Flow measurements at two 1.4 MW units of the T.W. Sullivan Plant of Portland GeneralElectric

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ABSTRACT

Portland General Electric (PGE) retained ASL AQFlow to conduct relative flow measurements at units 10 and 11 of the T.W. Sullivan Hydroelectric plant, located in West Linn, Oregon, in early 2005. The plant's 13 units (1.4 MW each) underwent a complete overhaul in 1954. During the second half of 2004, Units 10 and 11 received a runner and wicket gate upgrade. At the same time, modifications to the forebay were made.

The units do not have a conventional scroll case inlet to the propeller runner. Instead, a 6 ft long, 10 ft diameter 'penstock' leads to a 27 ft diameter chamber. This configuration has been described as an "open-flume" intake. Consequently, scroll case piezometer taps were not an option at TW Sullivan.

Instead, index flow measurements were conducted with AQFlow's acoustic scintillation flowmeter, to identify optimum wicket gate opening for maximum efficiency. Given the difficult hydraulic conditions, this objective has been achieved.

Introduction

ASL AQFlow (ASL) was retained by Portland General Electric (PGE) to conduct flow measurements at units 10 and 11 of the T W Sullivan Hydroelectric plant, located in West Linn, Oregon between January 31st and February 4th, 2005. The plant's 13 units (1.4 MW each) underwent a complete overhaul in 1954. During the second half of 2004, Units 10 and 11 received a runner and wicket gate upgrade. The generators were also rewound. As part of the upgrade, a training wall was added in the forebay in order to improve fish passage. The modifications to the forebay created strong currents along the face of the trash rack just upstream of the penstock inlet.

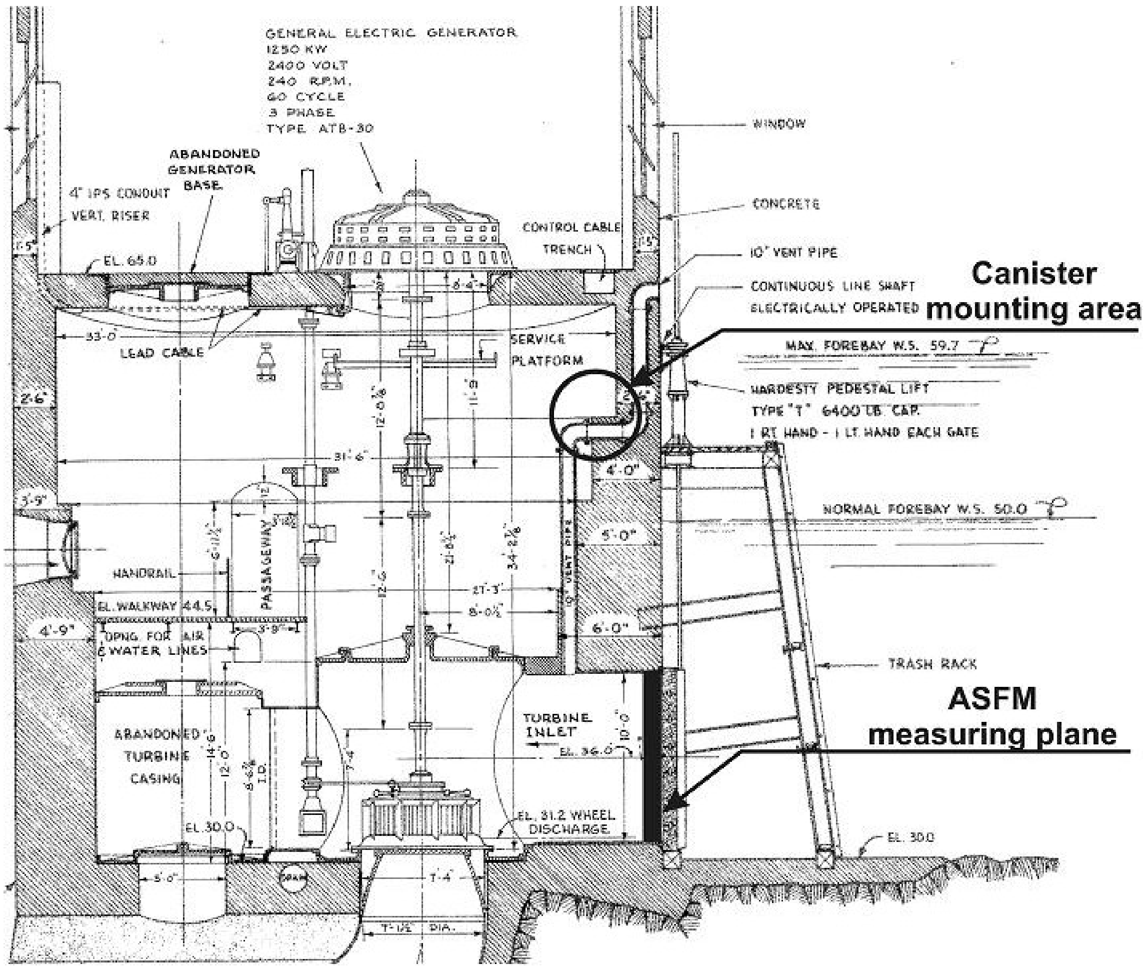

Fig. 1: Cross-section of the Unit

As shown in **Fig. 1**, flow enters the unit through a short (6 ft) circular (10 ft diameter) penstock. From there, the flow enters a large circular chamber. Due to this configuration, traditional Winter-Kennedy pressure taps cannot be used. Both Units 10 and 11 use fixed-blade propeller turbines. The wicket gate position is the only adjustment. The flow out of the draft tube of Unit 10 has a relatively straight path out to the tailrace. The draft tube of Unit 11 discharges against a concrete abutment where the water is forced to make a 90-degree turn (**Fig. 2**).

Flow measurements in units 10 and 11 were required to identify the optimum unit output power and wicket gate opening for maximum efficiency, and the Acoustic Scintillation Flow Meter (ASFM) was selected for these measurements.

Fig. 2: Discharge from Unit 11 draft tube

ASFM Operation

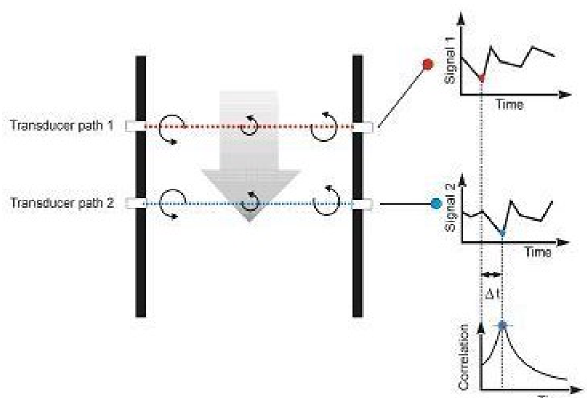

Fig. 3: Acoustic scintillation operating principle schematic

In its simplest form, an array of two transmitters is placed at one side of the intake, and an array of two receivers is placed at the other (**Fig. 3**). The signal amplitude at the receivers varies randomly in time as the distribution of turbulence along the propagation path changes with time and flow. If the two paths are sufficiently close, the turbulence remains 'embedded' in the flow and the pattern of the signal variations (scintillations) at the downstream receiver will be nearly identical to those at the upstream receiver, except for a time delay. The mean flow velocity is then the transducer separation distance divided by the time delay. With the use of an additional, vertically-separated element in each of the arrays, the average magnitude and average inclination of the velocity are measured at several levels. The discharge is then calculated by integrating the horizontal component of the velocity at each level over the total cross-section of the intake, providing results in real time.

During the last 10 years, the acoustic scintillation technique has been used effectively in more than 25 low-head, short-intake hydroelectric plants, mostly in North America.

Installation at TW Sullivan

As no suitable rectangular section and gate slots for the classical ASFM frame installation **[1]** were available at TW Sullivan, a circular fixed measurement frame, made to fit inside the 10 ft dia penstock, was used instead. In total, 9 horizontal paths and 5 vertical paths were installed as shown in **Figs. 4, 5 and 6**.

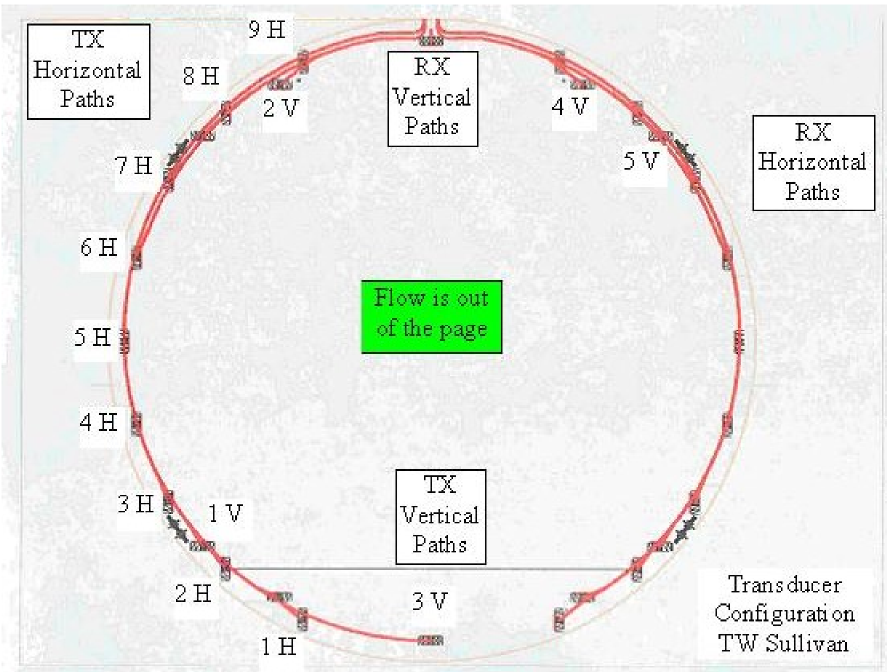

Fig. 4: Layout of the horizontal and vertical measurement paths

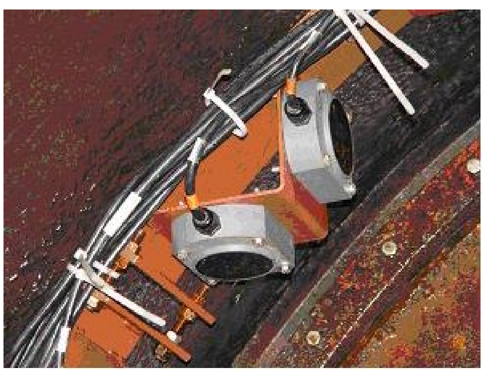

Fig. 5: Detail of transducer installation

On January 31st, 2005, ASFM transducers were installed on the frame in unit 10, which had already been bolted in place in the penstock, and system verification tests were carried out. Flow measurements commenced at 09:10 on February 1st, 2005 and were completed by 18:30. Flows were measured for 12 separate gate settings. At each setting, flow measurements were repeated 3 times and a standard deviation calculated. If the standard deviation of the flow measurements with the horizontal paths exceeded 2%, horizontal path flow measurements were repeated. In total, 16 flow measurements were obtained with the horizontal paths and 12 with the vertical paths.

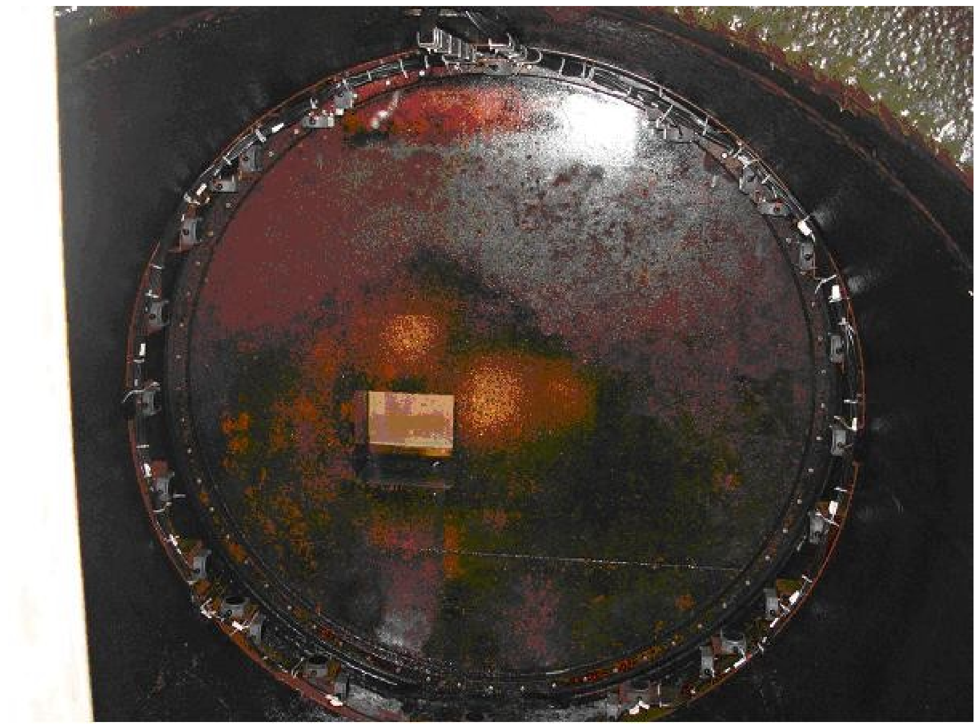

Fig. 6: Completed installation (Unit 10*)*

On February 2nd, the ASFM equipment was removed from Unit 10, installed on Unit 11, and ASFM system verifications conducted. On February 3rd, flow measurements were conducted on Unit 11, starting at 08:34 and finishing at 17:15. On February 4th, ASFM equipment was removed from Unit 11 and repacked for return shipment.

Discussion of Results

The brackets for mounting the transducers positioned them away from the penstock walls, so the flow behind the transducers was not sampled. The flow in that region and the form of the extrapolation to the boundaries in the integration were estimated using a CFD simulation.

The largest source of uncertainty in the unit efficiency measurements comes from the flow measurement. There are uncertainties in the head and power data, but they are relatively insignificant when compared with those in the flow data. For that reason, the error in the calculated efficiency is essentially the same as the error in the flow data. The uncertainty in the flow values consists of a random component and a systematic component. The random component refers to the level of variation in repeated measurements made under the same conditions, and arises from real fluctuations in the quantity being measured and noise in the instrumentation. The average of the repeated runs is the best estimate of the true value of the quantity being measured, and the error in that estimate decreases as the number of repeated measurements increases. The systematic component arises from biases in the instrument, or from the effect of external conditions on it, and is not reduced by repeated measurements.

Three repeat measurements of the flow were made for each gate setting at each unit. The random uncertainty in the average flow at each measured gate may be estimated from the standard deviation of the repeat runs at that gate. At the 95% confidence level, that value is:

$$S_X = t \cdot \sigma$$

where σ is the root-mean-square deviation of the N measured flow values and t is the Student's t-statistic for N-1 degrees of freedom. Standard deviations and random errors are summarized in **Table 1** below.

Table 1: Standard Deviations and Random Error of Repeated Runs

	Horizontal Paths		***Vertical Paths***	
	Standard Deviation (%)	Random Error with 95% confidence interval (%)	Standard Deviation (%)	Random Error with 95% confidence interval (%)
Unit 10 Average	***1.30***	***3.8***	***2.97***	***8.7***
Unit 10 Maximum	*2.99*	*8.7*	*5.11*	*14.9*
Unit 11 Average	***1.52***	***4.4***	***2.57***	***7.5***
Unit 11 Maximum	*3.24*	*9.5*	*3.82*	*11.2*

During the measurements, eddies (**Fig. 7**) were observed to develop along the trash rack face. They were about 7 to 10ft in diameter and had a period of about 7 seconds (i.e., every 7 seconds one of these eddies passed in front of the penstock entrance). It is suspected that these eddies contributed significantly to the random variability in the flow data.

In **Fig. 7**, flow arrives from the rear between the training wall on the right and the trash rack (and face of the dam) on the left. Water then makes a 90 degree turn into the intake. A portion of the water also travels between the trashrack and the concrete face of the dam (**Fig. 1**).

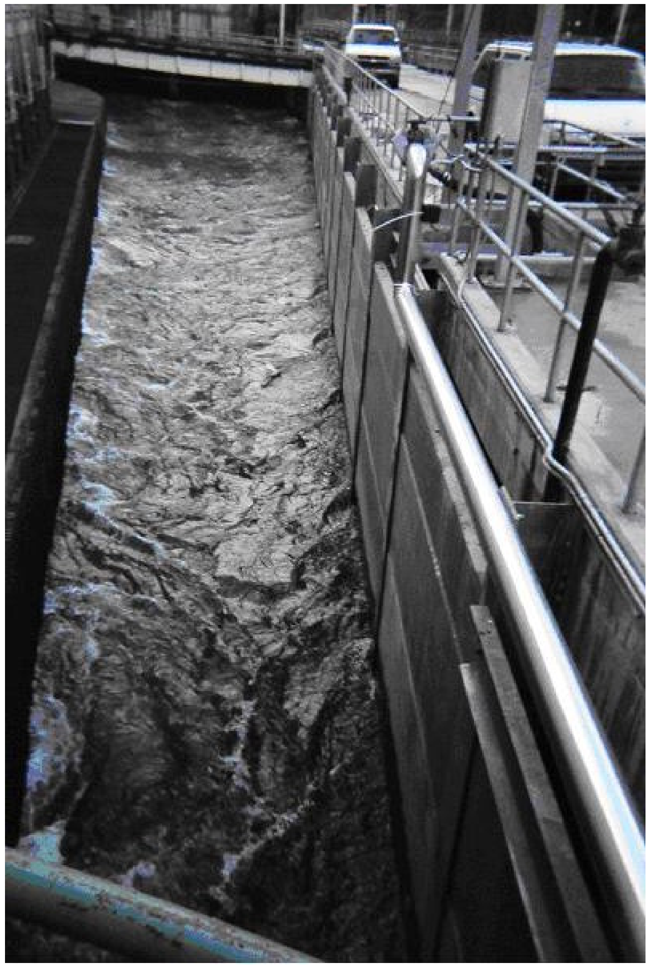

Fig. 7: Eddies at the Trash Rack in the forebay

The purpose of the measurement program was to conduct an index or relative flow measurement, to determine the maximum efficiency point for Units 10 and 11. It was accepted that accurate absolute flow measurements would not be possible, as the hydraulic conditions at the penstock entrances at TW Sullivan are sufficiently difficult and unsteady to result in a significant systematic error in the discharge measurements. Possible sources for such errors are in the estimation of the flow in the regions not sampled by the ASFM (the boundary zones and the region behind the transducers) and in possible biasing of the ASFM velocity values by non-uniformities in turbulence intensity and velocity along the acoustic path, arising from the effects of the wakes from the larger trash rack members and the oblique entrance flow.

Based on the results listed in **Table 1**, the random uncertainty is estimated at ±4%

Conclusions

The flows derived from the horizontal paths have lower variability than flows derived from the vertical paths. In other words, the results from the horizontal paths were more repeatable. This may simply be a result of having fewer vertical paths. Based on this, the flows from the horizontal paths have been used to define the optimum gate opening.

There is evidence of eddying in the approach flow to the unit entrances, which likely contributed to the size of the random variability in the flow data.

The ASFM measurement program at TW Sullivan produced flow data with sufficient repeatability to achieve its target of defining the peak efficiency point of each unit in spite of the difficult hydraulic conditions at the penstock entrances. The objective of identifying the optimum wicket gate opening for maximum efficiency was attained.

Acknowledgements:
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References:
1. Lemon, D.D and J. Lampa, Cost-effective turbine flow measurements in short intakes with acoustic scintillation, Hydro 2004, Portugal

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