HYDRO-QUÉBEC'S CONTINUOUS FLOW MEASUREMENT SYSTEM: DEVELOPMENT OF AN INDUSTRIAL PROTOTYPE

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ABSTRACT

Increasingly, Hydro-Quebec strives to optimize the efficiency of its turbines and the flow management of rivers. A precise measurement of the turbine discharge is required to optimize its operation. With this knowledge, it is possible to determine the real net head of the turbine in addition to the turbine flow. As an operator of power plants, Hydro-Quebec uses that information to work toward reducing the waste of water while increasing its control of river flow.

Hydro-Québec normally measures the efficiency of its turbines at the commissioning of a typical power plant unit. For the past decade, Hydro-Québec has been measuring the efficiency of all new turbines and is working to do the same for all other existing units. The measurements are taken in average operating conditions (net head, tail water, etc.) and serve to calculate discharge. Thus, the real efficiency outside these conditions is not well known and may produce significant error in estimating discharge, such as in the case of increased head losses due to debris.

Hydro-Quebec has developed a new system to continuously and precisely measure the flow in the turbine and the real net head of the turbine. This new technique uses a pressure differential that provides an accurate measurement (under ± 0.2%) once calibrated. The precision of the continuous flow measurement system is not influenced by head change, operation of adjacent units, head losses, etc.

INTRODUCTION

Increasingly, Hydro-Quebec strives to optimize the efficiency of its turbines and the flow management of rivers. Given the complexity of managing demand, the water reserve, the ecological flow rate, integration of renewables, and production constraints such as vibrations or cascade configuration for power plants, Hydro-Quebec uses its turbines in a variety of configurations. Nowadays, each drop of water is important in order to maximize production efficiency. Knowing how to operate a machine in every condition is a necessity in minimizing energy waste.

Hydro-Québec normally measures the efficiency of its turbines at the commissioning for of a typical power plant unit according to international standards [1][2]. Continuous efforts are also deployed to measure the efficiency of existing units when little information is available. Those measurements are made in average operating conditions (net head, tail water, etc.) and serve to calculate discharge. Once the efficiency curve is measured, the operator can use the power, gross head and wicket gate opening, based on a table associated with the efficiency test, to position the group optimally in order to meet demand.

However, efficiency outside average operating conditions is not well known and this may introduce some production losses. Special operating condition effects (turbine air aspiration, downstream level, cavitation, adjacent group operation, downstream restrictions, trash rack clogging, manifold losses, etc.) are usually not taken into consideration by the operator.

In order to address this problem, Hydro-Quebec has developed a low-cost and universal method to continuously measure the flow in a turbine. A system also provides the intake losses in real time. This article will address this measurement system, from how it works to the possibilities it provides.

1. CONCEPT AND THEORY

1.1 Requirements

Hydro-Quebec has developed a new system to continuously and precisely measure the flow in the turbine and estimate the intake losses of the turbine. This new way of measuring flow needed to overcome many difficulties to be viable and was developed with the following objectives in mind:

- System accuracy has to be very low to reach the maximal gain.
- The measuring concept should be general enough to be applicable to Francis and propeller turbines over a wide range of head.
- The cost of the system itself must be kept as low as possible.
- Installation must be simple and it should be possible to retrofit any existing group.
- The system must be stable and provide reliable data in all operating conditions.

1.2 Theory

Given these constraints, the project was naturally oriented towards index measurements. The principle of measurement is based on a pressure differential (Figure 1) that is proportional to the turbine discharge. The pressure differential is taken between the spiral casing inlet and the vaneless space between the distributor and the runner. In many ways, it is similar to the Winter-Kennedy (WK) method, but it uses a slightly different equation. The coefficient k cannot be a constant anymore but is now a function of the wicket gate opening. Also note that the variability in the pressure exponent is no longer necessary. More details about the development of this equation can be found in [3][4].

$$Q = k(wg) * \sqrt{\Delta p} \tag{1}$$

Q	flow rate	(m^3/s)
k(wg)	coefficient function of the wicked gate opening	$(m^{3.5}\,kg^{-0.5})$
Δp	pressure differential	(kPa)

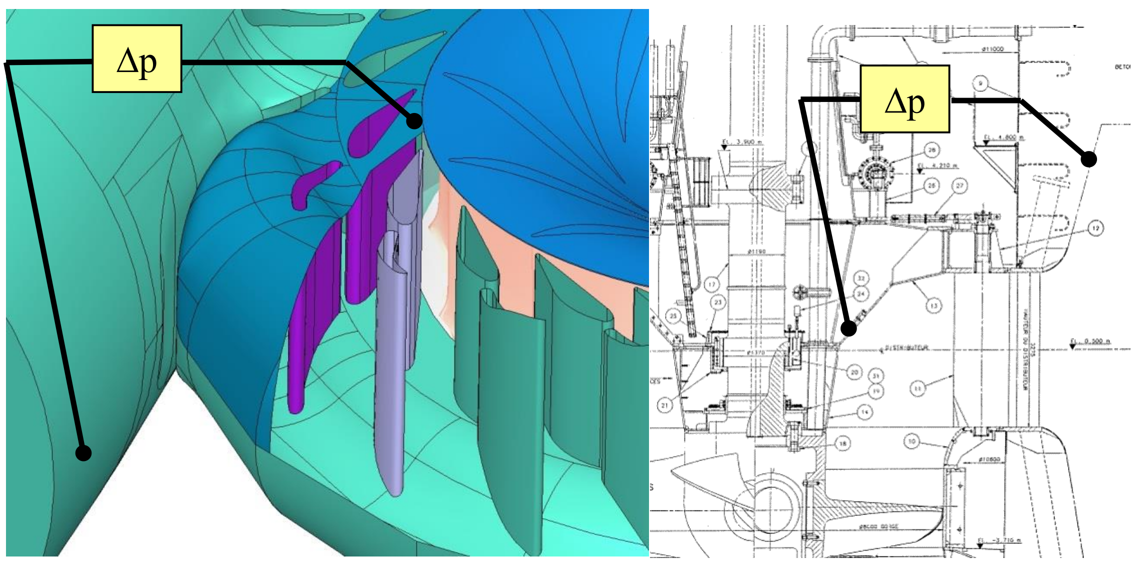

Figure 1 – Location of the differential pressure measurement for a Francis and a propeller turbine

1.3 Localization of pressure probes

As shown in Figure 2, the flow speed on the downstream side of the wicket gates is much higher than the case entrance. This translates into a pressure differential much higher than in the WK measurement (differential of two pressures inside the same radius in the casing). Instead of being a few kPa, the measured pressure can reach about half the head of water of the power plant. Consequently, the precision of the measurement increases since it is easier to measure.

The high pressure of the differential comes from the spiral or semi-spiral casing inlet. When available, the best location is from four piezometers at the entrance of the case. Otherwise, any other pressure tap from the case is usable by this system. When multiple pressure taps are used, a manifold is used to average them.

The lower pressure is measured between the turbine and the wicket gates. Four piezometers are installed on the head cover to ensure the stability of the measurement. The pressure is then averaged in a manifold. With four piezometers, the error introduced by a redistribution of the flow among the distributor sectors is mostly cancelled. The flow in this section is normally accelerating, which prevents flow separation and allows for greater precision in the measurement. These piezometers must be placed with great care. On a normal machine, the four pressure taps can be placed at 90° of each other. When the placement of the piezometers becomes complex, the use of a computer fluid dynamic calculation can be useful to help determine the best location.

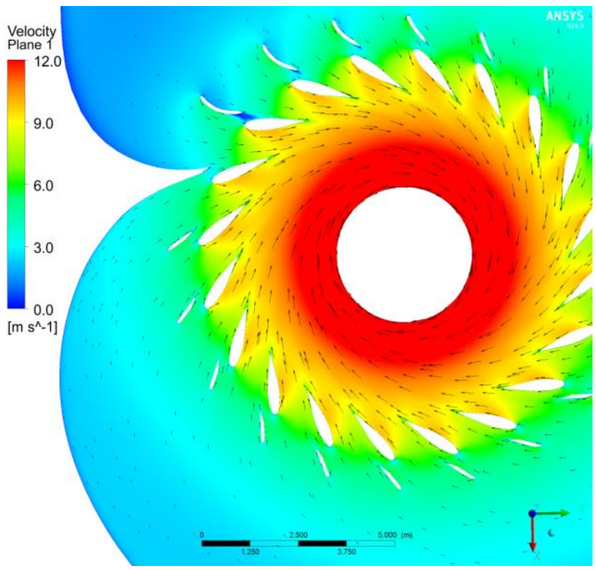

Figure 2 – Flow speed mapping in the distributor

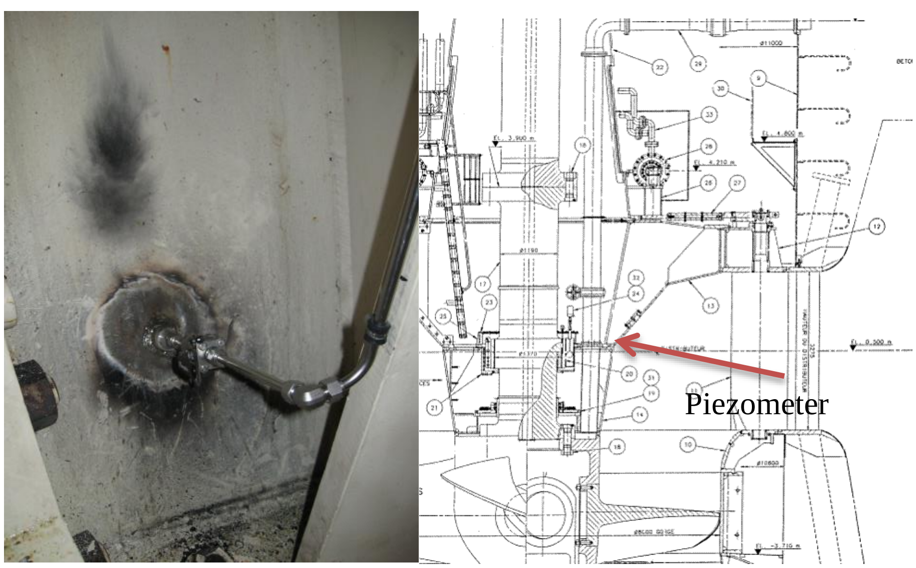

Figure 3 – Example of head cover piezometer placement

The localization is also influenced by the feasibility of the installation. On an existing turbine, the piezometer placement must be reachable from the inside of the power plant to lower the cost of the installation. In Figure 3, the placement has been chosen because it is easily reachable. On a new turbine, the piezometers can be installed when the machine is built.

1.4 Calibration

In order to make the Hydro-Quebec continuous flow measurement system operational, the coefficient k(wg) must be calibrated with an absolute measurement. Ideally, calibration and absolute flow measurement should be performed simultaneously. Using multiple absolute flow measurements with eq. 1, a relation between the coefficient k(wg) and the wicket gate opening can be found. A polynomial of degree 4 to 6 is usually enough to describe the relation as shown in Figure 4. Error introduced by the relation is also shown.

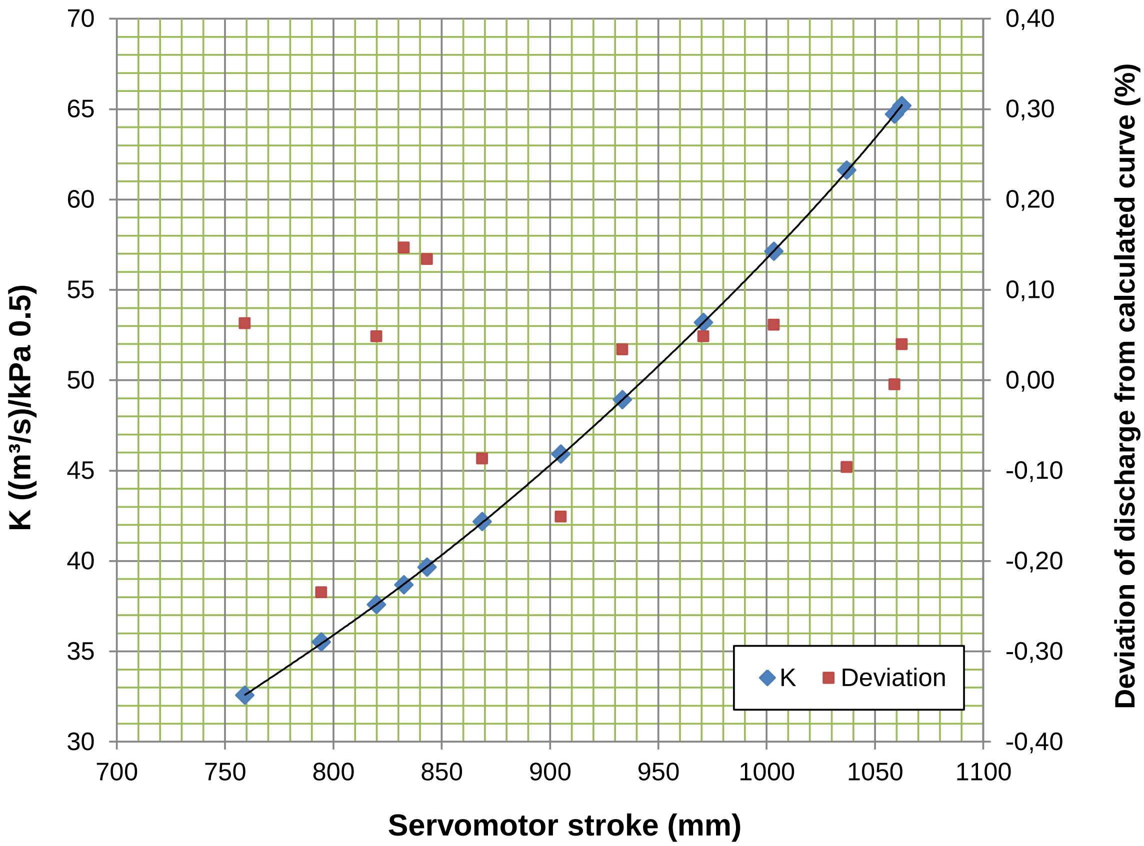

Figure 4 – Coefficient k(wg) and the error on the flow calculation

When the measurements of the pressure differential cannot be executed at the same time as an absolute flow measurement, it is still possible to calculate the coefficient k(wg) for many wicket gate openings by recreating the conditions of the existing absolute flow measurement. Given that the value of the coefficient is mostly geometrical, and that it translates the acceleration taking place in the distributor, CFD calculations can also be used to provide some insight into its evolution.

2. SYSTEM DESIGN

2.1 Components

Given that it is based primarily on a pressure difference, Hydro-Quebec's continuous flow measurement system design naturally started with the choice of the pressure transducer. Figure 5 contains a diagram representing how the system is installed.

The pressure transducers were chosen to meet system requirements. They have a precision of ± 0.025%, an adjustable span of 200:1, a guaranteed operating stability of 10 years and a reliability of 12 years. The transducers can then be calibrated precisely to the measured span of pressure. Each system uses three transducers. The first one is used to directly measure the pressure differential. The second transducer measures pressure at the intake and is required to provide the intake losses. The third one, measuring head cover pressure, was included to provide some system redundancy.

The transducers communicate with the numerical Foundation Fieldbus protocol. This protocol allows the pressure transducers to be powered and to communicate on only one cable. Diagnostics and alarms are also available.

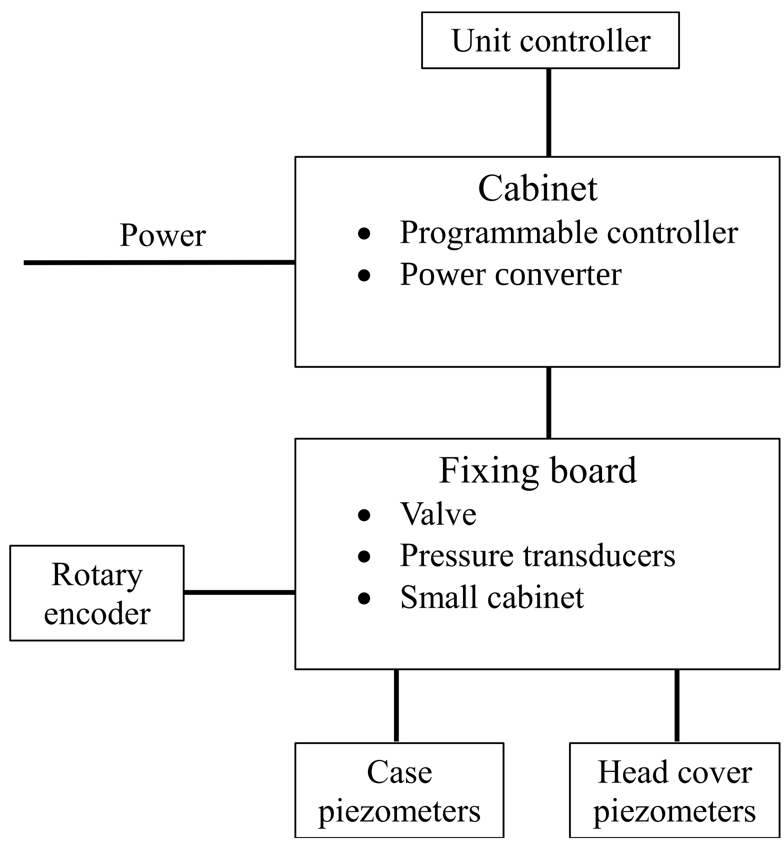

Figure 5 – Diagram of the continuous flow measurement system

The angle of the wicket gates is measured by placing a numerical Ethernet absolute rotary encoder on the top of the rotation axis of one wicket gate. It has a resolution of 18 bits (0.0014°).

To ensure high reliability, the tubing used to carry the pressure to the transducer must be purged regularly. An electric valve is controlled by an Ethernet analog output. The valve position is also monitored.

All the information is sent to a programmable controller, which communicates with all the components. The controller calculates the flow with the pressure differential and the wicket gate opening. With the flow known and the pressure at the entrance of the turbine, it is possible to calculate the net head at the intake, which can be combined with the upstream level to obtain losses in the penstock and the trash racks.

Also, with the intelligent transducers and components, the programmable controller monitors all the component alarms and can determine the validity of its measurements. The flow, the intake losses and the system state are then sent to the operator through the SCADA system.

2.2 Installation

The continuous flow measurement system is made in two parts. One part has the three pressure transducers and the purge valve. It is a fixing board with a small cabinet and is normally installed in the turbine well where the top of the wicket gates and the head cover are accessible. The rotary encoder is plugged into the small cabinet.

This board communicates with another cabinet, which is usually installed on the alternator floor for easy access. The programmable controller is located in the cabinet. The power is supplied to the cabinet, which sends some of it to the other cabinet on the board. The operator controller communicates with the programmable controller in this cabinet.

2.3 Cost

Many research projects are unable to evolve into industrial products even if they offer innovative solutions to existing problems. Often, a misunderstanding of the day-to-day production reality and a lack of communication between the different actors are to blame. Here, great care was taken to meet the various actors and to integrate their consideration as much as possible. Cost being an obvious factor, here are a few decisions that were taken to ensure the design of the system would be accepted.

The system is fully integrated into one programmable controller that can communicate with every component. This helps reduce the amount of equipment required to make the system work. The simple design reduces the purchasing and installation costs. The intelligence in the transducers and in the programmable controller reduces the routine maintenance to required actions only.

Many steps were taken to further reduce costs as much as possible. The numerical protocols reduce the number of communication and electrical cables, which further decreases the installation time. Use of industrial flexible hoses for pressure tubing instead of welded pipes can also reduce installation time and costs.

The pressure taps in the spiral casing are usually already in place in most of the power plants. The four pressure taps on the head cover are normally accessible from the turbine well. In existing power plants, those piezometers can be installed (piercing and tubed) without any scaffolding. This translates into lower downtime and faster installation.

Other steps were taken to lower the overall cost of the system. While the first system needed a signal to know if the group was in operation, this cable was then eliminated using logic from the programmable controller. Also, the bended tubes on the first version of the transducer fixing board required to link the manifold and the sensors between them were replaced by standard elbow connectors for uniformity and easier assembly and reduced construction time.

CONCLUSION & FUTURE APPLICATIONS

This paper highlighted the choices made for an online flow monitoring system from the research phase to production. This is a major step for every innovation and requires a lot of technical and communication skills. Many steps were taken to minimize the number of components and lower installation and maintenance costs as much as possible. The industrial prototype is now made of a transducers' fixing board and an electronic cabinet. This system requires some form of calibration to be operational.

Today, the system is currently installed on four different HQ turbines. Information gathered from these systems is still being processed to determine how much value they can generate. While no decisions have yet been made regarding the large-scale deployment of this technology, it is now mature and ready to be installed when necessary.

The Hydro-Quebec continuous flow measurement system can be pushed further to integrate the measurement of power, upstream and downstream levels to calculate efficiency in real time. A radar system was already added to one installation. Over time, the operators could determine the efficiency hill over the whole span of conditions of operations. With this information, the system could indicate to the speed regulator how to optimize its current operation. Constant flow rate operation, which is known to be a very efficient way to optimize operations for low head plants, could be achieved.

The system could also be used to optimize multiple turbines to obtain the best efficiency for the required power.

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