The Acoustic Scintillation Flow Meter - A breakthrough in short intake turbine index testing

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Introduction

After many years of relatively little technological progress in turbine discharge measurements in short intakes of low-head plants, the Acoustic Scintillation Flow Meter (ASFM) now offers a significant improvement. In recent years, several North American plant owners have discovered the ASFM's unprecedented ease of use and labour and cost effectiveness in producing highly repeatable discharge measurement results under very demanding hydraulic conditions prevalent in these short, rapidly converging intakes. Personnel from one utility recently estimated that in comparison with the current meter method, the ASFM saves a minimum of 10 to 20% of the cost of instrumentation procurement, installation and field testing and, often more importantly, at least two days of generation outage.

The paper briefly describes the ASFM technology and its application in turbine index testing during the last 5 years. The results from repeat measurements carried out at a number of North American hydroelectric projects are given in detail, demonstrating the ASFM's capability to produce repeatable results with an acceptable - on average, about ± 0.5% - random uncertainty in these hydraulically difficult intakes. It is noted that acceptable precision was obtained even when these intakes were equipped with fish diversion devices. The cost-effectiveness of using the ASFM is further illustrated by examples of the efficiency gains obtained from improved operation of poorly indexed or adjusted units.

1. Background

Index testing is widely used as a method of determining the relative efficiency of a turbine, often with the Winter-Kennedy method. In order to ensure satisfactory performance, the pressure taps must be frequently purged. Further, as the unit ages, or as a result of any configuration changes (retrofit, refurbishment, introduction of fish diversion devices, etc.), the index-testing tool must be recalibrated, i.e. the absolute flow rate measured by an independent method. Calibration is also required if the maximum efficiency of a unit, plant or a system is to be achieved.

Historically, current meters mounted on frames have been used to take these absolute flow measurements. However, their use is slow and labour intensive, or even unfeasible with fish-screened intakes. In contrast, as illustrated in this paper, the ASFM performs both the absolute and relative flow measurements faster and cheaper, and with acceptable precision. Recently (Ref. 1), the Independent Technical Review team report prepared for the U.S. Army Corps of Engineers stated that "…while measuring Kaplan turbine discharge … attaining a precision uncertainty of <±1.0% is feasible, and acoustic scintillation may therefore be acceptable to be used to obtain relative discharge measurements…". The report continued by saying "In the final analysis, the efficiency gains obtained by applying current state-of-the-art acoustic scintillation may significantly outweigh the losses resulting from continued operation of poorly indexed or adjusted units."

2. ASFM Operation

The ASFM utilizes the natural turbulence embedded in the flow. As shown in Fig. 1, two transmitters are placed on one side of the intake, two receivers at the other. The signal amplitude at the receivers varies randomly as the turbulence along the propagation paths changes with time and the flow. If the two paths are sufficiently close (Δx), the turbulence remains embedded in the flow, and the pattern of these amplitude variations (known as scintillations) at the downstream receiver will be nearly identical to that at the upstream receiver, except for a time delay, Δt.

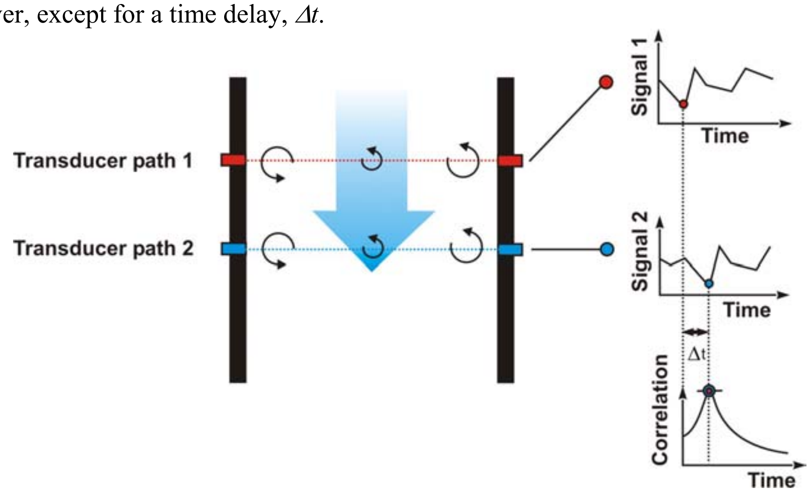

Fig. 1: Representation of ASFM operation

The mean (taken along the acoustic path) velocity perpendicular to the acoustic paths is then $\Delta x/\Delta t$, and because three transmitters and three receivers are used at each measurement level, the average inclination of the velocity is also obtained. The total discharge is then calculated by integrating the average horizontal component of the velocity at several pre-selected levels over the total cross-sectional area of the intake.

The ASFM mounts pairs of arrays of acoustic transducers on opposite sides of fixed or movable support frames, which are lowered into the intake stoplog or gate slots (Fig. 2). This permits its use in even the shortest intakes. It also minimizes the required plant downtime during installation and removal, does not require intake dewatering and, in multiple unit plants, permits repeated use of the same frame without removal/reinstallation of the equipment from/to the frame. No instruments are required in the measurement zone, which minimizes interference with the flow, and there are no moving parts requiring maintenance and calibration.

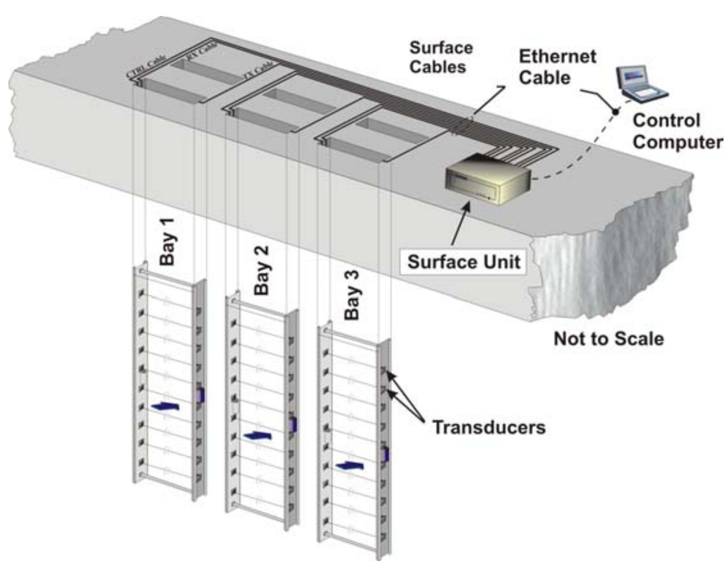

Fig.2: ASFM typical arrangement

3. Performance tests with the ASFM

To date, the ASFM has been used successfully in some 25 field measurements. Ref. 2 described the random uncertainties associated with the January/February 2002 ASFM measurements at the Lower Monumental plant on the Snake River in the northwest United States. In addition, repeat measurements have been carried out at the Little Goose (Snake River, Washington), Wells, John Day and McNary (Columbia River, Washington and Oregon) plants, all in the northwest United States.

Plant and Unit #	Fish Screens Installed	# of repeats	Before Generation Correction		After Generation Correction	
			Standard Deviation (%)	Random Uncertainty at 95%	Standard Deviation (%)	Random Uncertainty at 95%
McNary #5	NO	4	0.24	0.67		
McNary #5	YES	4	0.34	0.94		
McNary #5	COMBINED	8	0.28	0.65		
John Day #9	YES	5	0.30	0.77		
Lower Monumental #2 and #6	NO	6*	0.29	0.71	0.15	0.37
Lower Monumental #2 and #6	YES	21*	0.39	0.81	0.26	0.54
Lower Monumental #2 and #6	COMBINED	27*	0.37	0.76	0.24	0.49
Wells #3	NO	16+	0.30	0.64		
Little Goose #3	YES	11*	0.62	1.36	0.29	0.64
Average for all tests						
without screens		26	0.28	0.67	0.15	0.37
with fish screens		41	0.41	0.97	0.28	0.59
combined with and without screens		67	0.35	0.84	0.23	0.52

Table 1: Results of Repeat Tests

It should be noted that some of the repeat tests (shown with an *) were a mixture of on-cam and off-cam tests, with mostly two-repeat tests of 2-minute per level duration each (20 minutes total time, for 10 levels), where the individual test blade/vane openings were not always identical (and thus not strictly in compliance with the code requirements). For these tests, in addition to corrections for the head variation, corrections were also made for the blade or gate non-repeatability. The generation output, also corrected to the specified conditions, was used for these corrections. Because the generation output is measured independently from the measurement of the flow, and because the efficiency near the best cam position can be expected to remain nearly constant for these relatively small blade or vane changes, such corrections are considered justified and appropriate, as they reflect true precision capabilities of the ASFM. Results both without and with the generation correction are presented in order to generate discussion on the merit of this methodology for those tests where identical blade/vane settings cannot be assured.

One test (indicated with an +), consisting mostly of three-repeats and also of 2 minute per level duration, was carried out in immediate succession and thus with identical head and blade/vane settings. As seen in the table, and as would be expected, the random uncertainties associated with this test are at the low end of the results range, without correction for generation. It is expected that if the testing were done with five-repeat tests, in immediate succession and thus identical head, blade/vane settings, the random uncertainty would decrease further. However, such reductions in random uncertainty would have to be weighed against a somewhat longer period of time required to perform the tests.

In fact, in an attempt to shorten the overall time required to perform the testing, during the testing at Wells the 2-minute sampling period was temporarily shortened to 30 seconds. As would be expected, this resulted in a significant increase (by as much as a factor of 2) in the resulting random uncertainty. Thus, the code prescribed minimum of 2-minute duration of measurement for each run for the current meters has been indirectly confirmed as valid for the acoustic scintillation. And just as for the current meters, in cases of long period pulsations, it may be necessary to extend the duration beyond the 2 minutes.

It is of interest to note, based on the comparisons in the above table between the intake configuration with and without fish diversion devices, that the ASFM appears to produce repeatable results even under the dramatically worsening hydraulic conditions associated with the fish diversion devices. This makes the ASFM a particularly useful tool for calibrating the Winter-Kennedy piezometers under such intake configurations (Ref. 3). In addition, the measured efficiency loss (Ref. 4 and 5, Fig. 3) associated with the introduction of such fish diversion devices facilitates valid cost comparisons being made.

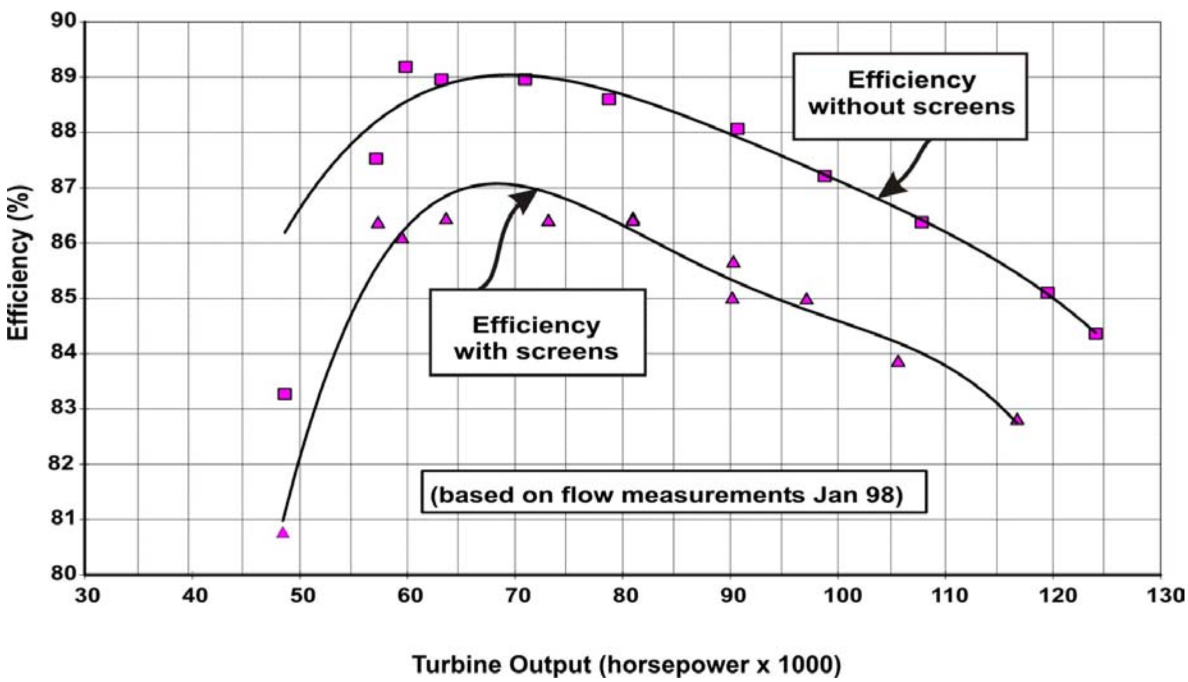

Fig. 3: McNary Unit 5 – Effects of fish screens (adapted from Ref. 4)

Another interesting feature of the ASFM, which is not reported in Table 1 directly, is its apparent insensitivity to the neighbouring unit operation. During the measurements at Little Goose Unit 3, Unit 4 was shut down, however the Unit 2 output varied from 86 to 99 MW for one (22.8 degrees) blade angle configuration, and from 0 to 110 MW for another (24.8 degrees). In spite of these large fluctuations in the neighbouring unit operation, the ASFM measurement repeatability appeared mostly unaffected (less than 0.25% increase in random uncertainty). While further work on this aspect of the ASFM performance will be required, if the findings from the Little Goose test can be confirmed, this could have a significant impact on the number of restrictions which need to be placed on the operation of neighbouring units during flow measurements, and thus on the overall cost (or even practicability) of such measurements.

Depending on the number of operating conditions tested and, to a limited extent, on the number of measurement paths, each unit test has taken between two and three days. For unusual intakes, pre-measurement testing may be required in order to optimize the elevations for the individual measurement levels. At Wells, for example, a 30 level pre-measurement was done in each bay separately, before the 10 levels were selected for each bay for the measurement proper. The initial installation and measurement of the transducers on the frame has to be done before the measurement, typically on a frame lying horizontally in the yard, for the first unit to be tested. For all subsequent units, the frame – complete with the transducers – is simply moved between measurements, saving additional time and expenses.

4. Summary

Based on the above performance tests results, the ASFM has proven its capability to produce repeatable measurement results with acceptable random uncertainty (on average about ±0.5%) in short, converging intakes of low-head plants, even when these intakes are equipped with fish diversion devices and, possibly, with relatively few restrictions on the operation of the neighbouring units. Furthermore, the ASFM produces these results with unprecedented ease of use and previously unavailable efficiency of use.

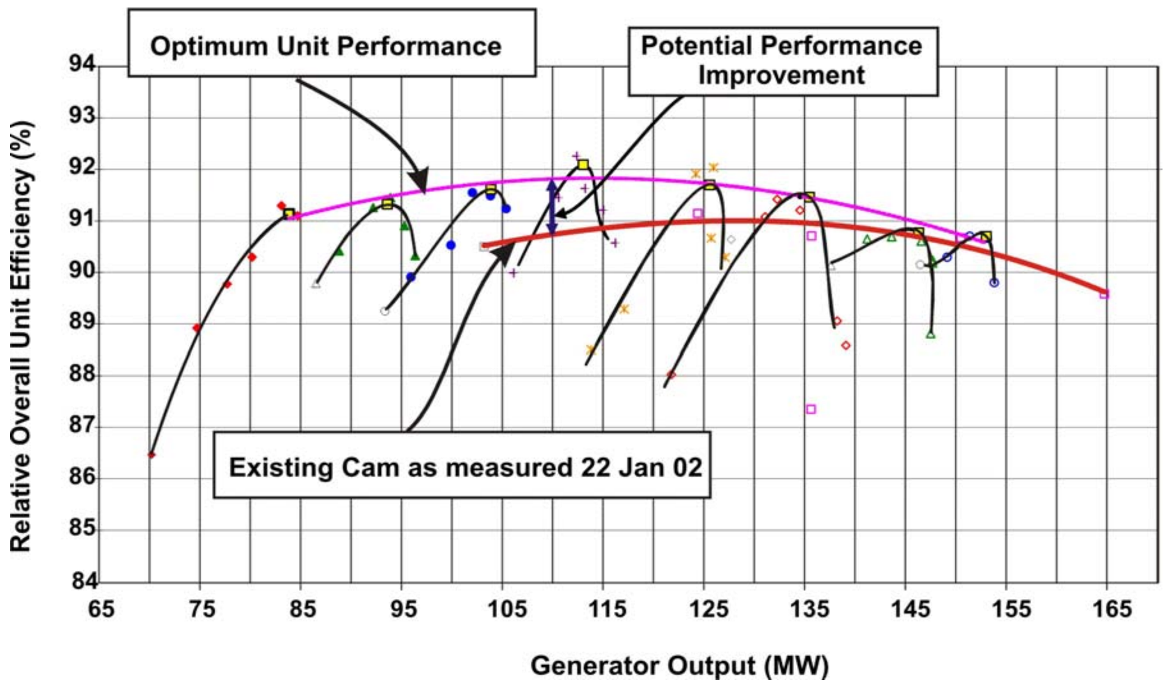

Fig. 4: Lower Monumental Unit 2 - Index test without screens (adapted from Ref. 6)

As a result, the ASFM users' benefits are threefold. Firstly, the turbine performance improvements which become obtainable from modified cam curves derived from the results of these measurements typically represent a 1 % (Lower Monumental Unit 2 – Fig. 4) or even 1.5 % (Lower Monumental Unit 6) gain near peak efficiency (Ref. 6, 7). Secondly, the savings in the cost of equipment, calibration and installation, when compared with the current meters (often the only other methodology usable in the short intakes) are typically of the order of $20,000 to $25,000 per test (Ref. 8). Thirdly, in cases where limited storage requires water to be spilled, additional major savings will be obtained: for example, the two days of 'saved' generation of a 300MW unit represent a saving of $500,000 (at $0.035/kWh - Ref. 8).

5. Future Work

In spite of the ASFM's proven performance in terms of random uncertainty, work remains to be done to resolve the persistent systematic uncertainty issues. As reported (Ref. 1 and 2), a negative bias of typically 1 to 2% has been found, and up to 6 or 7% in some intakes. During the last 12 months, significant progress has been made in this area: it was confirmed that the bias is dependent on the size and number of the vertical trashrack supports, particularly when situated close to the ASFM measurement plane and/or combined with oblique entrance flows (Ref. 9).

It is important to note that there are presently no field flow measurement methods for low head plants accepted by the ASME or IEC test codes, as the current codes require long straight in-penstock techniques. This is why the ASME PTC 18 Test Code Committee has recently (WaterPower XIII in Buffalo, July 2003) identified the problem of flow measurement in low head intakes as the most important issue to be addressed in the next revision of the code.

To this end, the ASME PTC 18 committee, together with Hydro Quebec and ASL AQFlow, are currently working to initiate a "Low-head intake comparative flow test project" through the CEA Technologies' Hydroelectric Plant Life Interest Group (Ref. 10). This work consists of comprehensive testing of the Acoustic Scintillation, Acoustic Time-of-Flight and Current Meter methods in terms of their systematic and random uncertainties and thus code acceptability for applications in low-head intakes.

Acknowledgments
The authors wish to thank the personnel at the U.S. Army Corps of Engineers Hydroelectric Design Centre, at Lower Monumental, Little Goose, Wells, John Day and McNary plants, and at Hydro Quebec, for their cooperation and assistance. Without these people the testing program and this paper would not have been possible.

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