Hydro-Québec Experience with Discharge Measurement in Short Converging Intake

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Presented at HydroVision 2011

ABSTRACT

Hydro-Québec performs discharge measurement for its low head power plants with the Current Meter method since a long time. Most of these measurements are done in short converging intake. The test procedure developed in the last fifteen years allows the measurement to be done in a short period of time compared to what was used before. The discharge measurement is made for commissioning or for plant operation.

Hydro-Québec has done a discharge measurement with the Acoustic Scintillation method for the first time in 1997. The results of this method were compared with the Current Meter measurements done in the intake. Since the results were encouraging, Hydro-Québec has done comparative tests between these two methods in four other power plants in order to evaluate the accuracy of the Acoustic Scintillation method for absolute discharge measurement. More recently, a comparative tests have been done between the AS method and the Pressure-time method.

The Acoustic Scintillation measurement is done by installing the transducers on the frame that supports the current meters. This has the advantage of reducing the cost and the time of the tests..

Introduction

Low head power plants represent a large part of the new and existing plant in North America. To perform the efficiency test, the measurement of the discharge in these power plant is difficult to perform with a good accuracy because the intake is normally very short, converging, with no usable length of penstock (Figure 1) to perform measurement that meet the standard of the ASME PTC-18 or IEC 60041 test codes. Performance test teams may use the Current Meter method but this often requires a large set up with a large amount of current meters. The measurement can be made with a fix frame supporting the current meters or a mobile frame supporting fewer current meters installed in the maintenance gate slot at a number of elevations to well define the velocity profile.

ASME PTC-18 revision committee has started a project sponsored by CEATI in order to compare the results of three methods that can be used for discharge measurement in intake with a reference method. The Current Meter method is well known for measurement in penstock and is used for a long time by some Utilities and test teams. The Acoustic Transit Time used for penstock measurement has been tested few times for intake measurement. Finally, the Acoustic Scintillation method developed since the last two decade is tested regularly for low head power plant.

This paper describes the Hydro-Québec experience of discharge measurement in low head short converging intake power plant. It also shows the results of many comparative tests done between the Current Meter and the Acoustic Scintillation methods.

Current Meter Set Up for in intake gate slot measurement

For the Current Meter measurement method, the discharge is obtain by integrating the velocity profile sampled at a number of points using the following equation:

$$Q = \int^{H} \int^{L} v(x, y) \bullet \cos(\alpha(x, y)) \partial x \partial y$$

where :

$v(x, y)$: *velocity profile*

$\alpha(x, y)$: *flow angle normal to the measurement section*

H : *height of the section*

L : *witdth of the section*

The method used by Hydro-Québec for performing the discharge measurement in intake gate slot is to use a trolley on which a number of current meters are mounted on (Figure 2). This method has the advantage of requiring a very short unit downtime in the order of half to one day. It also allows the velocity profile to be sampled for the entire height of the intake bay, from around 10 cm above the floor to the ceiling.

A typical trolley is made of two horizontal profiled rods attached to two end plates and steel cables for increasing the stiffness. Steel wheels help guiding laterally and longitudinally the trolley in the gate slot. The profiled rods have a low drag coefficient of less than 0.1 and have the same profile that the one used for the calibration of the current meters. For the typical measurement section width (less than 7m), it is possible to avoid building a frame with lot of reinforcement and help to maintain a low blockage effect of the trolley.

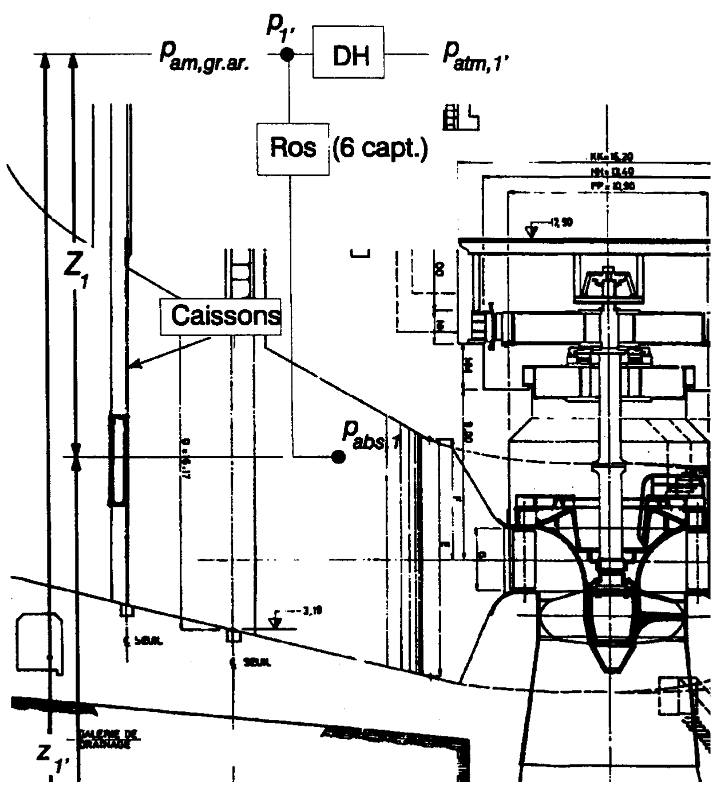

Figure 1 - Typical intake cross section of a recent low head power plant

This blockage is normally less than 2% of the measurement section area.

The trolleys (on in each bay) are move by using two independent chain hoists synchronized by a variable frequency power drive. Their positions are measured by a linear transducer.

Figure 2. Frame supporting the Acoustic Scintillation transducers and current meters trolley (rigth) and chain hoists (left).

The current meters are set horizontally on the lower rod. The types of current meter used are self compensating Ott type A or type R that read directly the component of the velocity vector normal to the measurement section. According to the manufacturer of the current meters, the uncertainty of the measured normal component of the velocity is less than 1% for angle up to 45^{o} (15^{o} for type R) between the current meter axis and the velocity vector.

Another method for the velocity profile measurement is to first determine the flow angle by using a mechanism that change the horizontal angle of the current meter axis according to the local flow angle [1][2][3], which can vary largely in the measurement section. The mechanism is also used to determine the flow angle by using the property of the current meter that read lower velocity when it is not perfectly align with the flow. This method requires additional measurement instrument (angle transducer) and need a lot more analysis time. At the end, the measurement uncertainty is not better than with the self compensating current meters.

The electrical signal of the current meters is provided by an in-house developed electronic circuit that allows the direction of rotation of the propeller to be detected. For short converging intake measurement, it is of particular importance since under some circumstances, the flow can be locally highly distorted and even reversed.

Data recording

The data acquisition software developed by Hydro-Québec allows recording the instantaneous rotational velocity of each current meter, i.e. it records the time stamp of each revolution and the rotational velocity itself. A negative value indicates a reverse flow. The displacement transducers signal that measures the trolley elevation is recorded at 100 sample/s.

Figure 3 - Current Meter measurement Set up in a Penstock.

The primary velocity profile exploration method used for most of the test at Hydro-Québec is the Profiling method (Pr). This method consists in continuously measuring the velocity of the current meters while the trolley is slowly moving, whether up or down (see [4][5][6] for more details). Because the current meters are moving during the measurement, the traveling velocity is kept very low. ISO 3354 [18] recommends this traveling velocity to be less than 5 % of the mean flow velocity. For a large measurement section, Hydro- Québec uses a velocity of 27 mm/s, which gives the possibility to measure to as low as 0.5 m/s. The recoding time is in the order of 15 min. With this method, the velocity profile was sampled over the entire height ; so there is virtually no vertical sampling uncertainty. For each test, at three to four different discharges, the measurement is repeated to assess the effect of the travelling direction. This effect is generally less than 0.1%. Once the rotational velocities are recorded, it is easy to calculate the mean value for different time intervals. Typically, the recording is divided in 100 subintervals for which the mean rotational velocities and current meters elevations are calculated.

A second method is sometimes used by setting the trolley at a number of fixed elevations (FE method). At Kootenay Canal Power plant [10], twenty predetermined elevations were used that was more closely spaced at the bottom and at the top in order to better define the velocity profile in this area. The current meters were maintained for 30 seconds at each elevation. With 14 current meters on the lower rods, the velocity profile was sampled with 280 points. As a reference, the IEC 60041 [5] test code recommends 25 sample points for a fully developed flow in a rectangular section and between 80 and 120 if the velocity profile is not uniform.

Current Meter Set Up for Measurement in Penstock

It is sometimes impossible to use a trolley in the gate slot for the discharge measurement. An optional method that can be used is to install a fixed frame with a number of current meters in the penstock ([7], Figure 3). This requires a larger number of current meters in order to sample the velocity profile appropriately. It can be possible to use the same frame at two different elevations to improve to velocity profile sampling.

This method is generally more difficult to perform (it require large scaffolds) and is more expensive than the intake gate slot method. It also requires a long unit downtime of about five days for setting up the instruments and at least two for dismantling. Even if the measurement section is sometimes located in a straight section, the velocity profile is not necessarily smoother that in a convergent section.

Acoustic Scintillation Measurement Method Principle

Acoustic scintillation drift measures flow by utilizing the effects of naturally-occurring small-scale turbulence on underwater sound signals sent across a water passage. The variations of refractive index caused by the presence of the turbulence produce random fluctuations in the amplitude of the received sound signal. If two propagation paths are placed across the passage, and are sufficiently closely spaced that the turbulence does not evolve significantly during the time required for the mean flow to carry it from the upstream to the downstream path, then the pattern of fluctuations observed at the downstream receiver is the same as that observed at the upstream receiver, except for a small time delay (Figure 1). The time delay can be measured by recording both received signals and computing the time-lagged cross-correlation between them. The position of the peak of the cross-correlation function gives the time delay, Δt. If the spacing between the paths, Δx, is known then $V = \Delta x/\Delta t$ is the along-path average of the component of the velocity perpendicular to the propagation paths. For typical hydroelectric intakes, Δx = 35 mm has been found satisfactory.

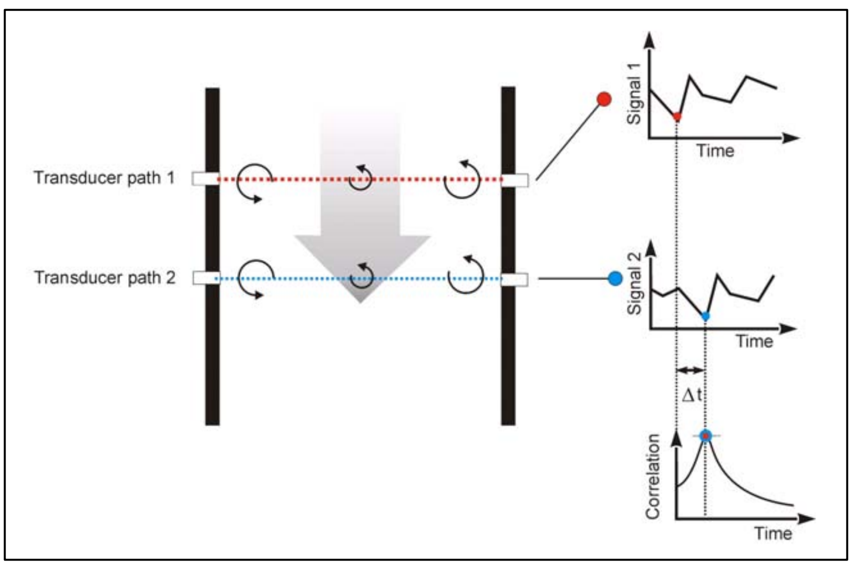

Figure 4- Illustration of acoustic scintillation drift principle

Using three propagation paths arranged in a triangular array allows both the magnitude and the inclination of the laterally-averaged velocity to be measured. Placing a number of paths over the height of a turbine intake bay and integrating the horizontal component of the velocity over the height of the bay gives the discharge through the bay. The sum of the discharges in all bays gives the total turbine discharge. For a typical Kaplan turbine intake, the transducers are mounted on removable frames installed in the stop-log slots. With 10 paths per intake, measurement accuracy of ± 1.5% can normally be achieved

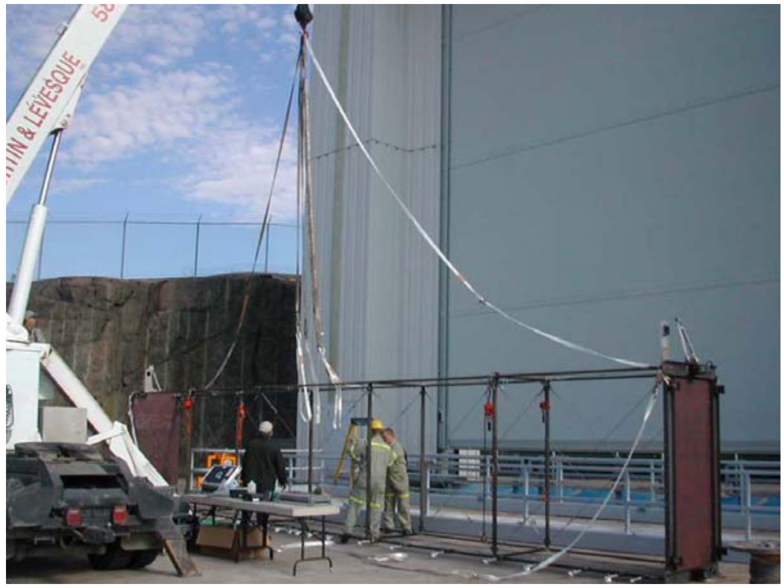

Figure 5.Trolley supporting the Current Meters at Power Plant A

Recently, an improvement to the algorithm for calculating the flow angle has been developed which uses the magnitude, in addition to the position, of the correlation peaks. The revised algorithm has been found to improve the ASFM's performance in a number of intakes with angled approach flows or anisotropy in the turbulence field (11).

Power Plant A

The main purpose of the tests was to determine the performance of each units of the power plant to increase the overall efficiency and get better management of available water resources by selecting the best unit to operate first and to operate them at their maximum efficiency. This plant has three units equipped with Francis turbine with a nominal power of 155 MW under a net head of 82.91 m. The three turbines are supply

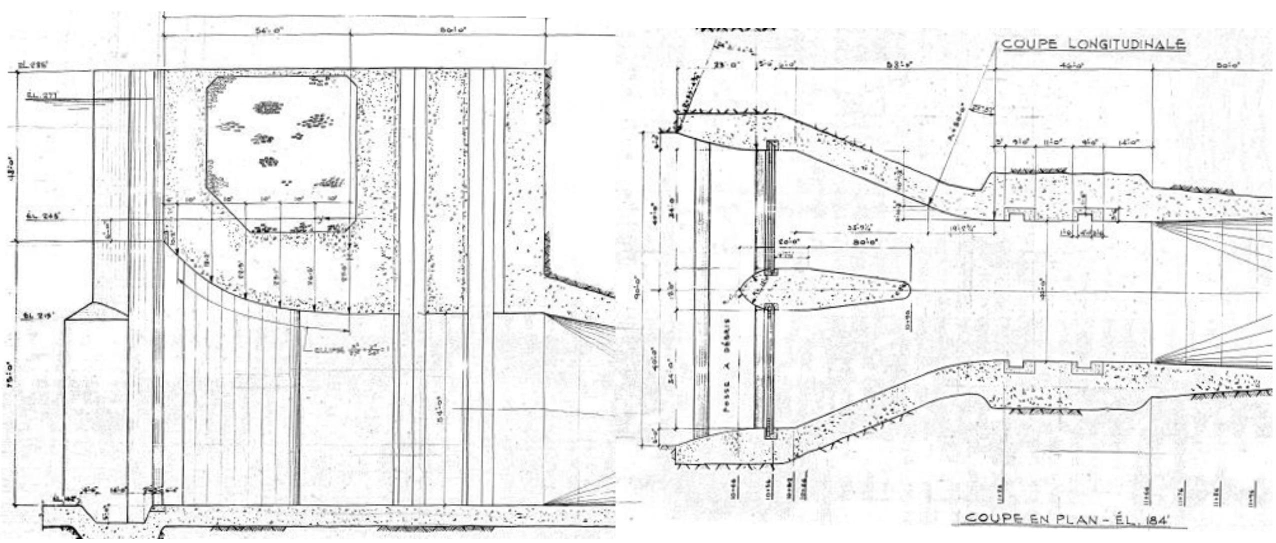

Figure 6.Plan View and Cross Section of Intake of Power Plant A

by a single water intake connected to a penstock equipped with a surge tank and a collector that brings the water in each turbine. Even if this power plant is not a low head power plant, the measurement made in the intake falls in this category according to IEC 60041 and ASME PTC-18 test codes.

The current meters were installed on a large trolley (Figure 5) into the stop logs slot just upstream of the intake gate and about 22 meters downstream of trash racks (Figure 6). The measurement section was located just at the end of convergent part of the intake and the flow was anticipated to be close to horizontal (the flow angle was expected to be between 0 and 10 degrees). Because of this, 15 degrees self compensating current meters were used for this test. The measurement section is 12.19 m wide and 16.46 m high. The cross section show that the intake ceiling has a bell shape whereas the plan view show a center pier and irregular convergent shape upstream of the measurement section.

The major advantage of current meter method was to allow making the measurement of the discharge of each turbine with the same trolley and without moving any instruments other than the power and head measurement instruments. Also, the trolley can be installed with units running thus reducing downtime.

The results show that even with a trash racks close to the measurement section, the instantaneous velocity is rather stable with a random deviation of around 2.3 % except for the current meter near the walls where it is close to 10 % and 6 % for the central current meters in the area of the wake generated by the pier. The wake of the pier is not that intense with a smooth decrease of the velocity of 5 % compared to the mean velocity (see the horizontal velocity profile in Figure 7). The highest velocity was

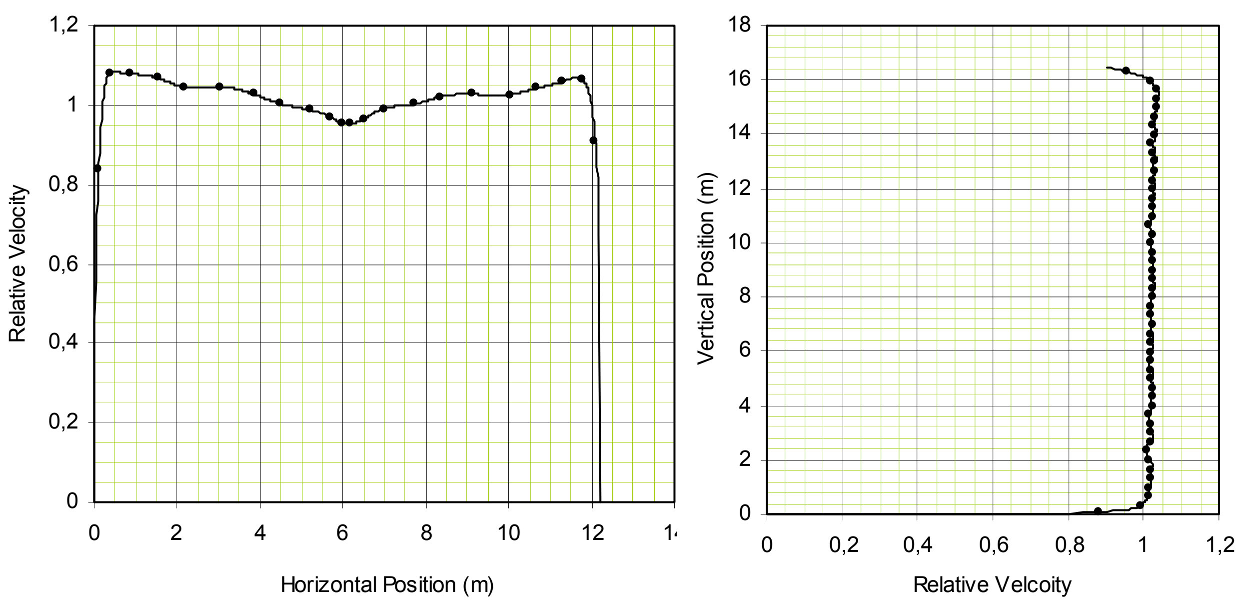

Figure 7 – Laterally average Vertical and Horizontal Velocity Profile of Current Meters Measurement at Power Plant A

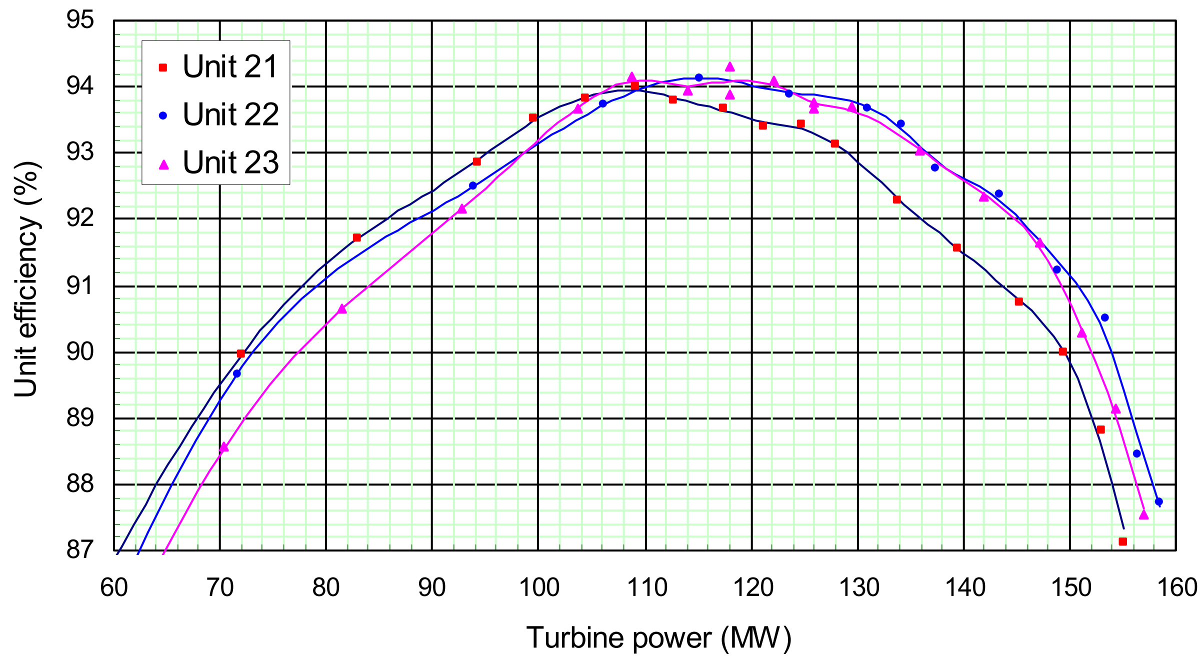

Figure 8.- Efficiency curve for the three unit at Power Plant A

measured by the second current meters closest to the wall and this can be explained by the change in direction due to the convergence of the flow.

The vertical velocity profile (Figure 7) is very smooth and almost flat with no sign of wakes from the main cross members of the trash racks. T his gives a good confidence on the hypothesis that the flow angle was less than 10 degrees from the horizontal.

The efficiency curves of the three units are shown in Figure 8. The random uncertainty of the m easured efficiency curve is estimated to be less than 0.2 % which is small. It gives a good confidence for the operator to choose between the units to operate first and to set the power to maximiz e the efficiency.

Power Plant B

The power plant B has 12 units with 116 MW propeller turbines under a net head of 27.5 m. The goal of the tests

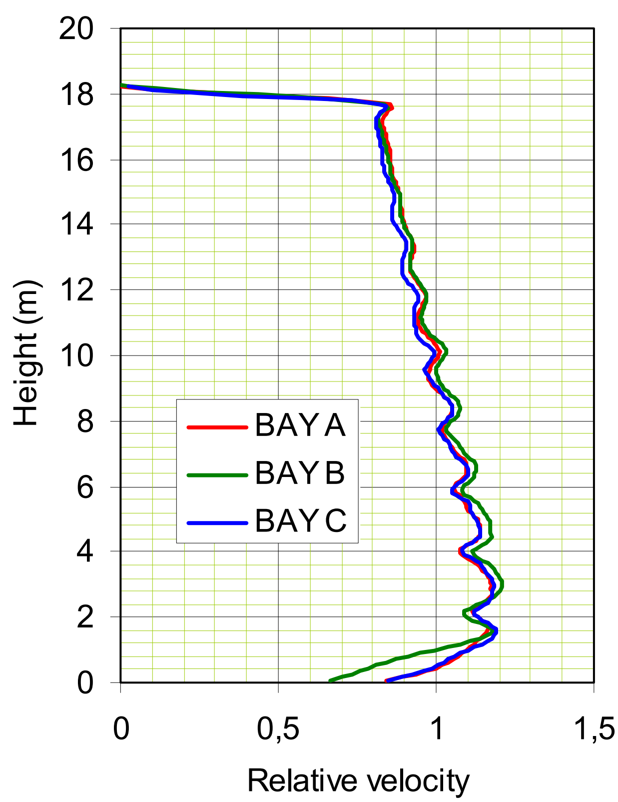

Figure 9 – Velocity profile in the three bays of power plant B

was to measure the efficiency of all units of this power plant as well as the efficiency of the two different types of turbine (two different suppliers) at three different net head. In effect, the net head can vary by more than 30% from the nominal value between the high head in summer and low head in winter. Up to now, 5 different units were tested.

Each turbine has a short converging intake with 3 bays (Figure 1). Thirty self compensating current meters were set on three trolleys (Figure 2) which were installed in the maintenance gate slot. The measurement section width is 5.56 m and the height is 17.87 m and is located 5 m downstream of the trash racks. The theoretical flow angle at the floor is 13.5 degrees and 31 degrees at the ceiling (see references [2][3][4]. Again, the current meter method allows doing the measurement in a short period of time. After the first set up, one unit can be tested every three days including a short downtime.

The velocity profile measured in each bay, scaled by the averaged velocity in this bay, show similar shape (Figure 10). We clearly see the effect of the large cross member of the trash racks. With the continuous velocity profile sampling, it is easy to detect that kind of fluctuation. With a fix elevation velocity sampling method, care should be taken in order to well define the profile. The lower velocity near the top is due to the increase in the flow angle which diminishes the normal component as well as decreases the flow velocity due to the local section area that increases.

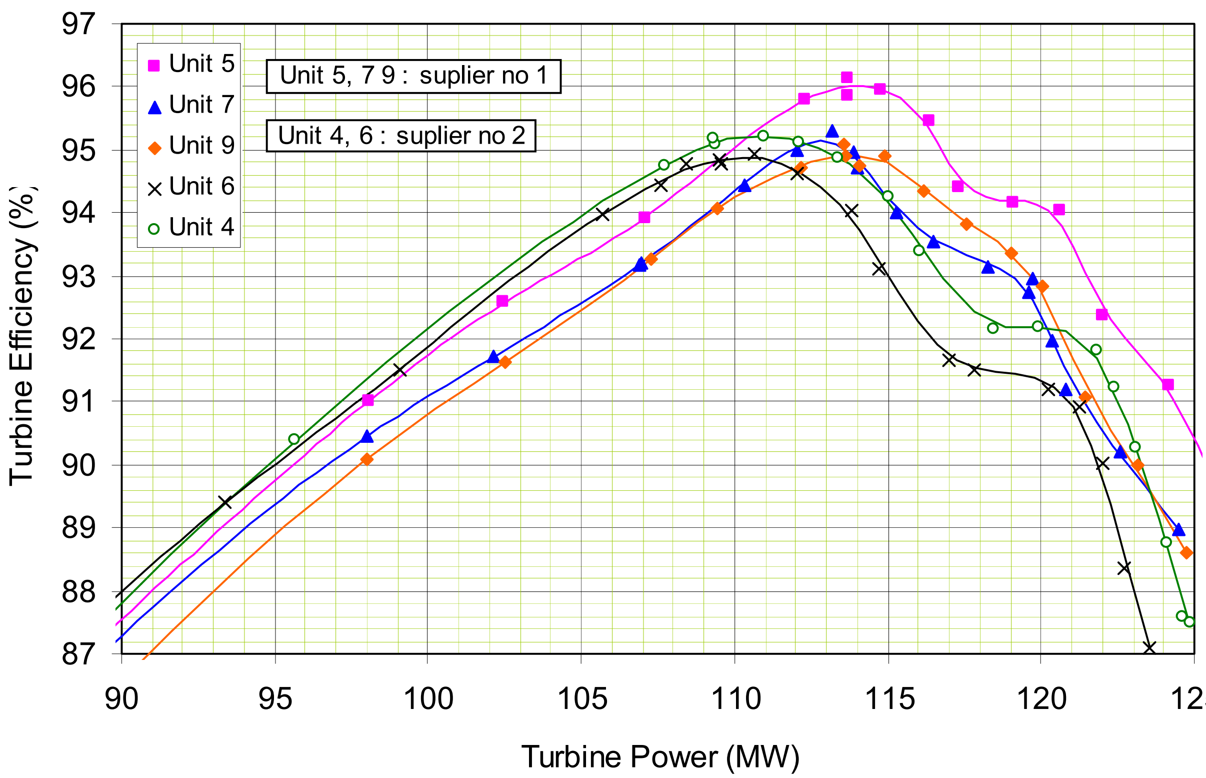

Figure 10 – Efficiency curve of 5 units of power plant B

The efficiency curves of five units tested at power plant B are shown in Figure 10. There are large differences between units of the same suppliers as well as between units of the two suppliers. The difference of the maximum efficiency can be as high as 1 %. At right of best efficiency point (BEP), the difference can be as high as 3% for the same power output. The power at BEP is also different from one unit to the others. What at first may look as random a deviation of the measured points at the right of the BEP is indeed a real bend. Almost all units exhibit the same trend around 118MW. For all units, repeated measurement at the gate opening show very small variation between the result (within ±0.2% or less).

Kootenay Canal

The purpose of the tests at Kootenay Canal, was to compare the results of three methods perform in the intake to a reference method which is code accepted. The Current Meter (CM), Acoustic Scintillation (AS) and Acoustic Transit Time in Intake (ATTI) methods are not code accepted according to the ASME PTC-18 test code. The reference method was the Acoustic Transit Time in the penstock. The measurement condition was considered "favourable" for all three intake methods (see [10][11][12][13][14][15] for more details).

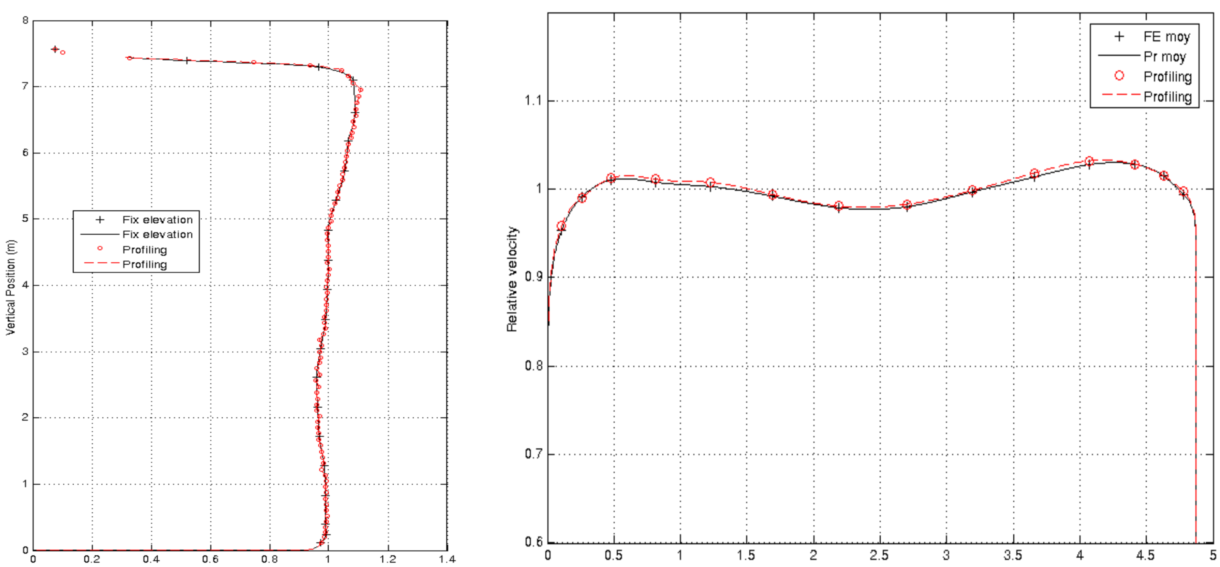

Figure 11 - Vertical velocity profile (left, each point is the result of the horizontal integration) and Horizontal velocity profile (right, each point is the result of the vertical integration) at Kootenay Canal

Again, the velocity profile is smooth with no sign of trash racks which in fact (Figure 11), were very far from the measurement section. The following table show the results of the current meter measurement compare to the reference discharge. The results of both velocity profile sampling methods (profiling or fix elevation) show that both have similar results to within 0.1 %.

Table I. Deviation of the Current Meter Measurement Method Compared to the Reference Discharge

Traveling direction	Down		Up		Up&Down	
Mean discharge (m3/s)	Fix elevation	Profiling	Fix elevation	Profiling	Fix elevation	Profiling
Average deviation (%)						
all points	1,15	1,08	0,88	1,00	1,02	1,04
37,70	0,98	0,92	0,65	0,80	0,83	0,87
70,40	1,26	1,14	0,87	1,01	1,06	1,07
105,83	1,22	1,17	1,13	1,19	1,18	1,18
Random deviation (%) at a confidence level of 95 %						
all points	0,53	0,56	0,74	0,70	0,67	0,61
37,70	0,61	0,83	0,70	0,65	0,68	0,68
70,40	0,50	0,50	0,85	0,87	0,75	0,64
105,83	0,50	0,33	0,60	0,61	0,49	0,42
Uncertainty of the average deviation (%) at a confidence level of 95 %						
all points	0,11	0,12	0,16	0,15	0,10	0,09
37,70	0,23	0,31	0,29	0,27	0,18	0,18
70,40	0,19	0,19	0,32	0,33	0,19	0,17
105,83	0,19	0,13	0,25	0,25	0,13	0,11

Acoustic Scintillation Results

Many comparisons were done by Hydro-Québec between the Acoustic Scintillation and the Current Meter methods. The measurement was done mainly by installing the ASFM transducers on the current meters trolley (Power plant A, C, D, see [1][4][5][6]). The results of the comparative measurements are shown in Table II. Overall, excluding the results of power plant E with the measurement upstream of the trash racks, the ASFM discharge is within ± 1.8 % of the current meters results. The results for some power plant were reprocessed using different technique in order to improve the results.

Table II. Deviation of the Acoustic Scintillation Measurement Compared to the Current Meter Method

Power Plant	Average difference $(Q_{asfm}-Q_{jm})/Q_{jm}*100$	Remarks	Reference papers
A	-1.8 %	Original data	[4]
A	-0.9 %	Filtered, 1024 data block length	[4]
A	-0.0 %	Filtered, 8192 data block length	[4]
C	-0.3 %	Original data, large difference in the two bays	[5],[6]
C	-1.1 %	Reprocessed data, low pas filter, lower difference	[6]

Power Plant	Average difference $(Q_{asfm}-Q_{jm})/Q_{jm}*100$	Remarks	Reference papers
		between the two bays	
D	-1.5 %	Reprocessed data, low pas filter, lower difference between the two bays	[1]
Kootenay Canal	+0.6 %	ASFM performed by AQFlow	[11][12][13]
E	-7.8%	Upstream of the trash racks, low turbulence level	[5]
E	+1,75%	Downstream of the trash racks, higher turbulence level	[5]

Conclusion

The measurement made by Hydro-Québec in low head power plant has proved that in many case, the velocity profile can be as smooth as a velocity profile in a penstock. This should give a good confidence in the discharge measurement results. The recent results from the comparative test at Kootenay Canal indicate that they can be accurate. However, cares should be taken in order to assess in advance some possible bad measurement condition like reverse flow. A careful analysis of the flow like with a CFD analysis should prevent this. Smooth hydraulic contour shape and clean trash racks should give good results.

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