# Comparison of Discharge Measurement by Current Meter and Acoustic Scintillation Methods at Rocher-de-Grand-Mère

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ABSTRACT

*Rocher-de-Grand-Mere is a typical modern design of a low head power plant. It has a very short converging intake that makes the discharge measurement very difficult to perform with high accuracy. According to the IEC 41 test code, while no existing standard deals with short intakes of low-head plants, clauses in ISO 3354 may be used as a guide for the Current Meter (CM) method. A fairly new method called the Acoustic Scintillation Flow Measurement (ASFM) has been used and compared to the CM method.*

*The initial results showed an overall mean difference between the two methods that was very low. However, large deviations were evident in the discharges measured in the individual bays by the two instruments, which also varied with the discharge. Possible causes for these differences include the effect of the approach angle of the flow in the forebay and asymmetry in the velocity and turbulence profiles which can cause flow angle calculation errors in the acoustic scintillation data. An improved flow angle algorithm recently introduced for the scintillation method and some revised filtering and other analysis techniques have been used to re-analyze the data from Rocher-de-Grand-Mere and have improved the agreement between the two methods. The major cause of the deviations was the effect of interference in the acoustic signal from the current meters mounted in close proximity on the frame.*

## Introduction

According to the IEC 41 test code, no existing standard deals with discharge measurements in short intakes of low-head plants. ISO 3354 may be used as a guide for measurements with the current meters, but attempts to remedy difficulties associated with uneven and/or unstable velocity distributions as well as oblique flow to the current meters should be made by straightening devices or other special measuring techniques. The ASME PTC-18 test code does not recognize any method as valid for flow measurement in these conditions, as the intakes of these power plants are generally short and converging and often have irregular layouts. Hydro-Québec has therefore decided to explore a new method to improve flow measurement at low head power plants.

The Acoustic Scintillation Flow Measurement (ASFM) method initially developed for measurement in oceans and rivers has been adapted for measurement in low head power plants. Among other advantages of this method is that the instruments can be installed outside of the main flow since they are generally installed on frames inserted in

the stop log or gate slots. This method can thus be used for permanent measurement. Also, the transducers do not require any calibration.
A good way to establish the accuracy of this new method is to do comparative measurements with other methods. This has been done in five of Hydro-Québec's power plants since 1997 [9, 10, 13] by comparing the ASFM method to the CM method. This paper presents the results of the last comparative measurement done at the Rocher-de-Grand-Mère power plant. Detailed analyses of the data have been done in order to explain large deviations between the two methods. This has led to reprocessing of the data and considerably improved results.

## Principles of Acoustic Scintillation Measurement Method

Acoustic scintillation drift measures flow by utilizing the effects of naturally-occurring small-scale turbulence on underwater sound signals sent across a water passage [1-7]. 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, $\Delta t$. If the spacing between the paths, $\Delta x$, 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, $\Delta x$ = 35 mm has been found satisfactory.

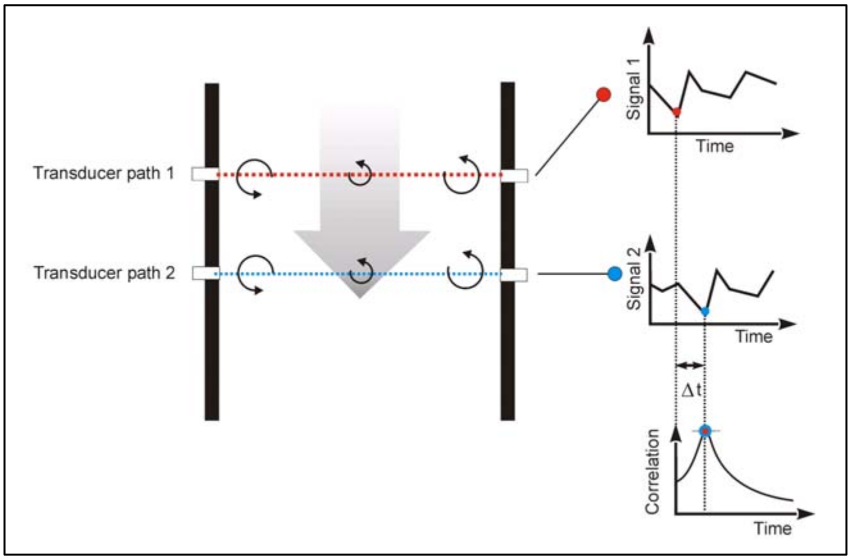


**Figure 1 - Illustration of acoustic scintillation drift principle**

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

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).

## Rocher-de-Grand-Mère power plant

The Rocher-de-Grand-Mère power plant was commissioned in 2004. It has been built on the left bank of the St-Maurice River at the site of the existing Grand-Mère power plant which has been in service since 1915. Rocher-de-Grand-Mère has three Kaplan units of 75.6 MW rated power. Each intake has two bays and the layout is typical of a modern design with a relatively smooth converging form (Figure 2). The floor and ceiling angles are 37° and 45° respectively. Each bay is 8.16 m wide by 12.6 m high at the measurement section in the stop log slots.

## Current Meter Measurement (CM)

Given the dimension of the intake, the net head, etc., the only suitable method for the discharge measurement according to IEC 41 test code was the current meter (CM) method. Nonetheless, it would have been too expensive and require a very long downtime of the unit to install a fixed frame in each of the two bays. Instead, Hydro-Quebec uses for this type of power plant a continuously moving frame made of profiled bar connected to two end plates [10, 13]. Fourteen self compensating current meters were mounted on each of the lower bars (Figure 3). The frame is moved up or down by two independent electrical hoists controlled and synchronized electronically. The frame travel velocity can be set according to water velocity in the measurement section. For these tests, the frame velocity was set to 2.7 cm/s, which represents about 1.7 % of the mean water velocity at the maximum discharge. ISO 3354 recommends less than 5 %. The complete measurement for one point took around 10 minutes.

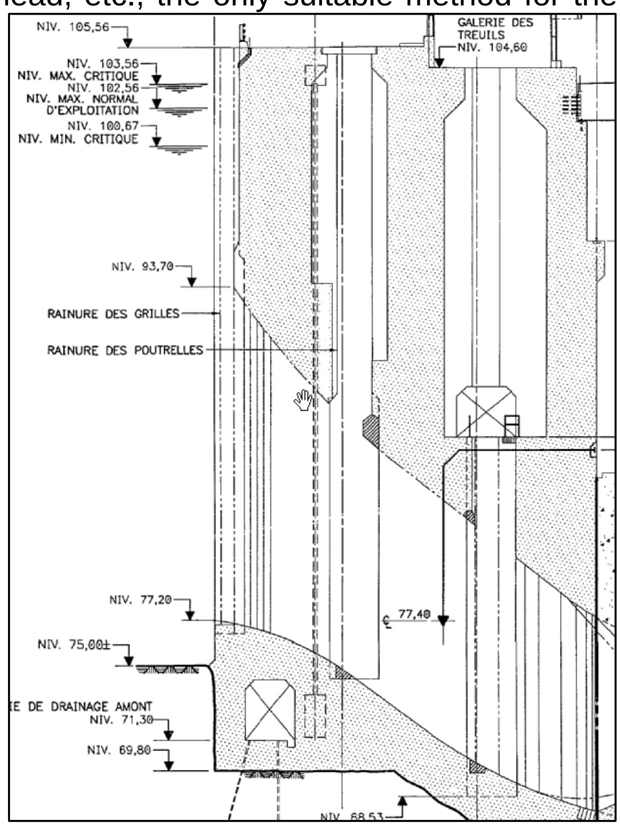


**Figure 2 - Rocher-de-Grand-Mère intake cross section**

This technique 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. For the computation of the discharge, the mean velocity for one hundred equally spaced height intervals was calculated for each of the current meter. Using these data, cubic splines were calculated and integrated vertically, then horizontally and then vice versa. For a solid boundary (floor and vertical walls), the velocity profile was assumed as exponentially decaying as specified in ISO 3354. At the top of the section, the velocity profile was integrated all the way since the measurements were taken well beyond the roof line.


**Figure 3 - Rocher-de-Grand-Mère frame**

**Acoustic Scintillation Flow Measurement (ASFM)**

The ASFM transducers were mounted near the upstream edge of each end plate, around 30 cm above the lower row of current meters (Figure 3). The profiling version of the ASFM Advantage software was used. This version allows the ASFM to perform continuous measurement while the transducers are moving (the standard version uses fixed transducers). The acoustic amplitude of each of the three elements of one bay is recorded at a rate of 250 Hz. The velocity is calculated at every 4 s (1024 samples). The improved ASL AQFlow software reprocesses the data using modified number of data samples for the velocity calculation, as well as modified methodology for detecting bad results.

**Initial results of the discharge measurement**

A first series of measurements was done to verify the cam curve of the Kaplan turbine. A second series was done with the on-cam setting of the speed governor. To establish the influence of the traveling direction on the current meter results, comparative measurements have been done for the frame moving up and down at four different discharges,. A correction of ±0.1 % dependent on the direction has been applied. With that, the random uncertainty of discharge measurement by the CM method was estimated at 0.3 %. The overall uncertainty was estimated at 1.2 %.

The comparison between the discharge measurements with the two methods is shown in Figure 4. In the initial calculation of the ASFM measurement, the mean difference between the CM and ASFM discharge was very low. However, large differences were

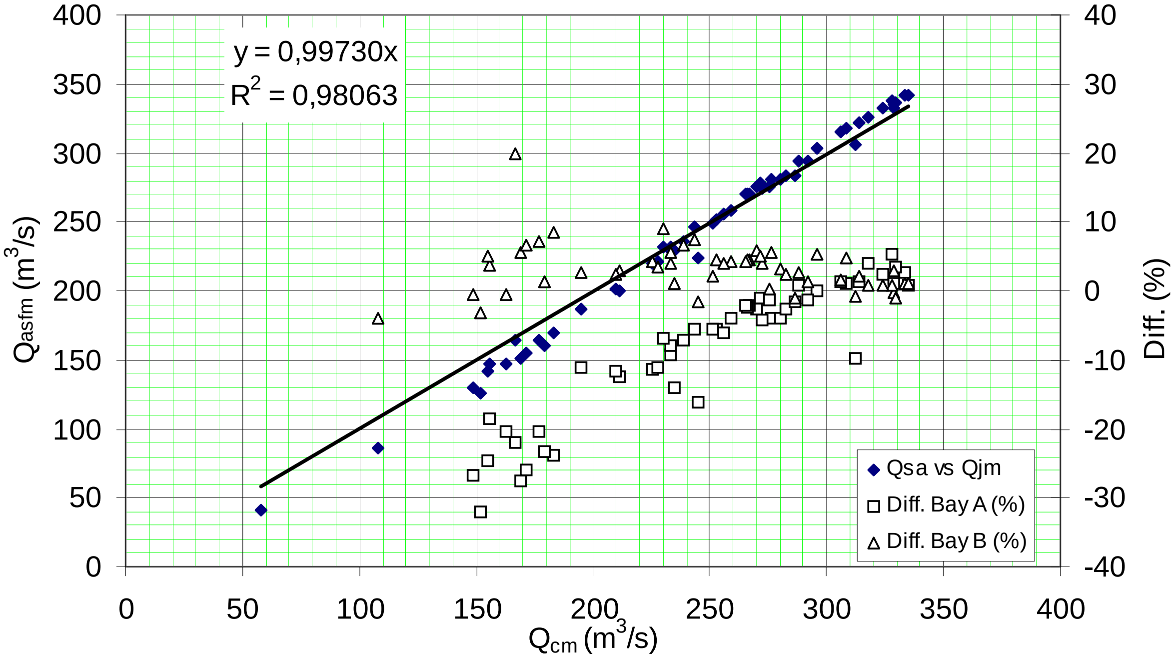


**Figure 4- Comparison of discharge measurement by CM and ASFM at Rocher-de-Grand-Mère, original data**

observed as a function of the discharge in the left or right bay. A series of analyses has been done to understand the reason of these large deviations.

Firstly, the analysis of the velocity profile from the current meter measurements (Figure 5, [13]) shows evident signs of asymmetry with more velocity on one side of the bays and a nearly dead zone at the bottom of the section. The horizontal asymmetry is due to flow in the forebay arriving with a 50° angle to the intake upstream face. This can cause a non-uniform turbulence level and lead to an over-weighted velocity in some portions of the measurement section. This has been observed in other tests by ASL [14]. The asymmetry is more pronounced in bay A in which the error was the highest.

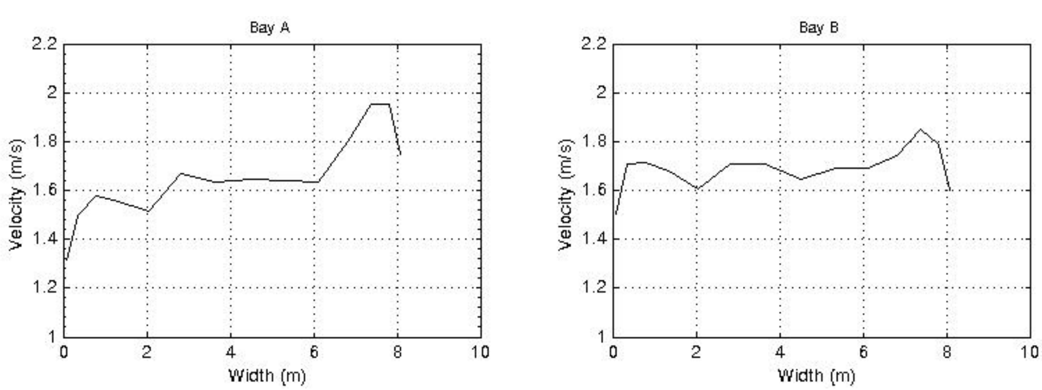


**Figure 5: Horizontal velocity profile**

Secondly, the spectral analysis of the acoustic signal shows evident signs of frequency contamination (Figure 6). The normal spectral amplitude curve should be uniformly decaying and have the same shape at different discharges. The plots in Fig 6 show two zones (double arrows on the figure) of higher than normal amplitudes. The lower limit of the low contamination zone varies linearly with the discharge. The most likely source of the contamination is the location of the current meters just under the acoustic path. The perturbation produced by the two bladed propeller of the current meters can produced cyclic fluctuations that are recorded by the ASFM. The blade passing frequency related to the two central current meters is very close to the lower frequency of the contamination zone (Figure 7). Normally this frequency would be expected to be lower than the blade passing frequency because water velocity varies with time and with height.

This kind of coherent fluctuations should be avoided because it biases the cross-correlation calculation of the ASFM. Consequently, this lower frequency has been used in the reprocessing of the data to set the low pass filter.

### Reprocessing of data

Due to the frequency contamination due to the current meters, a low pass filter has been used prior to the angle-velocity calculation. The low pass frequency was set as shown in figure 7. For the lowest discharge, the low pass frequency was set as low as 3 Hz and not exceeding 20 Hz even at the highest discharge. These two values represent 1.2 % and 8 % of the acquisition frequency.

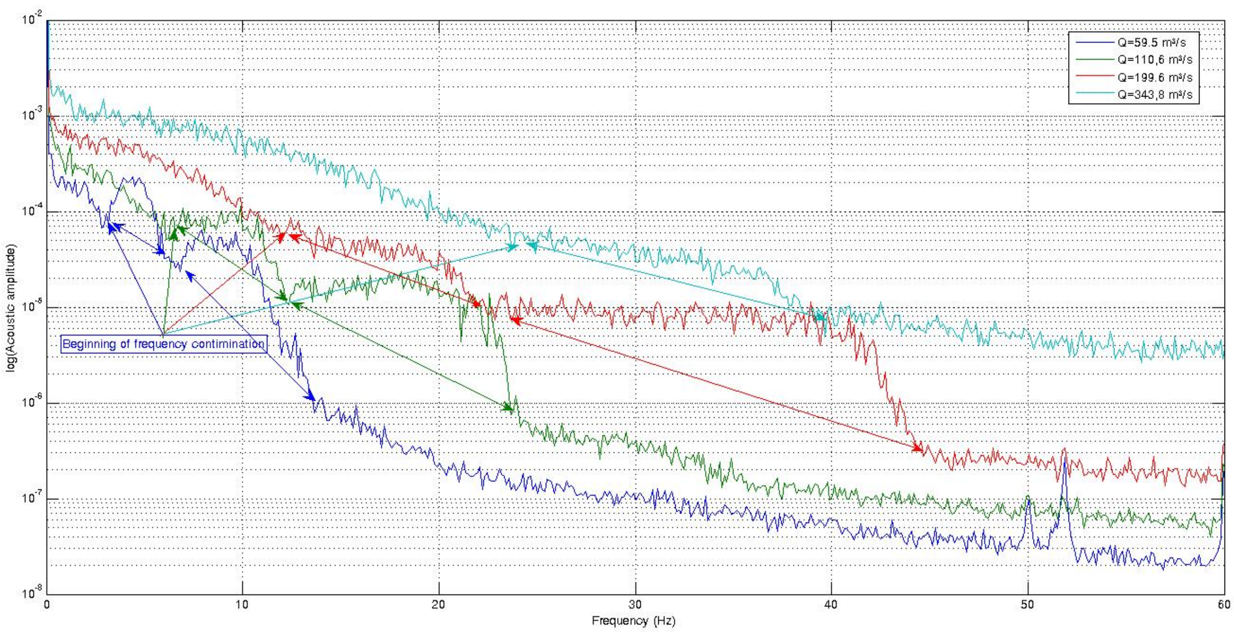


**Figure 6- Spectral analysis of the acoustic amplitude**

The low discharges have greater error, since a large fraction of data gets discarded; the contamination and resulting filtering preserve more of the data at high discharges with consequently less error.

Different methods of velocity calculation from the acoustic signals have been tested. Given the three time drifts from the three pairs of transducers, we can calculate the velocity and flow angle (two unknown) on the least square basis. This is the classical method. We can also use only the two pairs that have the two highest correlations. Due to the flow angle, these were generally the upstream-downstream and vertical-downstream pairs. In effect, the pairs that are closely aligned with the flow normally have the best correlation. This method is named MAXCC.

Another method (angle calculation from cross-correlation magnitudes) developed by ASL [11] assumes that the correlation of the three pairs varies with the difference of orientation angle of the pair and the flow. The flow angle may be found by fitting the correlation values to an assumed Gaussian spatial correlation field. Once the flow angle is found, the velocity can be calculated using the time drift. Here two methods have been tested. The first uses the three time drifts to calculate the velocity on the least square basis. The second is to calculate three individual velocities and do a weighted average. Other methods are possible like considering only one or two pairs with the best correlation.

Among other parameters that have been changed is the number of points that are used for individual velocity calculation. From the standard 1024 samples which correspond to an average velocity over a height of 10 cm, the sampling length was changed to 8192 which approach 1 m in height.

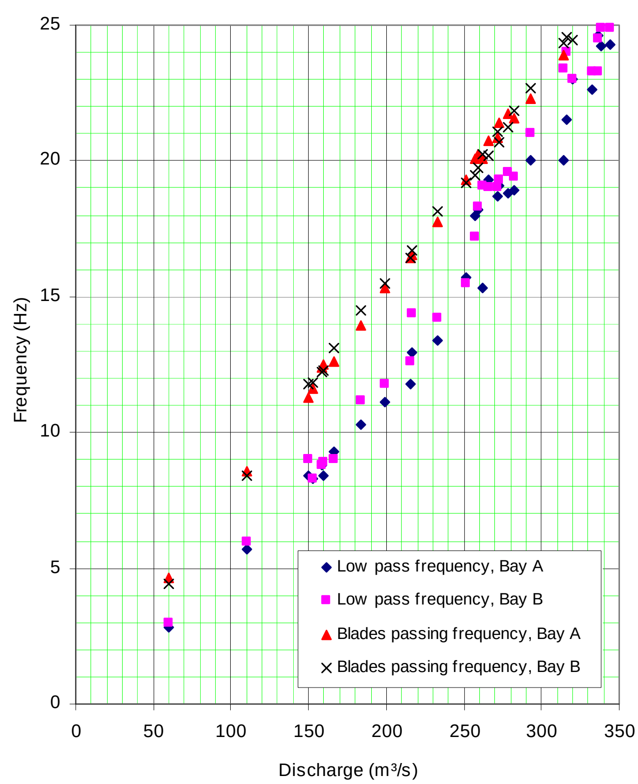


**Figure 7-Low pass filter frequency and blade passing frequency of current meter as function of the discharge**

### Results of data reprocessing

The reprocessing of the data greatly improves the ASFM results. The low pass filtering was necessary because without this, no valuable results would have been obtained. Some filtering was already done by the ASFM system during the tests, but the post-processing starts with the raw data.

The velocity and angle calculation method that gave the best result in terms of the difference with the current meter results and random uncertainty was MAXCC (as described above). The original method was very close second, while the two methods based on the new algorithm for flow angle calculation over predicted the discharge by a large amount (>10%).

In a closer look at the correlation of the three pairs, it is likely that the variations of correlation do not follow the assumed Gaussian shape with the orientation of the pair with the flow, because of the effects of the coherent fluctuations caused by the current meters, and their incomplete removal by the filtering. This new algorithm has shown improvement of the results in other power plants [11] but this is not the case here due to the probable disturbance of the correlation peak values. However, the performance of both algorithms can probably be improved by altering the orientation of the transducers and aligning one of the pair of elements with the flow. This can be done by doing a first measurement and calculating the flow angle with the standard method and then complete the measurement with the reoriented transducers. The procedure would be easy for the fixed paths method but would not be optimal for the profiling method as used at Rocher-de-Grand-Mère. There, the flow angle varied from 20º to 45° and it would not be possible to physically rotate the transducers as a function of the frame position.

The reprocessing results are shown in Figure 8. 4096 data samples with an overlap of 75% were used to calculate the discharge. The low pass filtering frequency used is shown in Figure 7. The mean difference between CM and ASFM methods is 1.1 %, with a random uncertainty of a point of ±3.5 % and a random uncertainty of the curve of 0.8 %. The difference is particularly large at low discharge values, where it can be explained by the low pass filtering which has removed a large part of the spectral

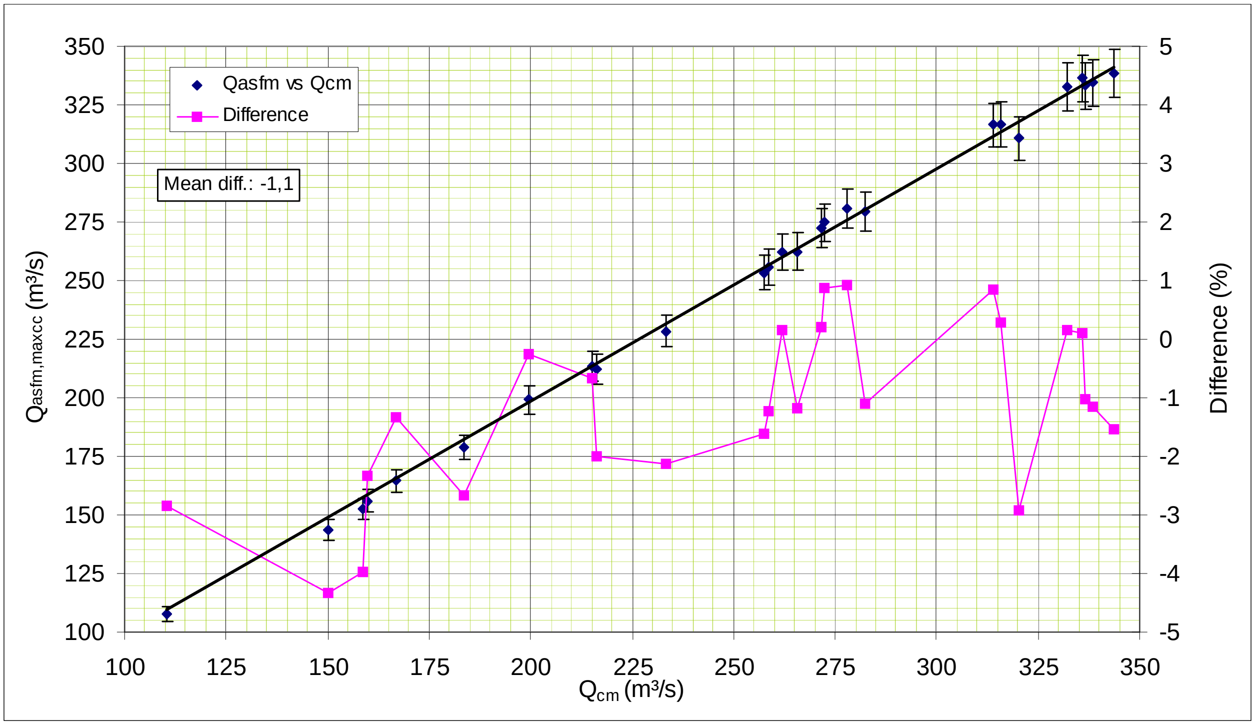


**Figure 8-Reprocessing results (MAXCC method)**

content. The discharge difference of each individual bay now do not show the large value compared to the original calculation (Figure 4). The random uncertainty of a sample is considered to be on the high side.

## CONCLUSIONS

A comparison of the discharge measurement by the Current Meter and Acoustic Scintillation Flow Meter methods has been done at the Rocher-de-Grand-Mere power plant with the following results:

In the initial calculation of the ASFM measurement, the mean difference between the CM and ASFM discharge was very low, but with large differences observed with the current meter results as a function of the discharge in the left or right bay. The analysis of the acoustic signals identified a frequency contamination due to the current meters as the main reason.

Reprocessing of the data by using a low pass filter to remove the effect of the current meters has shown a great improvement in the results from the ASFM methods even though this process has removed a large part of the spectral content of the acoustic signals; better results were found at high discharge where more of the signal was retained.

Different methods of calculation of the velocity for the ASFM method have also been tested. The new algorithm developed and implemented in the acquisition and post-processing software has not shown satisfactory improvement in this particular case, likely due again to the residual frequency contamination from the current meters which led to the error in the calculation of the flow angle. In other power plant measurements, including those done with the transducers mounted on current meter frames but with the transducers farther from the current meters, this new algorithm has shown improvement by producing a more accurate measurement of the flow angle. It is likely that further improvement in the flow angle measurement could be achieved by aligning one pair of the transducer array elements with the flow.

Although the installation of the ASFM transducers on the same frame as the current meters allows making a comparative measurement at low cost, this should not override the need to have the best possible measurement conditions for both methods. In the present case, it would have been better to install the acoustic transducers farther from the current meters. Another means would be to use the profiling version of the ASFM with the transducers mounted on an independent frame or to use a fixed frame with fixed paths.

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