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Flow Tests Lead to Increased Efficiencies and Benchmark Measurements

07/30/2015

Measuring water flow to generating units at the 1,520-MW Manic-5 powerhouse, with the goal of maximizing unit efficiency, is a monumental task but the long-term benefits could help Hydro-Quebec customers and establish industry-wide benchmarks.

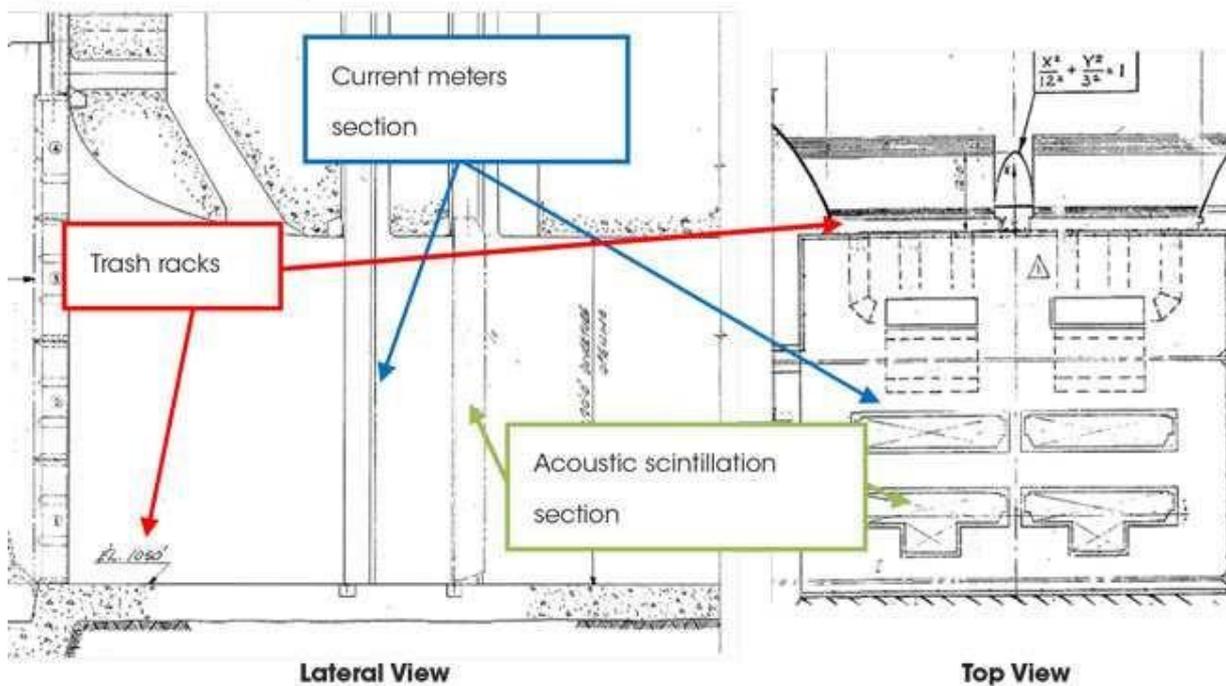
By Bertrand Reeb, Guillaume Dubois, Gilles Proulx, Ion Candel and Cornel Ioana

In 2013, personnel with Canadian provincial utility Hydro-Quebec performed penstock intake flow comparison tests to measure characteristics of the flow to its turbines at the Manic-5 powerhouse, part of the Daniel-Johnson hydroelectric facility, constructed between 1959 and 1970. Daniel-Johnson Dam is a multiple-arch buttress dam on the Manicouagan River that creates the Manicouagan Reservoir, 133 miles north of Baie-Comeau in Quebec, Canada.

The facility produces hydroelectric power and supplies water to the Manic-5 and Manic-5-PA powerhouses that have a combined capacity of 2,596 MW. The dam is 702 feet tall by 4,311 feet in length making it the largest dam of its type in the world and one of the company's largest hydroelectric plants.

Information from the tests allow plant engineers to achieve optimal performance from Manic-5's eight 190-MW Francis turbines.

Figure 1 — Intake Layout



Measurement objectives

In their efforts to keep the total cost of the measurement tests as low as possible, engineers carefully considered flow measurement methods. Engineers consider the Manic-5 design intakes favorable and decided to use two types of measurements within the intake: the current meter (CM) and the acoustic scintillation flow meter (ASFM) methods.

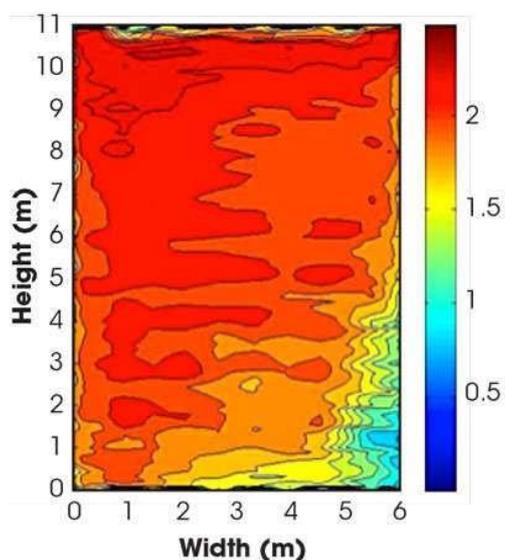
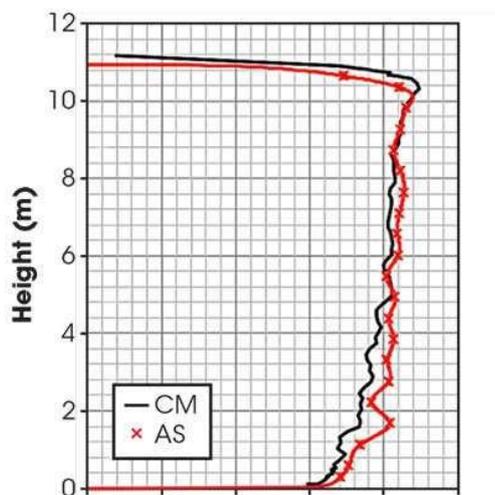
Flow entering each penstock intake passes through two measurement systems after moving beyond the trashracks apparatus, but prior to reaching turbine-generators.

Hydro-Quebec's CM method uses trolleys that support a single row of meters.¹ The meters move vertically, allowing velocity sample profiles over the entire height of the measurement section. This set-up reduces the installation time because it can be used for flow measurement for as many as four units at this location (during the test, only one of the four units was operated). Even though flow measurement is traditionally considered difficult to perform within intakes, especially in a short converging intake, the measurement is proving accurate in many situations such as shown in Kootenay Canal comparative tests² and showing many advantages over penstock measurement.²

Within the penstock and aft of the CM measurement system, engineers used an ASFM to measure discharge as part of a three-year partnership between Electricite de France's General Technical Division (EDF DTG), Hydro-Quebec and the manufacturer of the ASFM, ASL AQFlow (the "SMASH" project).³

The main focus by partnership members studied ASFM in more detail and, depending on their findings, would possibly extend ASFM's range of usage. As a matter of fact, the ASFM measurements from the Manic-5 study now serve as benchmarks for normal measurement conditions.

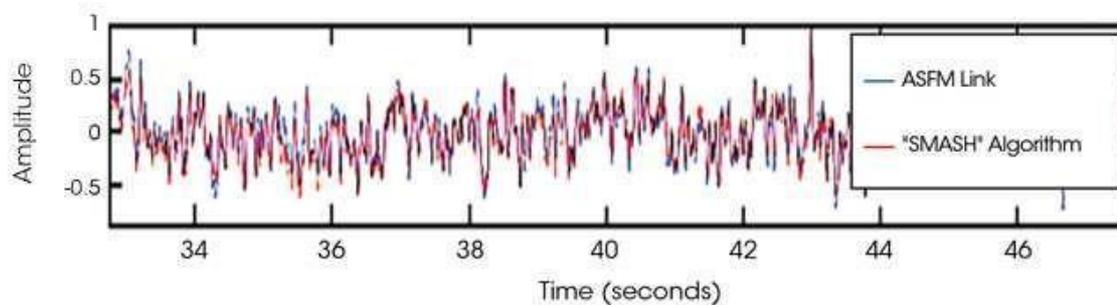
Figure 2 — Contour Lines of the Velocity Profile (m/s)



The power plant

The power plant has eight 190-MW Francis turbines operating with a net head of 141.8 m (465 feet). Two sets of conduits each provide water to four units and each conduit has two rectangular bays, which converge into one circular section downstream from the head gates. The measurement sections are 10.97 m by 6.1 m (36 feet by 20 feet). The CM measuring section was located about 10 m from the trash racks in the stoplog slots, while the ASFM measuring section was 3.4 m farther downstream in the gate slots (see Figure 1). With only one unit in operation, the average velocity was in the range of 1 to 2.5 m/sec, which falls within the usual range of both the CM and ASFM.

Figure 3 — Time Series from the Upstream Side



The measurement conditions were considered good for both CM and ASFM. In effect, the smooth transition between the trashracks and the measurement sections is likely to produce smooth velocity profiles. The only concern were the trashracks cross members, which can generate large wakes. This has been taken into account in the selection of the number of ASFM measurement levels. The flow angle was expected to be near horizontal.

ASFM

ASFM uses a technique called acoustic scintillation drift to measure the flow velocity perpendicular to a number of acoustic paths established across the intake to the turbine. Short (16 μ sec) pulses of high-frequency sound (in the order of 307 kHz) are sent from transmitting arrays on one side to receiving arrays on the other, at a rate of about 250 pings/sec.⁵



Frame supporting the current meters. The frame had 14 current meters installed on the bottom of a simple trolley made of two end plates, profiled rods and steel cables.

Fluctuations (known as scintillations) in the amplitude of those acoustic pulses result from turbulence carried along by the flow.

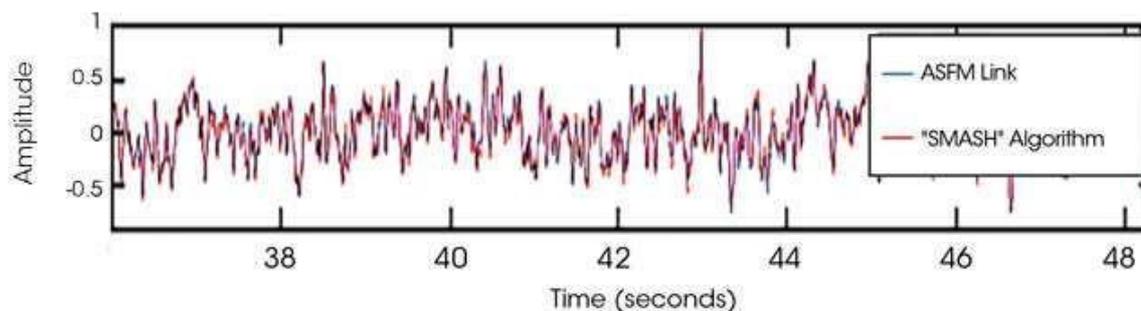
ASFM measures scintillations and from them computes the lateral average (i.e., along the acoustic path) of the velocity perpendicular to each path. In its simplest form, two transmitters are placed on one side of the measurement section and two receivers at the other. The signal amplitude at the receivers varies randomly as the turbulence along the propagation paths changes with time and flow.



A steel frame, which is formed by two main vertical beams, supports 21 ASFM transducers.

If the two paths are sufficiently close (Δx), the turbulence remains embedded in the flow, and the pattern of these amplitude variations at the downstream receiver will be nearly identical to that at the upstream receiver, except for a time delay, Δt . This time delay corresponds to the peak in the time-lagged cross-correlation function calculated for Signal 1 and Signal 2. The mean velocity perpendicular to the acoustic paths is then $\Delta x/\Delta t$. Using three transmitters and three receivers at each measurement level allows both the magnitude and inclination of the velocity to be measured. ASFM computes the flow through each bay of the intake by integrating the horizontal component of the velocity over the cross-sectional area of the intake. In a multi-bay intake, the flows through each bay are summed to compute the total flow.

Figure 4 — Time Series from the Downstream Side



For the measurement, 21 pairs of transducers were installed on a steel frame. The number of transducers was chosen in order to resolve the possible oscillation of the velocity profile due to wake of the trash racks main cross members. All transducers were set horizontally because the expected flow angle was

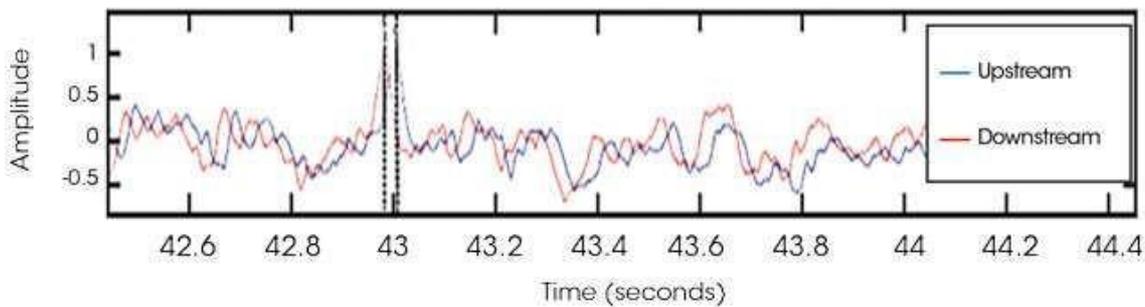
horizontal, as it was later confirmed by the measurement.



This is a close up of horizontally installed ASFM transducers on a steel frame used for flow measurement.

In addition to the normal ASFM, a high-speed data acquisition system was used to record the raw acoustic signal for each element. In total, 12 signals were simultaneously recorded at a rate of 3.3 mega samples per second) for each 7-minute run. Those data were used after the tests for an alternate post-processing analysis.

Figure 5 — Delay Between the Time Series



CM measurement set up

CM measurement was done with 14 meters installed on the bottom of a simple trolley made of two endplates, profiled rods and steel cables (see photos on pages 72 and 73).

The CMs were equipped with Type A self-compensating propeller that compensates for up to 45-degree flow angle. The profiled rods are the same that are used for calibration of the CMs. Steel wheels help guide the trolley in the gate slot both laterally and longitudinally. The frame was moved by means of two hoists controlled by variable-frequency power drives, which allowed selection of the travel velocity. The two hoists were synchronized by means of encoders. Two displacement transducers measured the elevation of each end of the trolley.

The trolley velocity was set to 50 mm/sec except at the top and bottom of the measurement section, where it was set to 10 mm/sec for better defining the rapidly changing velocity profile. Total measurement time was 8 minutes for each run. The trolley velocity for the profiling method represents about 2% of the average velocity at the lowest flow. The data acquisition software developed by Hydro-Quebec allows recording the instantaneous rotational velocity of each current meter, (i.e., it records the time stamp of each revolution). Once the rotational velocities are recorded, it is relatively easy to calculate the mean value for different time intervals.

Results

Due to the presence of trashracks and a rigid and vibration-free support frame for the ASFM transducers, the conditions for ASFM testing were very close to ideal, meaning that all flow velocities were used in computing the flow (see Figure 2 on page 71). The velocity profile measured by ASFM shows small oscillations that are related to the trashracks cross members.

CM results show that the velocity profiles produced are similar to the ones from ASFM, with ASFM results slightly higher. The small difference (higher velocities in the bottom part of the measurement section) can result from the ASFM measurement section being farther downstream than the CM section, as the velocity profile tends to develop or flatten as the turbulence is mixing the different layers of the flow. A part of the difference can also be due to two other factors: the acquisition times for the CMs and ASFM are not concurrent and the sizes of the measurement sections of the two methods are marginally different.

The three-dimensional velocity profile (also Figure 2) from the CM measurement shows some asymmetry, especially in the bottom part of the section. It is likely due to the asymmetry of the intake upstream of the trashracks or the presence of some debris there. This asymmetry of the velocity profile in the bottom part of the measurement section can be the source of difference between the CM and ASFM methods.

Flow measurement comparison

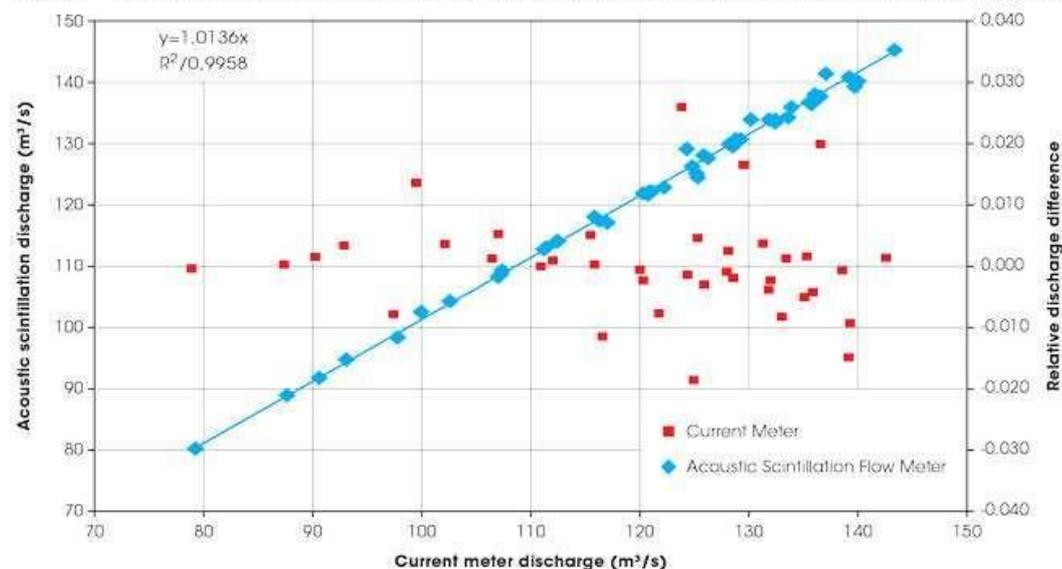
The comparison of the flow measured by CM and ASFM (see Figure 6) includes the results for four units and 40 runs. Overall, the difference between the two methods is 1.4 %, with the ASFM flow being higher. The standard deviation is ± 0.8 % and includes the deviation of both methods. The random uncertainty of the regression line is ± 0.3 %, which means that there exists a statistical difference of 1.1% between the two methods. There is no significant variation of the difference between the two methods as a function of the flow. Both methods have an expected uncertainty of $\pm 1\%$ to $\pm 1.5\%$. This means each method's uncertainty band overlaps. Thus, project engineers consider the agreement between the two methods as "good."

Reprocessing ASFM data

Project personnel compared the standard time series computed by ASFM and the recomputed time series based on the recorded raw signals. They used a new algorithm to determine the amplitude of the acoustic pulses. This algorithm has already shown to improve the results of ASFM in case of very low turbulence³, which is not within the normal range of usage of the method.

This new algorithm is not expected to have a significant effect on the calculated flow under normal stipulated conditions of usage of ASFM.

Figure 6 — Discharge Comparisons Measured by Current Meter and Acoustic Scintillation Flow Meter Methods



Figures 3, 4 and 5 (see pages 72, 73 and 74) show a very high resemblance between the two time series, which leads to close values for the total flow. The quality factor of the measurement, for each individual level⁵ was above 0.9, thus a high degree of confidence in the ASFM results.

From the eight runs reprocessed with the new algorithm, the difference from the original calculation is 0.35%, which is low. As expected, the difference for the present tests is not large, unlike what was found for low turbulence level tests. The new algorithm will be tested more thoroughly in future ASFM comparison tests as Hydro-Quebec, EDF and ASL AQFlow continue to collaborate on this matter.

Comparison of efficiency

Figure 7 (see page 79) shows the efficiency of Unit 4 (this unit represents an average one from the point of view of flow comparison between the CM and ASFM). The efficiency measured with the CM and ASFM in 2013, the thermodynamic method (Unit 8) measured in 1992 and the expected efficiency obtained from the model test step up are plotted as a function of the turbine output. At peak efficiency, all four curves are within 1.4%. Both the CM and ASFM intake measurement methods can be considered to have a measurement uncertainty of about ± 1 to $\pm 1.5\%$.

At peak efficiency, the difference between the eight units reaches 0.3 % and will be taken into account for optimal dispatching. There is also some difference between the powers at peak efficiency, which will also be taken into account for turbine set up. In addition, for turbine output toward the maximum values, the difference of efficiency reaches 1.5% between the most and least efficient units. Again, knowing this fact will help Hydro-Quebec to properly operate its units, because they are often used during high load periods.

Conclusions

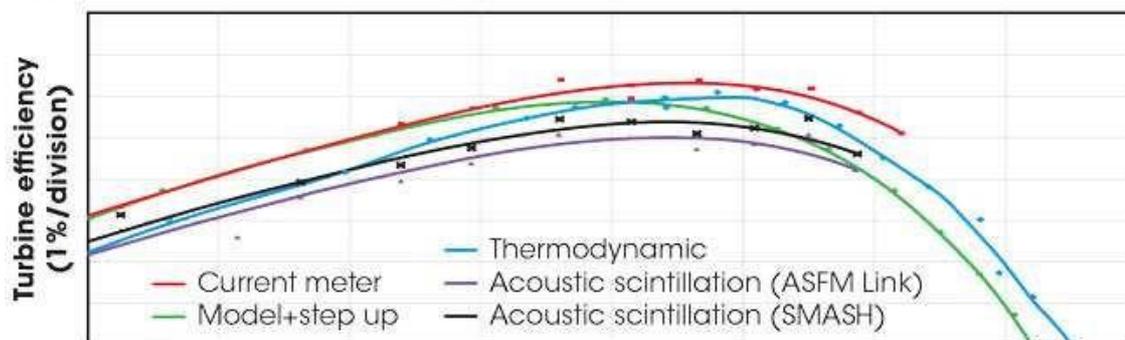
Hydro-Quebec has performed efficiency tests in the intake of one of its major power plant. The goal of those tests was to measure the efficiency of all eight units for optimal dispatching. It was also a good opportunity to perform comparative test between two methods, CM ASFM.

The results show that the flow measured by the CMs and ASFM are within 1.4% from each other, which is considered excellent. The results of the CMs and ASFM also compare well with the previous tests done with the thermodynamic method.

Significant differences exist between each unit at peak efficiency and near maximum power.

The results of those tests will help Hydro-Quebec to better operate this plant.

Figure 7 — Turbine Efficiency Measured with Current Meter for Unit 4



Notes

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4. ASFM Operations Manual, AQFlow.
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Briefly

Several methods exist to measure absolute water flow rate in hydro plants, some of which include the current meter, pressure-time (Gibson), tracer and ultrasonic methods. The newest is the ultrasonic method and it is being applied more frequently at hydro plants because it allows for continuous monitoring of the flow rate. However, the basic flow measurement methods used for efficiency tests of hydraulic machines are the current meter and Gibson methods.

The current meter method has frequently been applied at hydroelectric facilities. Another possibility for continuous measurement of the discharge is the non-absolute Winter-Kennedy method.

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