A Report of
Acoustic Transit Time Accuracy Field Work
Performed In
North America
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Flowrate Measurement Background

The use of multiple path acoustic transit time flowmeters has gained acceptance for turbine performance testing and hydroelectric plant optimization in applications world wide. Transit time meters take advantage of the influence the water velocity has on the arrival time of an acoustic pulse as it propagates either upstream or downstream along a path at a known angle to flow. As the acoustic pulse propagates downstream the pulse arrival time is shortened by the velocity of the water. The same principle is true for the pulse as it is propagated upstream against flow which retards the arrival time of the acoustic pulse. The difference between the upstream and downstream arrival time directly corresponds the spatial averaged axial velocity at the elevation of the acoustic path.

In North America, turbine acceptance applications typically use16 acoustic transducers to form 8 acoustic paths that are positioned in the penstock as recommended in turbine performance test codes. Once the acoustic paths are installed several parameters are measured that calibrate the acoustic flowmeter. The acoustic path elevations, angles and lengths are measured once installed. Bounds can be placed on path and measurement geometry but the integration uncertainty has always been a source of heated debate.

To investigate the integration uncertainty several field tests involving additional acoustic paths have been performed in several penstocks in the 6 meter diameter range. The Chebvyshev numerical integration technique consists of sinusoidal functions that determine path spacing. Additional paths can be chosen such that the spacing of the additional paths can be directly compared to the ASME PTC –18 2002 code accepted paths spacing. Flowrates based on the higher numbers of acoustic paths can be compared with the flowrates based on the ASME PTC-18 1992 and IEC 60041 path spacing. In this way a bounds on the numerical integration technique can be obtained.

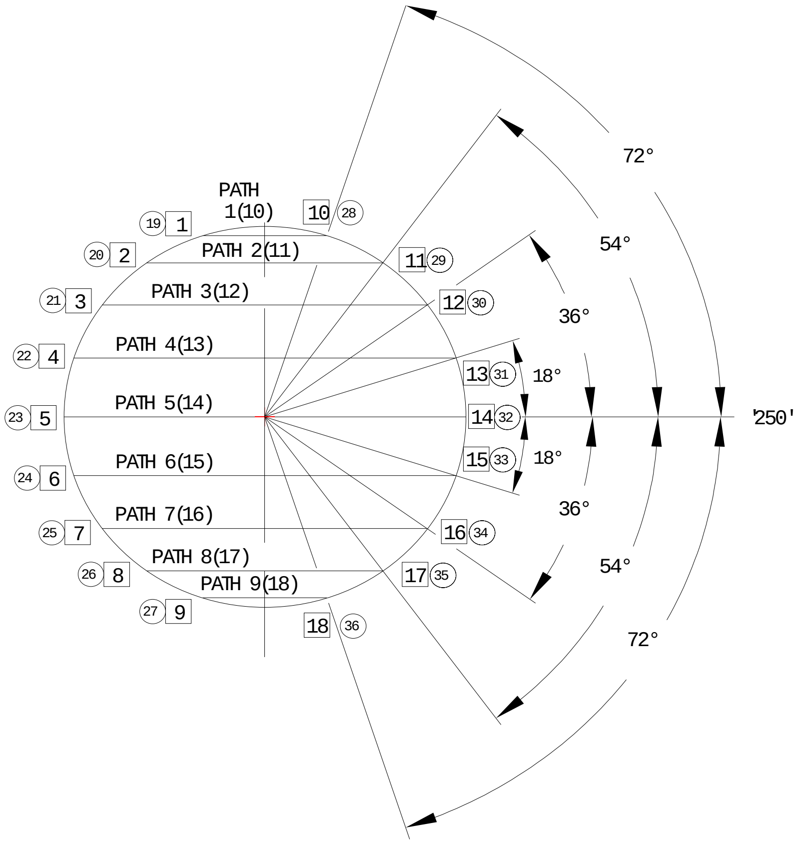
Flowrate tests at three separate power plants are discussed here. The plants are:

- Robert Moses in New York -- owned and operated by New York Power Authority
- La-Forge power Plant in Quebec – owned and operated by Hydro Quebec
- Hiawasse Power Plant in Tennessee -- owned and operated by Tennessee Valley Authority

Comparison of 8 / 18 path data

At most turbine performance tests in North America, the units are fitted with standard 8 path measurement sections. In unit 13 at Robert Moses an 18-path system (9 chordal paths in two crossed planes) was installed in April of 1994. The end-view arrangement of the 18-path system is shown in Figure 1. All meter sections (e.g. transducer locations) are installed 2 diameters downstream from an elbow (as shown in figure 2). The 18-path meter section has additional paths located on the diameter, and in between the standard path locations and is described below (see figure 1).

Figure 1 - End view of 18-path meter section showing chord elevations



In all cases the elevation of the 9 paths was determined by the same integration technique. Nine paths were chosen since 4 of the 9 elevations corresponded to the standard 4 path elevations as shown in figure 1. This is due to the sinusoidal function for path spacing. This arrangement allows direct comparison of the 4-path measurement with the 9-path measurement. This arrangement is also included in the new ASME code which is now available.

On most hydroelectric units, two symmetrically crossed planes each having 4 horizontal acoustic paths are positioned in the penstock such that a nominal acoustic path angle of 65 or 45 degrees is made with respect to the penstock centerline. The acoustic paths in each plane are positioned at 4 chords in the penstock at locations corresponding to normalized elevations of +/- 0.309 * R and +/- 0.809 * R (where R is the penstock radius). This can also be described as angles of +/-18 and 54 degrees with respect to the horizontal centerline elevation of the penstock. The elevations and weights of the acoustic paths are determined by the Gauss-Chebyshev numerical integration technique. This flowrate measurement technique is in the international and American codes for turbine performance testing that specifies the path elevations and numerical integration weighting coefficients (IEC Publication 41-1991 and ASME PTC -18 - 2003).

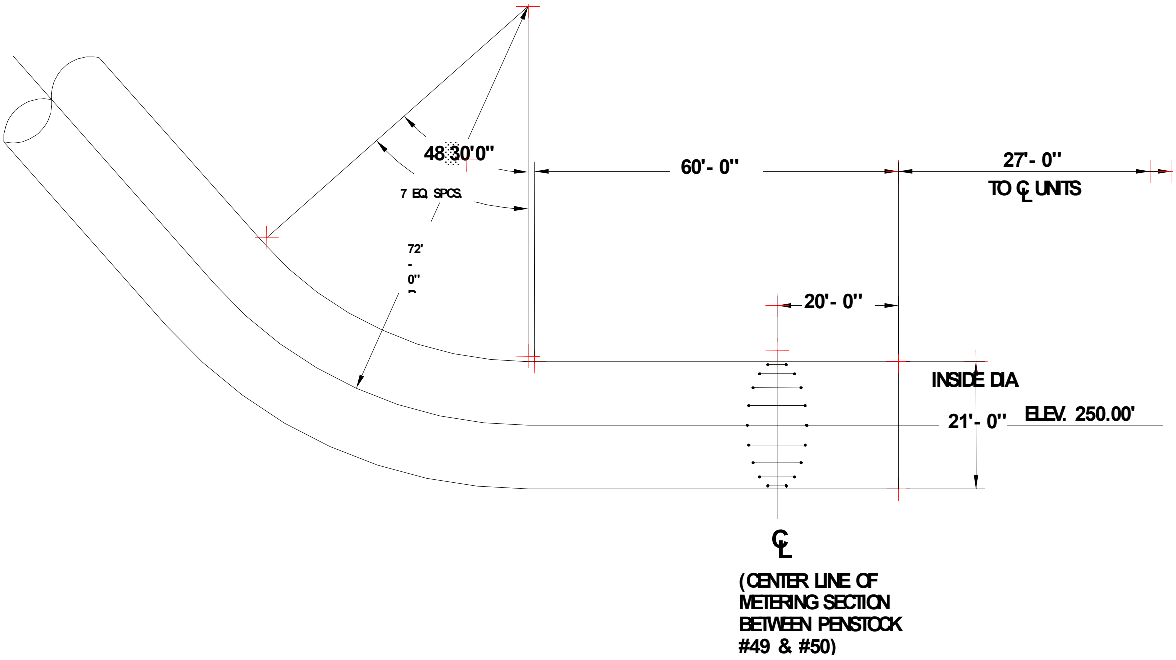
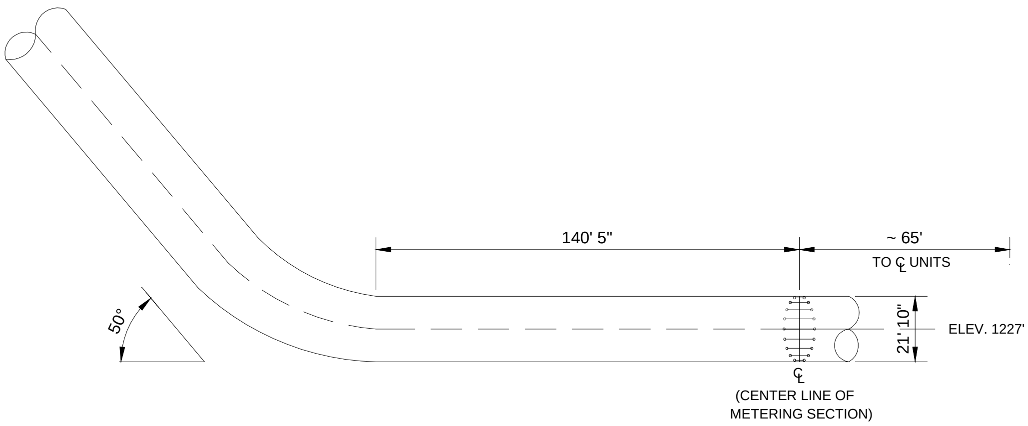


Figure 2 - Meter section location Robert Moses Power Plant

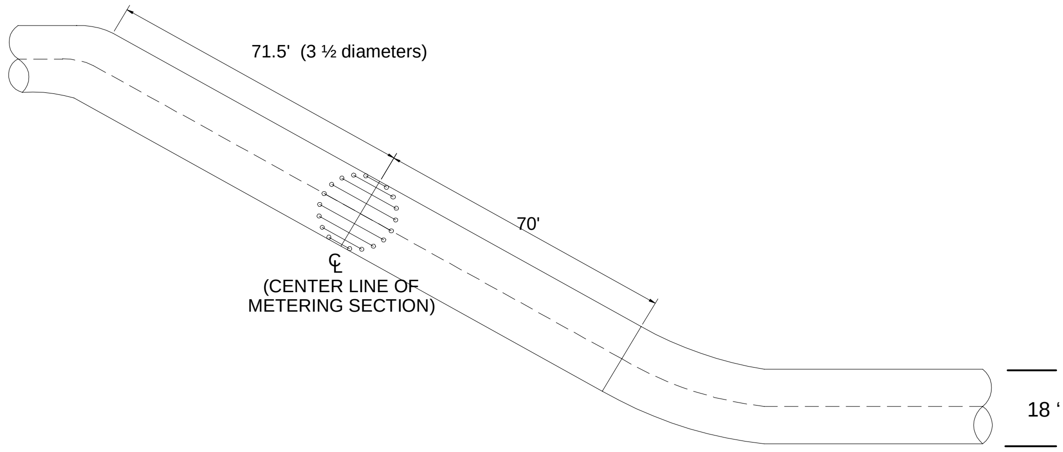
At all power plants, turbine discharge tests were run concurrently with a turbine performance acceptance test. At Robert Moses Power Plant, the flowmeter section was placed in a convergent section just 2 diameters downstream from a hydraulically smooth elbow as shown above.

Figure 3 - Meter section location LaForge Power Plant



At La-Forge Power Plant, the flowmeter was installed in accordance with figure 3 in a 22-foot diameter penstock 7 diameters downstream from a hydraulically smooth elbow. The comparative data shows no significant statistical difference between the 18 and 8 path measurement techniques.

Figure 4 Location of meter section at Hiawasse



At TVA Hiawasse Pump Storage Plant, the flowmeter was installed in accordance with Figure 4 in 18-foot diameter penstock 3.5 diameters downstream from a hydraulically smooth elbow. The main purpose of installing an 18-path meter was to assess the pump and turbine discharge under less than ideal hydraulic conditions.

Uncertainty

In any field measurement test there are always two categories of uncertainty. The bias, which influences the absolute results of the test, can usually have uncertainties assigned. There are also random measurement uncertainties, which are usually characterized by the repeatability representing the variations in the measurement and the hydraulic phenomena, which do not and are not expected to agree.

Bias errors resulting from the installation of transducers and their effects on accuracy in flowrate measurements have been quantified[1] and generally are in the 0.1 % range. Since the transducers comprising the eight and eighteen path meters are installed in the same section of penstock, the penstock radius bias is the same and cancels in both comparative discharge measurements. The differences in the weighted path uncertainties among the 8 and 18 path length and angle measurements are negligible. This is because the length and angle uncertainties are in the 0.05 to 0.1% ranges. Therefore, the remaining uncertainties in flowrate measurement are random and integration uncertainties. The data presented is the difference between the eight and eighteen path method of flowrate integration. The integration uncertainty has been the subject of debate among various flowmeter manufacturers, utilities, and turbine suppliers. Prior to installing the eighteen-path flowmeter, several discussions between Accusonic and NYPA, Hydro Quebec and TVA were held to address the integration

[1]Voser, Alex CFD calculations of protrusion effects, IGHEM Proceedings, Montreal 1996. Walsh et.al Acoustic Transducer and conduit protrusion, IGHEM Proceedsing, Reno, 1998.

uncertainty when the velocity distribution is skewed downstream from a bend. Skewed velocity distributions that take on forms that may be other than logarithmic, similar to profiles observed at Robert Moses, were analyzed. A bound on the uncertainly of the integration technique was placed on the 8- path flowmeter and is described below.

Field Data

Robert Moses

Presented in Figure 5 is the data from the first 60 runs performed at Robert Moses Power Plant Unit 13. This data was collected concurrent with a contractual performance test. Figure 5 shows the differences between the 18 and 8 path flowmeters as a function of flowrate indicating that there is no bias that is time varying.   On average, the 18-path derived flowrate is 0.9% lower than the 8 path flowrate.

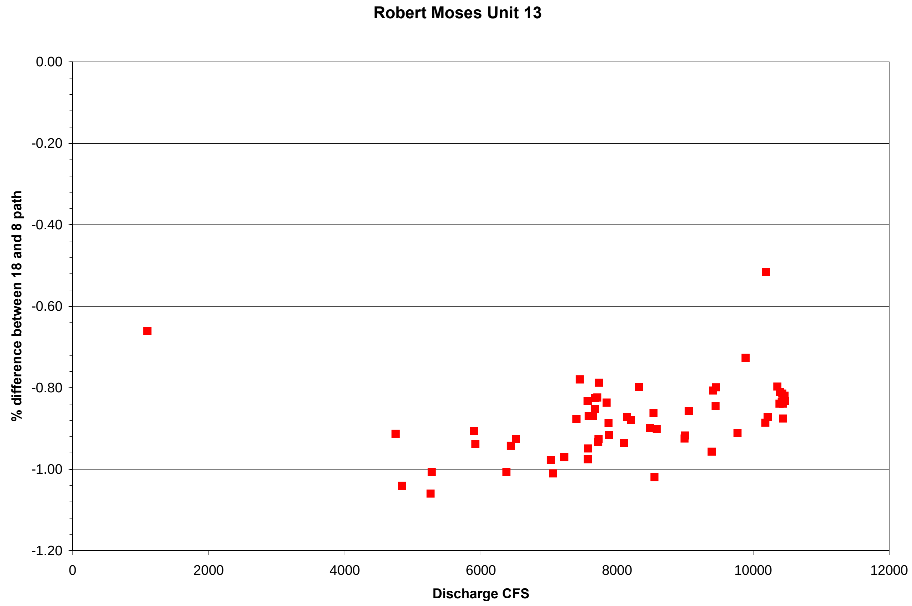
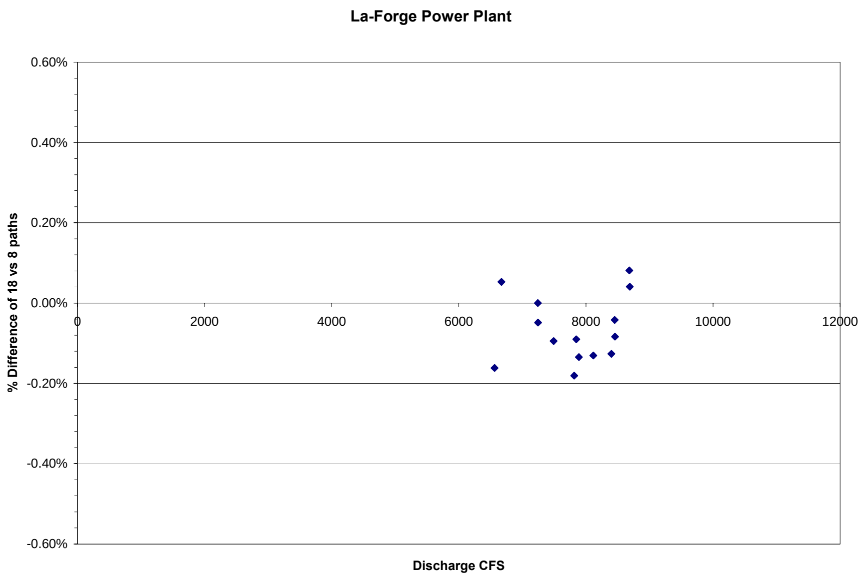


Figure 5 Robert Moses Data

LaForge

Presented in Figure 6 is the data from La-Forge Power Plant. This data was also conducted concurrently with a contractual performance test. On average the data shows no statistically significant difference (<0.1%) between the 18 and 8 path data.

Figure 6 – Flow data from La-Forge



Hiawasse

Presented in Figure 7 is the turbine discharge data from Hiawasse Power Plant. This chart shows an average difference between the 18-path flow and the 8-path flow of less than 0.1%; however, there seems to be a second order effect in the difference between both the 18-path and 8-that varies with discharge or has second order time-varying components. The variation of the difference between discharge as a function of discharge is may be due to the relatively short time interval for acquiring data. The pump data shows a fixed bias of -0.6%.

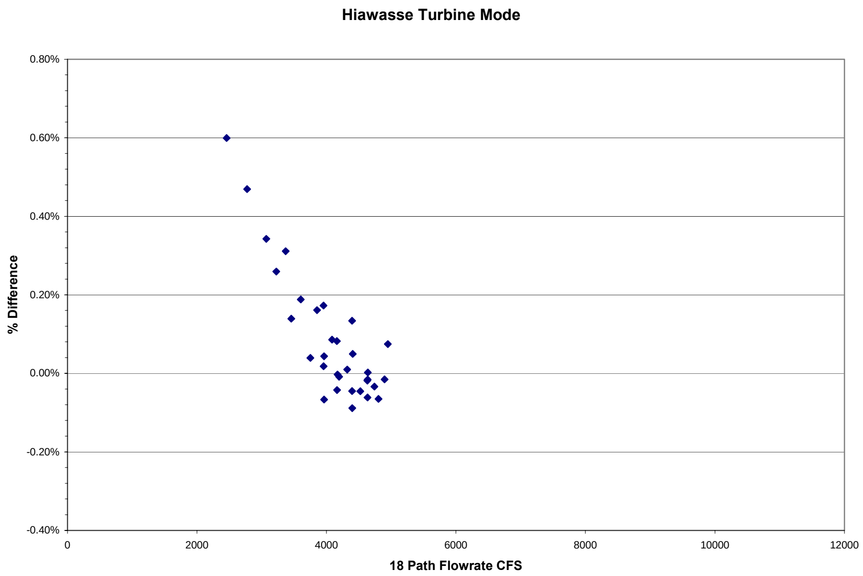


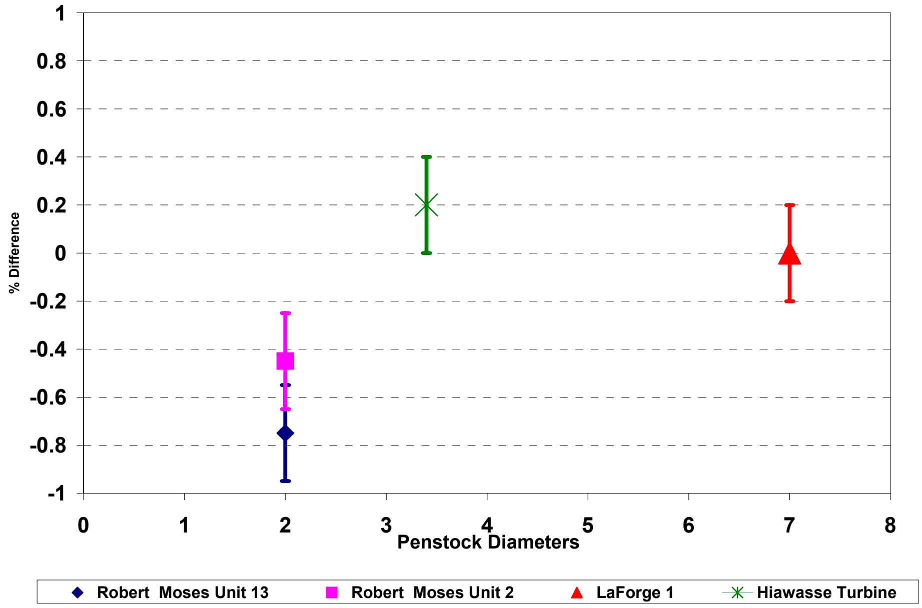
Figure 7 -Turbine discharge data

Results and Conclusions

It has been shown that there is a difference between the 18-path and 8-path acoustic flowmeter 2 diameters downstream from the elbow at Robert Moses. This is chiefly due to a velocity deficit that was found in the upper half section of the penstock. This is discussed in more detail[2] in a separate report furnished to New York Power Authority.

At Hiawasse, the velocity distribution in the turbine mode looked similar to the velocity distribution at Robert Moses but the velocity deficit, was not as extensive. Clearly, the less pretreated velocity profile is due to increased length between the upstream bend and the meter section. In the turbine mode of operation, the meter section is nearly twice the distance from a bend as compared to Robert Moses. Since there are 3 ½ penstock diameters between the meter section and the elbow, one expects a smoother velocity distribution. The effect of secondary flow fields tends to perturbate the flow and will bias flowrate integration, particularly when placed in close proximity to an elbow.

At La-Forge the 18-path flowmeter is located 7 penstock diameters away from an elbow. The testing results suggest that an 8-path acoustic flowmeter is highly accurate when placed sufficiently downstream (> 7 diameters) from a disturbance.



In a separate analysis, a hypothetical velocity distribution was used to analyze the sensitivity of the 18-path (9 chord) numerical integration technique[3]. This analysis was performed and compared to the 36-path (19 chord) integration technique. The results of this analysis indicate that the 18-path (9 chord) integration error has an upper limit of 0.1% uncertainty under highly perturbated velocity distributions.

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[2] Walsh Performance of 18 path Acoustic Flowmeters at Robert Moses Niagara, **Brazil ICM 2002**

[3] Internal Turbine Performance Test Reports by Walsh

We can deduce from the information above that the integration uncertainty varies with the distance the meter is located downstream from an elbow or disturbance. Based on the field testing we can state when an 8-path acoustic flowmeter is located:

- Two diameters downstream from a bend the integration uncertainty will range from 0.8 to 1%.

- Four diameters downstream from a bend the integration uncertainty will range from 0.2 to 0.5 %

- Seven or more diameters downstream from a bend the integration uncertainty will be 0.1% or less

Several years have passed since the adoption of the acoustic method in PTC-18 in North America. The author and others in the industry do not understand why the IEC fails to recognize the multipath acoustic travel time meter as a primary method of measurement.