Online flowrate monitoring experiences at Hydro-Québec

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Abstract. This paper describes recent experiences with an online flowrate monitoring system designed for hydraulic turbines. The angular index method used in this paper was developed by Hydro-Quebec with the goal of delivering an accurate and affordable system to monitor flowrate under all circumstances. Accuracy and applicability of the method is demonstrated using code accepted experimental results for a 200 MW Francis and a 110MW propeller turbine. The last section describes in details the requirements to apply the method.

Introduction

For a hydroelectric utility like Hydro-Québec (HQ) who relies almost exclusively on hydropower to produce its energy, knowledge of the flowrate and efficiency of its powerhouses is essential. It allows for production optimization at various levels in the company going from short term efficiency monitoring to long term reservoir management.

While many tests on efficiency and flowrate are done internally to provide an accurate picture of the machine operation at a given moment, there always arise situations where additional data would be helpful. Because they are more sensitive to head changes, low head plants seem particularly affected by a number of factors such as interactions between groups, impact of aeration, tail water level, trash rack clogging and so on... Unfortunately, many of the testing procedures concerning low head plant involve large (and costly) experimental setup.

A research project was thus started to address those difficulties. The goal of this project is to obtain an accurate and affordable mean to monitor the flowrate in a hydraulic turbine. In the long run, such system should provide experimental efficiency hill and improve operational practices. By pinpointing when the turbine is operated in a non-optimal regime, an improvement in the energy output for a given amount of water is expected. While it was designed with low head turbine in mind, it should also work on higher head machines.

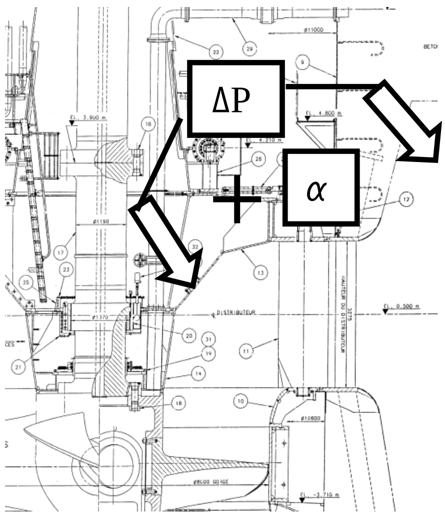

Figure 1 : Overview of the angular index measurement system on a propeller turbine

This paper is divided into four parts. The first one provides an overview of the method. Then, the results obtained on two very different powerhouses are presented. The last section provides experimental details for those who want to reproduce the method.

1. Description of the measurement system

The angular index was first presented in [1] with a combination of numerical and experimental results. It is illustrated in figure 1 for an axial propeller turbine. As most relative methods, the angular index system is based on a pressure difference but, as its name says, it also integrates the angular position of the guide vane. For this system, the pressure difference is measured between the spiral casing inlet and a location behind the guide vane. Because of the downstream probes, the pressure difference is strongly correlated to the angular position of the guide vanes. This interaction is taken care of by the modification of the index coefficient Kop in eq. 1 which is not a constant but an expression.

Calibration of the coefficient Kop should normally be provided by an absolute method. The variation of the index coefficient translates the fact that the flow inside the spiral casing evolves with the opening. A simple polynomial expression is usually enough to describe the coefficient evolution with the position. As an index method combines dynamic pressure and streamlines losses, two phenomena that evolve with the velocity square, the index exponent should be fixed at exactly 0.5. Modification of the exponent is no longer necessary because the slight changes in the flow distribution are taken into account by coefficient variation.

$$Q = K_{op} * \Delta P^{0.5} \quad (1)$$

The system remains accurate with head fluctuations and is almost insensitive to adjacent unit operation. This is because the measured pressure difference is sizeable and the distributor acts as a filter that smears local phenomena happening at the inlet. The angular index system provides a description of the flow. To obtain the unit efficiency, it is also necessary to monitor the power output and the head.

2. Experimental investigation of a 200 MW Francis turbine

A first system was installed on a 200 MW Francis turbine. The upstream pressure was taken at the very beginning of the spiral casing while the downstream probes were located in the small space between the guide vane and the runner (figure 2). The main reason for choosing this powerhouse was that an 8 paths acoustic transit time (ATT) flowmeter, previously installed in the penstock, was available as a reference.

First a calibration of the system was needed. For this, the reference data from ATT flowmeter were used to determine the coefficient curve of Kop. The calibration points are presented in figure 3 where the calibration curve appears smooth and predictable. In this case a 2nd order polynomial equation was found accurate enough to describe the coefficient evolution.

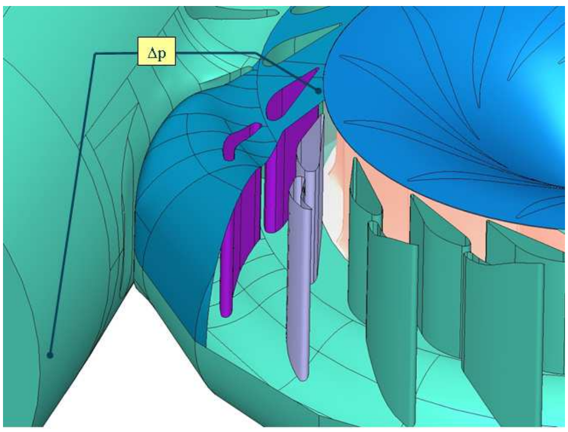

Figure 2 : Angular index installation on a Francis turbine

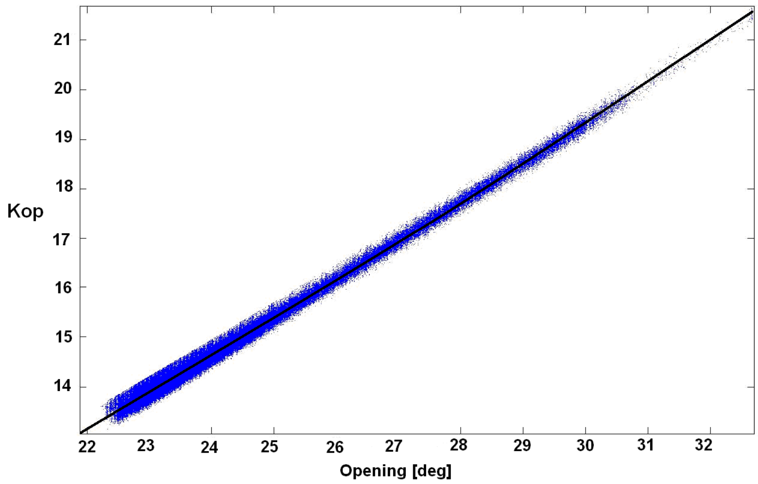

Figure 3 : Calibration of the angular index coefficient Kop

Once calibrated, the evaluation of the performance of the angular index could start. Figure 4 presents 10 days of monitoring for both the ATT flowmeter and angular index method. The period shown was not included in the calibration. The two data series were not discernable one from another which is quite remarkable for two independent methods. Statistical analysis was needed to obtain an objective evaluation of the accuracy of the angular index method and is presented in table 1. While both systems provided excellent flowrate monitoring, the angular index dispersion was half the one of the reference flowmeter.

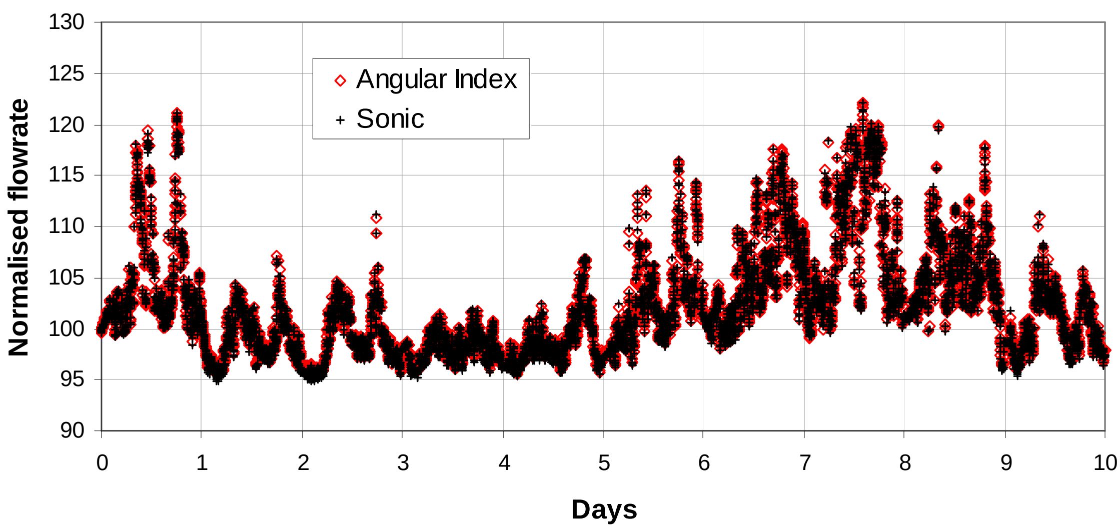

Figure 4 : 10 days of flowrate monitoring for the sonic and angular index method

Table 1. Performance of the angular index for a 200 MW Francis turbine

	Flowrate dispersion	RMS
ATT flowmeter (reference)	+1 m^3/s	0.5 %
Angular index	+0.5 m^3/s	0.2 %

At one point during the measurement, a constant offset between the two methods occurred. At first, it was thought that something went wrong with one of the pressure probes of the angular index but this was discarded after observing that all the pressure probes exhibited the same behavior. The origin of the discrepancy became apparent by plotting the predicted flowrate against the guide vane opening. Then, it appeared that the offset originated from the ATT flowmeter. In figure 5, we can see the two parallel curves for the ATT flowmeter that indicates that the measured reference flow was divided in two series. Distinction between the series was based on the date. The angular index was not affected. Also noticeable in this figure is the spread of the measurement around its mean. Again, it is clear that the angular index method has a very low dispersion and thus is able to predict accurately the flowrate.

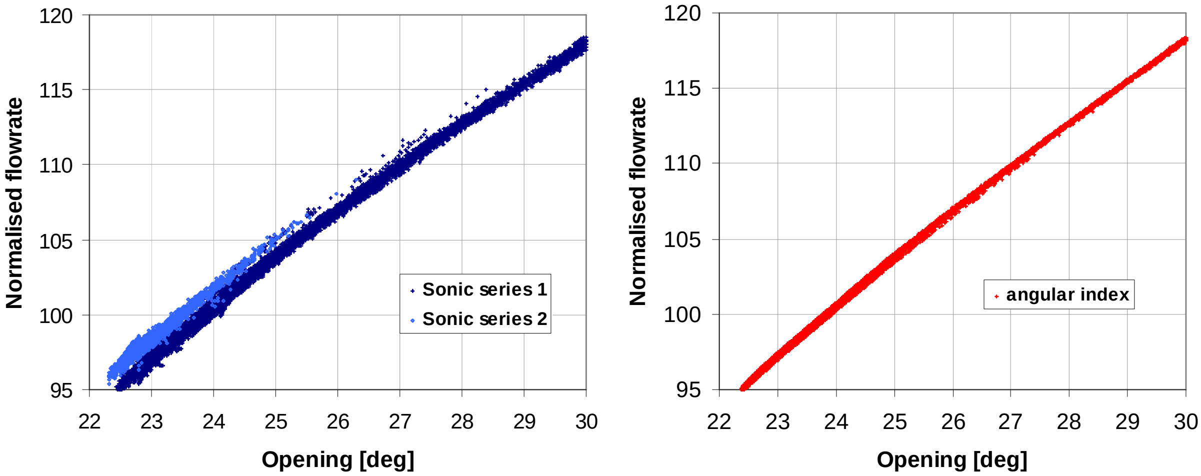

Figure 5 : Flowrate against angular displacement for the ATT reference and angular index

3. Experimental investigation of a 110 MW propeller turbine

A second experimental set of the angular index measuring system was installed on a low head 110 MW propeller. In this case, since there was no pressure probe adequately placed at the semi-spiral casing inlet, one of the outer WK probe was used instead. Because there is ample room between the guide vane and the runner, the downstream pressure probe was installed mid-way on the upper cover as shown in figure 1. The coefficient calibration came from previous measurements that were performed some years before with current meters.

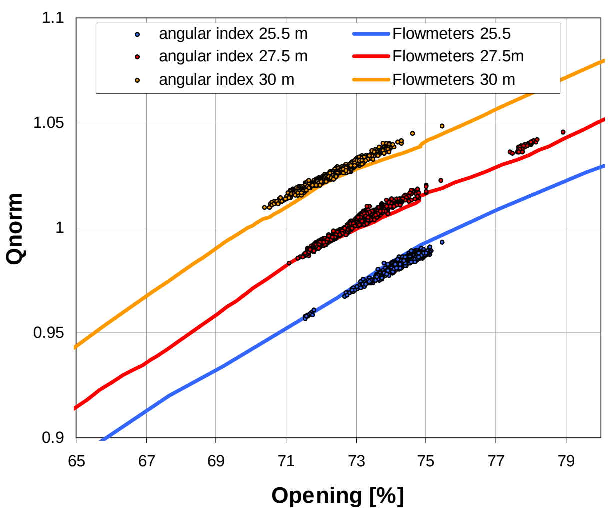

Figure 6 : Comparison of the flowmeter and angular index at various head

The two main interests of testing the system in this powerhouse were to see if the concept was applicable to different types of turbines and to evaluate its performance with head fluctuations. To do this, the data from a two months production period were used. They were classified by head and then compared to the measurements obtained at 3 different heads on a similar unit. In figure 6, we can see that the angular index is able to follow head fluctuations. Also, despite the more complex nature of the flow distribution in the semi-spiral casing and distributor, the flowrate dispersion remained in the same range than with the Francis turbine as shown in table 2.

Table 2. Performance of the angular index for a 110 MW propeller

	Flowrate dispersion	RMS
Angular index	+0.95 m^3/s	0.25 %

Even though there was no continuous reference method that was available for this powerhouse, a simple online monitoring system was designed to follow the turbine flowrate and efficiency. It also allowed to evaluate the effectiveness of the actual automatic power frequency regulation (PFR) procedures and to compare those with optimal ones. To simulate the optimal operating mode, the operator was asked to periodically adjust the opening of the unit. A clear indication of the optimal path (in red) on the efficiency hill was provided along with a band of +/- 3 m^3/s. A capture of the system is presented in figure 7 while the operator did a good job of keeping the group near optimal operation.

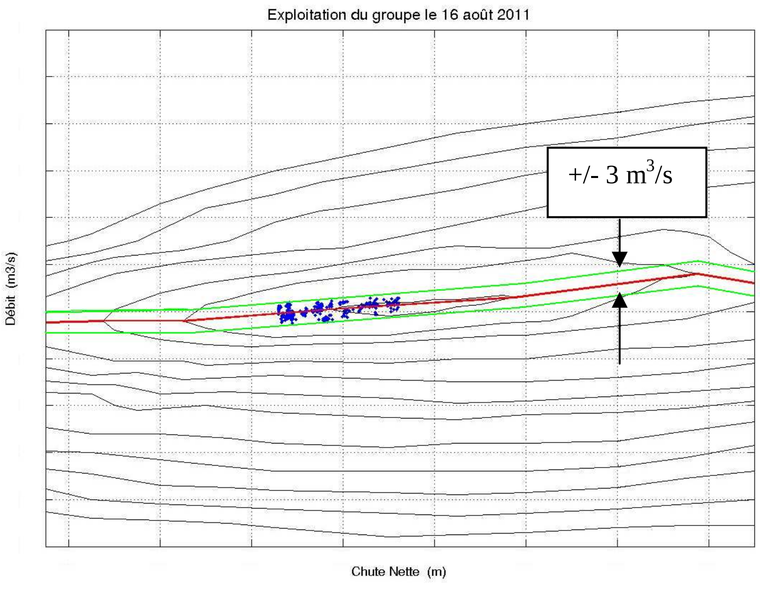

Figure 7 : Flow monitoring during optimal operation (head vs flowrate)

Then, the automatic system took place. It has two different operating modes. In the first one, designed to keep the operation optimal, the automatic system was able to partially correct the required power with the head variation, but was usually struggling to lay on the optimal line (figure 8, left). With the second automatic mode, having less operational constraints, the correction just did not happen (figure 8, right) which led to non optimal operation. Clearly, while it is acknowledged that efficiency is not the only issue here, there might be some room for improvements. The online monitoring system allows just that by providing a clear picture of the turbine operation that would be difficult to obtain otherwise.

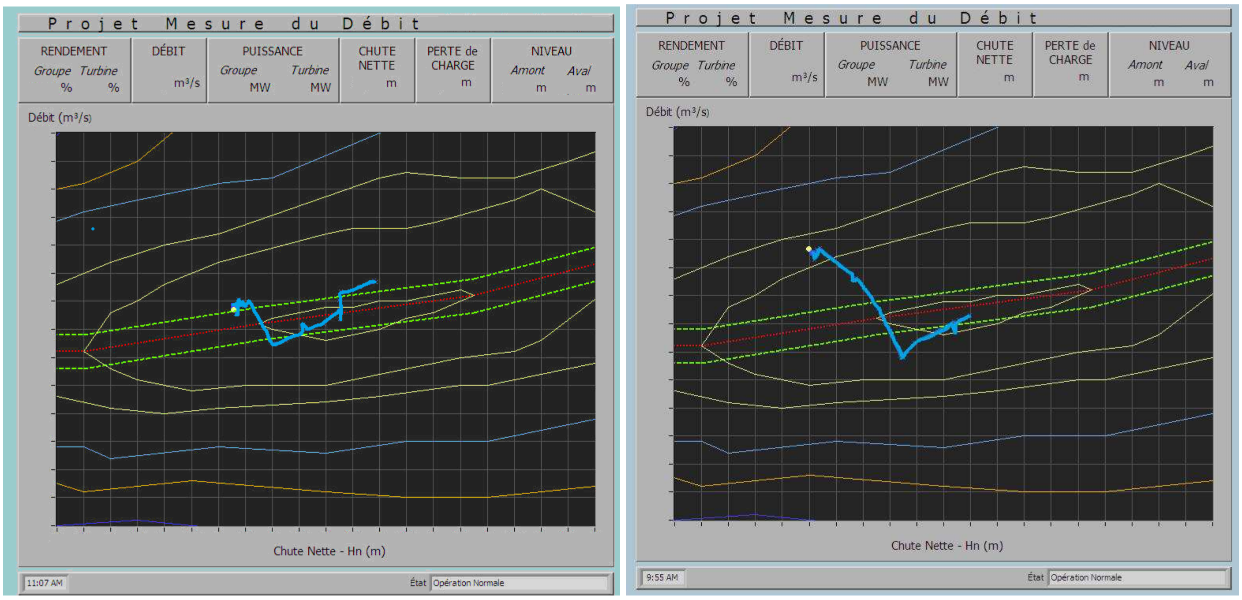

Figure 8 : Flow monitoring during automatic operation of the turbine

4. Description of experimental setup

This section is provided for those who are interested in deploying a similar system.

<u>List of material</u>

- pressure transducer
- angular encoder
- manifold
- bleed valves
- steel tubing & valves
- data acquisition & control system

4.1. Pressure probes

The upstream (or high pressure) tap should be as representative as possible of the low velocity inlet conditions but should be located behind the trash rack. Ideally, probes located at the beginning of the spiral casing should be used. If not available, WK external probes can also provide useful information. The downstream (or low pressure) taps should be linked together with a manifold to average the spiral casing flow non uniformity (figure 9). We found that at least 4 probes were necessary to maintain a realistic average of the flow behind the guide vanes. They should be disposed about 90 degrees from each other in the distributor cover ring. The exact location of the downstream probes is not so important as long as it is the same for each sector. Different positions will lead to different calibrations but the method should remain effective. However, if possible, the wakes of the guide vanes and the lip of the spiral casing should be avoided. In some situations where the flow in the distributor is thought to be strongly non-uniform, more probes could be needed. An important point to mention is that pressure holes can usually be drilled without entering the spiral casing.

It is very important to install automatic bleed valves on pressure probes to make sure that no air enters the system. They should be allowed to work after each startup and on a daily basis to keep the system operational. For the pressure sensor itself, it should be as accurate as possible but keep in mind that it will measure the full head when the guide vanes are closed.

Figure 9 : Manifold for pressure mixing

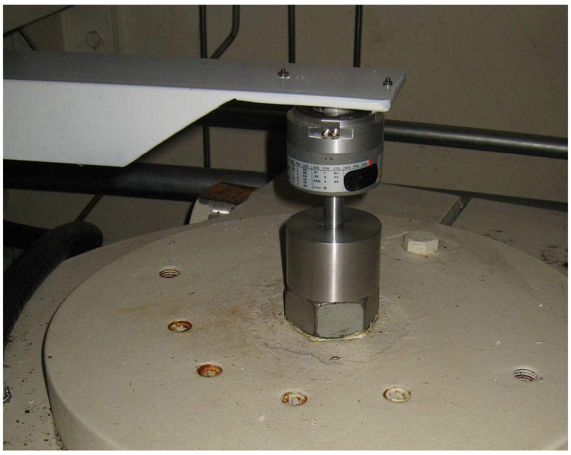

Figure 10 : Angular encoder attached to the guide vane axis

4.2. Position of the guide vane

The angular encoder (figure 10) gives an accurate measurement of the guide vane position and is preferred to servomotors stroke that is easily affected by the operating ring mechanism preloading and might slightly differ from one group to the other. Since the angular index method is very sensible to the position of the guide vane, great care should be taken to obtain the best description of this quantity.

4.3. Calibration of the coefficient Kop

The calibration of the system should be provided by a code accepted method [2] [3]. A number of points on the curve should be adequate. Based on limited experience, a second order polynomial fit is usually enough to describe the variation of the coefficient. Since the system is able to capture moderate head changes, calibration only needs to be performed at one head.

4.4. Acquisition of the signal

It is suggested to average the signal over a period of 300 seconds and to exclude the points where the guide vane moves more than 0.2 degrees. Obviously, the points where the bleed valves are in function should also be excluded.

Conclusion

This paper intended to demonstrate the applicability and usefulness of the angular index. Being a relative method, it is complementary to absolute measurements and open the way for fine tuning hydraulic production. It allows for accurate prediction of the flowrate when head change or other phenomena occur. While being applicable to a variety of turbine, it is one of the only reliable and affordable relative methods that can be used with low head plant to investigate the flow over long period.

Future plans include the design of a new, more industrial, experimental set that should be more accurate and more robust. It should be installed in a number of units for the powerhouse mentioned on this paper. The integration of the online flow data to the various HQ systems also begun. The data will be provided to the various business units who will then decide how to use it.

References

[1] Nicolle J, Proulx G, 2010, *A new method for continuous efficiency measurement of hydraulic turbines*, 8th IGHEM conference, Roorkee, India

[2] IEC 60041 Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines

[3] ASME PTC 18-2011, Hydraulic Turbines and Pumps-Turbines Performance Test Codes