings, but increases to -1.1% at the highest flow condition, however the scatter in the difference is greatest at the lowest flow.

The variability of the flow measured by each instrument is similar at the two lower flows and slightly larger for AS at the highest flow. A plot of the deviation of the flow from the average at each repeat condition in Figure 6 shows that the majority of the variability for each method is from changes in the flow conditions, as they largely track each other from one repeat to the next (less so at the 185 MW setting). More details of the statistics of the flows measured by the two instruments are provided in Taylor et al, 2016.

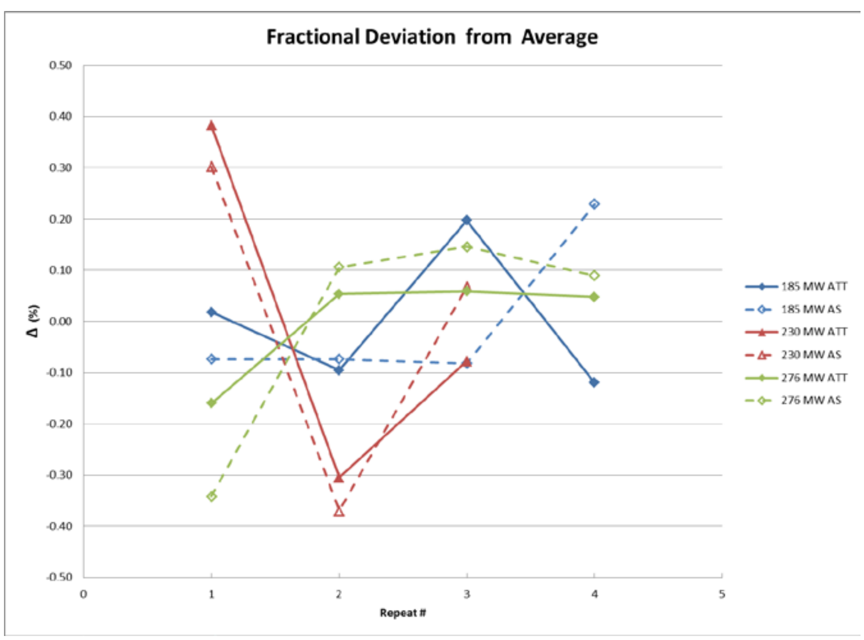

Figure 6: Fractional difference from the average flow for each repeat setting, AS and ATT.

7 Uncertainties of the two methods

The estimated uncertainty of the ATT method is ±1% when installed and operated in accordance with the requirements of the ASME PTC-18 Code (ASME, 2011). The difference between the AS and ATT flows ranged from -0.3% to -1.1%, with an average value of -0.9%.

The significance of the difference between the two methods may be evaluated through the normalized error, which is a means for assessing whether two measurements, both of which have associated errors, differ in a statistically significant sense (IEC, 2005). If, as is the case here, the error associated with one method is better known than the other, it affords a way to estimate the less well-known error.

Here, we may define the normalized error, E_n, as

$$E_n = \Delta Q/(U^2_{AS} + U^2_{ATT})^{½}$$

If $|E_n| < 1$, then the two measurements are not significantly different. If we assume that U_{AS} is also ±1%, then E_n ranges from 0.2 for the minimum ΔQ of 0.3%, to 0.8 for the maximum ΔQ of 1.1%, and is 0.6 for the average ΔQ of 0.9%. The conclusion may therefore be drawn that the flows measured with AS in the intake are not significantly different from those measured by the ATT in the penstock, and have an uncertainty of no more than ±1%.

Since the geometry and velocity profiles for all GMS turbine intakes are the same, the systematic component of the AS uncertainty measurement will also be the same. This means that the uncertainty in differences between units will depend largely on the random error, which for this test was indicated to be less than 0.5% of flow measured. As variations in measured flow are usually accompanied by corresponding changes in measured power and as the number of repeats can be increased, random errors in calculated efficiency (power/flow) should be much smaller than for flow, probably approaching ±0.2%.

8 Conclusions

The comparison test indicated that the measurement uncertainty of the AS method is comparable to the uncertainty of the ATT method at ±1.0%. The test further indicated that the anticipated uncertainty of the AS measurement at the GMS units could be as low as 0.2%. That is certainly sufficiently accurate for the dispatch optimization.

The test also confirmed the assumptions about the cost-effectiveness of the AS method in multi-unit power plants made in the 2011 BCH study (Taylor et al, 2012).

The test thus confirms that BCH is in a position to take advantage of the accuracy, repeatability and cost-effectiveness of the AS method for multi-unit testing at GMS.

Acknowledgements

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