Flow Measurement at Douglas County Public Utility District's Wells Dam with the Acoustic Scintillation Flow Meter

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Abstract

Wells Project, owned and operated by the Public Utility District No. 1 of Douglas County (the District), is located on the Columbia River in North Central Washington State between Seattle and Spokane. In late September and early October 2002, diagnostic and comparison flow measurements were conducted at Unit 3 using a transportable acoustic scintillation flow meter (ASFM) and a previously installed acoustic time-of-travel instrument (AVM). As a result of the comparative measurements, the District purchased an ASFM to assess the performance of all units in the plant. Further diagnostic measurements were conducted in January 2004, when a single frame equipped with 30 measurement levels was deployed in each of the 12 intake bays of Units 1, 2, 6 and 10. In late August and early September 2004, full flow measurement performance tests were completed on Units 3 and 4. Performance testing of the remaining units is planned for 2005-2008.

This paper describes the work to-date in some detail, together with the process that has led to measurements being planned for all units in the future, and the benefits the District derived from these measurements.

1. Introduction

The District has been interested in performance testing the turbine-generator units at the Wells Project since the plant was constructed, and the first unit commissioned, in 1967. The District's goals have been to improve plant knowledge, operation, maintenance, efficiency, and production.

The Wells project has a unique hydrocombine structure with ten generating units rated at a combined 840 megawatts (Fig 1a and 1b). Each unit has three intake bays that measure approximately 22' (6.7 m) wide by 36' (11 m) tall. The distance from the trash rack to the start of the scroll case is only 20' (6 m). This geometry, while excellent for turbine and spillway efficiency, makes the project a difficult plant for traditional flow measurement methods, which are often time-consuming and costly in such large intakes.

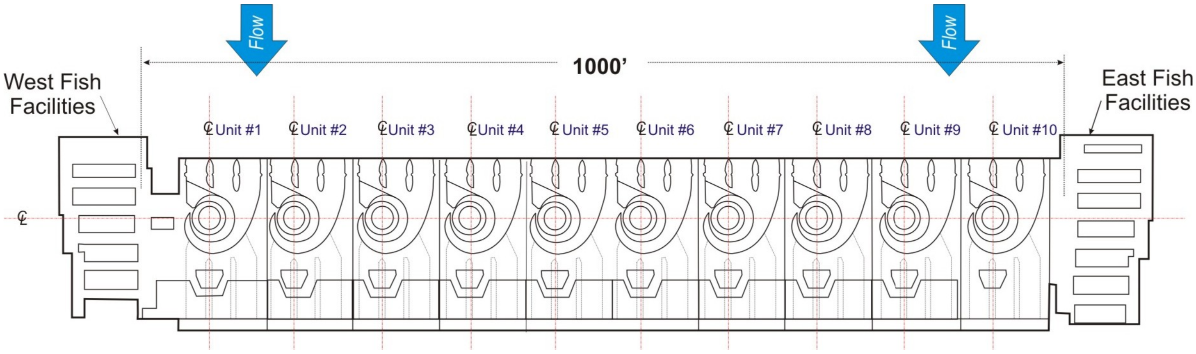

Figure #1a: Plant Plan View

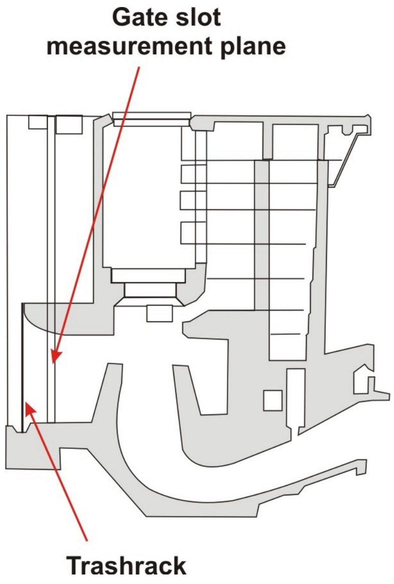

Figure #1b: Section View of the Generator Unit

In the early 1970s, turbine flow measurements were conducted at Wells as part of a Columbia River system discharge rating program using current meters. The program used standardized test equipment and procedures at ten Columbia River projects in order to measure flows in a consistent manner for river flow coordination. In the 1980s, the District conducted index type performance tests correlated to Winter-Kennedy differential head measurements. Test results were used to optimize the replacement of all ten turbine runners. In the 1990s, the District began a program to measure flow using modern technologies in conjunction with an upgrade of plant supervisory and governor controls from analog to digital. AVM flow measurements were conducted on Unit 3 in 1999, resulting in good correlation with previous current meter and index tests.

Since 2002, the District has continued its program of performance testing using the ASFM technology, and it is this program that is described in more detail in this paper.

2. Acoustic Scintillation - Principles of Operation

By utilizing the natural turbulence embedded in the flow, the acoustic scintillation technique has successfully reduced the traditionally prohibitive costs of flow measurement in short intakes of low-head plants such that the resulting efficiency improvements now pay for the testing costs relatively quickly. While relatively new in hydroelectric applications, the technique has been well proven in measuring solar and atmospheric winds for more than half a century, and ocean currents for almost a quarter century (Farmer & Clifford, 1986).

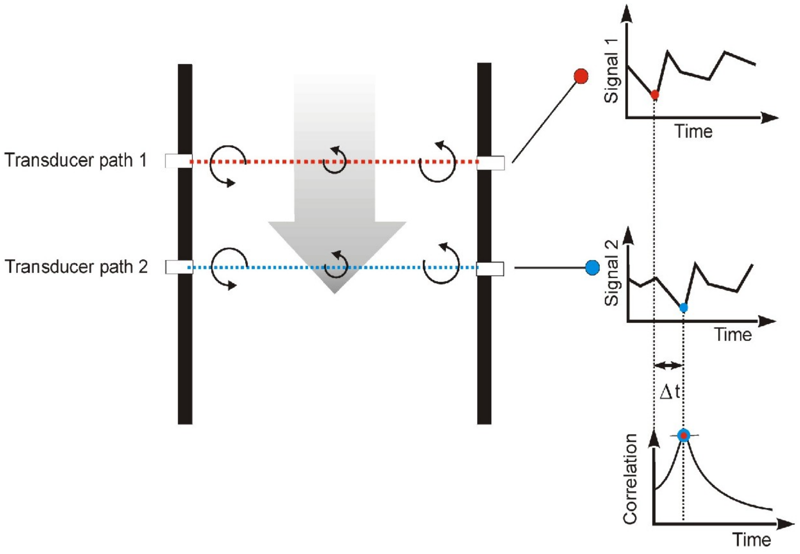

Figure 2: Acoustic scintillation operating schematics

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. 2). 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.

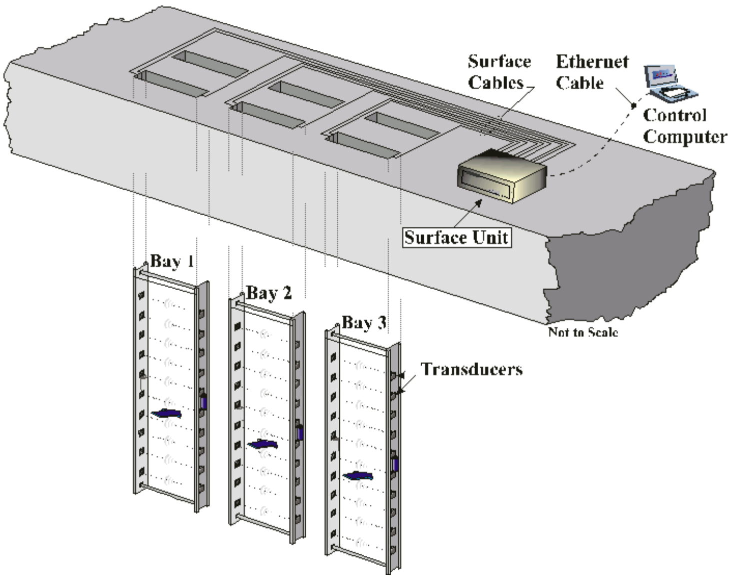

Figure 3: Typical arrangement

Acoustic transducers are mounted on opposite sides of a frame (Fig. 3), which is then lowered into the existing intake stoplog or gate slot. Thus the technique can be used in very short intakes and without dewatering for installation and removal. In multiple unit plants, a fully instrumented frame can be simply moved from intake to intake, again saving plant downtime. Furthermore, no instruments are exposed to debris damage or interfere with the measured flow, and there are no moving parts requiring maintenance and frequent calibration.

During the last 10 years, the acoustic scintillation technique has been used effectively in more than 25 plants, mostly in North America (Lemon, Billenness & Lampa, 2003).

3. 2002 Comparison and Diagnostic Flow Measurements

The District started investigating the ASFM as a potential flow measurement tool for Wells Dam in the late 1990s. District representatives witnessed tests performed at U.S. Army Corps of Engineers Columbia River projects and determined that the technology had promise for use at Wells. In 2002, the District arranged for ASFM measurements on Unit 3 using equipment leased from ASL. This unit has a previously installed AVM, which allowed comparisons to be made with its data as well as with the relative flow values from the Winter-Kennedy taps.

The trashracks at Wells contain 9 large horizontal members whose wakes cause significant variations in the velocity field. The proximity of the ASFM measuring section to the trashrack therefore required that each bay be sampled at high vertical resolution before the measurements began so that the optimum path positions could be determined. Thirty holes were provided in each frame, as shown in Fig. 4. The densely-packed sets at the top and bottom were included to define the flow in the boundary zones near the roof, and behind the lower cross-pipe. All thirty available transducer array pairs were mounted on one frame, which was then deployed in each of the three bays in succession. Data were collected at four nominal unit loads, 55 MW, 65 MW, 75 MW and 85 MW. The observed flow patterns were stable with discharge. The locations of the 10 paths to be used in each bay during performance testing were determined by choosing the set of 10 whose calculated discharge for that bay agreed most closely with the 30-path result. The average difference in total discharge between the selected 10-path sets and the initial 30-path sets, over the four cases tested, was less than 0.5%.

Flow in the boundary zones was determined from the closely spaced sensors at the top and bottom of the frame. Two different forms were required for the upper boundary zone, because the hydrocombine design of Wells Dam, which has the spillway flows passing over the turbine intake bays, results in water being able to enter the turbine passage through the intake gate slot in the floor of the spillway. A small horizontal trash-rack in the gate slot stops debris from travelling to the turbine. Half of the bays in the plant have rubber mats in place which block this flow, while the other half are open.

Flow data were collected at twelve on-cam conditions spanning the full range of turbine output. Repeat runs, mostly in groups of three were made at each setting; the measurements required slightly less than two days to complete. The average deviation among repeats was 0.3%, with a maximum of 0.9%.

The successful results of the measurements on Unit 3 satisfied the District that accurate, repeatable measurements with good correlation to previous performance tests using AVM and Winter-Kennedy taps, can be performed at Wells. An attractive feature of the ASFM technology was that the frame mounted transducer system could be deployed at any of the Wells turbines without intake dewatering. Since the District desired to conduct performance tests on all ten Wells turbines with a consistent, repeatable method, the purchase of the ASFM system was cost justified compared to using leased equipment.

4. 2004 Diagnostic Flow Measurements

Further diagnostic measurements, intended to identify differences in velocity profiles between the bays, were conducted in January 2004. A single frame equipped with 30 measurement levels was deployed in each of the 12 intake bays of the Units 1, 2, 6 and 10. Data were collected for 3 power settings.

Sufficient data were obtained to define the structure of the velocity field in each intake. The results were used to determine the optimum 10 sampling locations in each of the three bays for Units 1 and 2, which had regular profiles similar to those observed in 2002 at Unit 3. For Units 6 and 8, the velocity profile was found to be highly irregular with significant vertical velocity gradients (Fig. 5); the cause was presumed to be trash accumulation.

As all units would have the trashracks cleaned before performance testing can take place, the diagnostic profiles obtained for Units 1, 2 and 3 (previously) were used to derive path placements for future testing of all units, both with and without rubber mats on the gate slot trashracks.

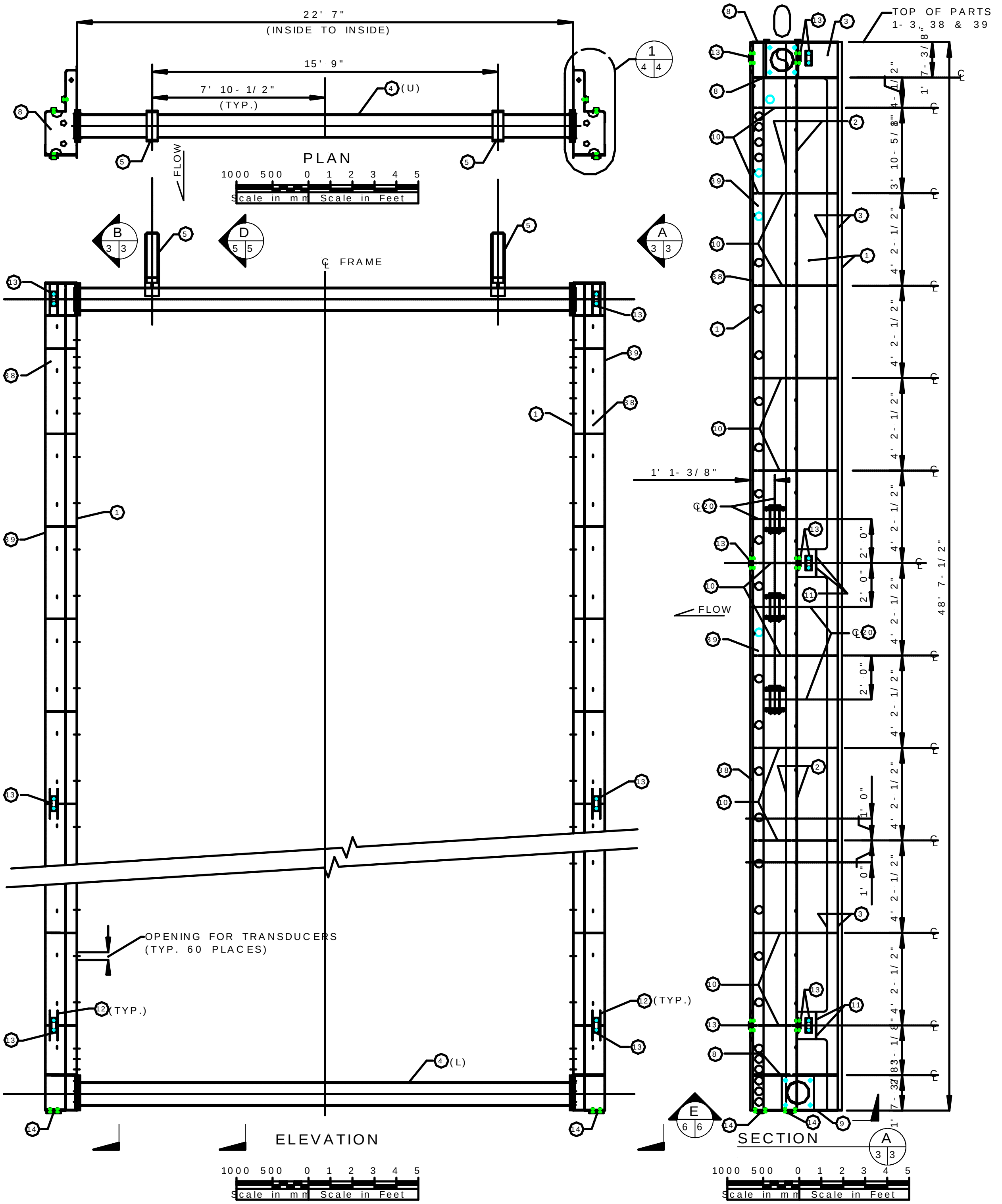

Figure 4: Schematic diagram of the ASFM frame

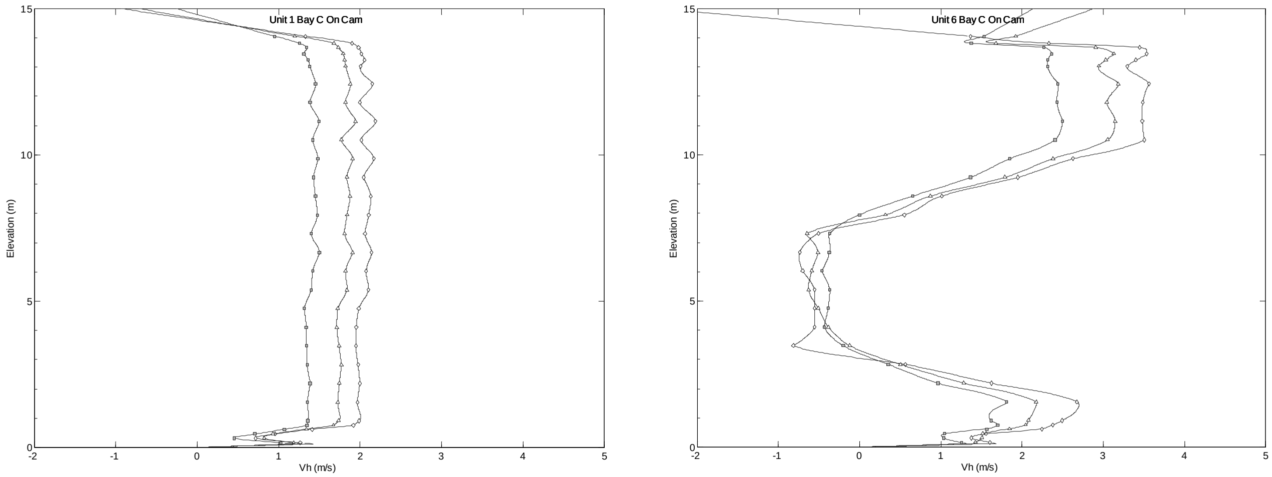

Figure 5 Profiles of the horizontal component of velocity for three power settings in Unit 1, Bay C (left) and Unit 6, Bay C (right).

5. 2004 Flow Measurement Performance Testing of Units 3 and 4

Between August 23 and September 2, 2004, performance testing at Units 3 and 4 was carried out to assess the existing cam curves, and to optimize them if beneficial. The turbine was taken off cam, i.e. the blade angle was fixed at a particular setting, and then measurements of flow, head and power were taken at a series of wicket gate settings spanning the expected peak efficiency point. Readings were taken for seven different blade angles at Unit 3, and five at Unit 4, as power limitations in the Unit 4 generator prevented measurements at the upper two blade angles. Five or six gate settings were found to be sufficient to clearly define the peak operating efficiency at each blade angle.

The Unit 3 efficiency graph (Fig. 6) shows a pattern in which maximum efficiency falls to the right of the current cam point for flatter blade angles, close to maximum for median blade angles and to the left of current cam for steeper blade angles.

For Unit 4, maximum efficiencies also fell to the right of published cam at the lowest blade angle, but were relatively concurrent with published cam for remaining blade settings.

Figure 7 shows the on-cam efficiencies for both Units 3 and 4 versus power as calculated from the two-week 2004 ASL measurements. Both are adjusted to 66 ft of head. Unit 4 appears to have efficiencies that are higher by 1% or slightly more. These differences in the overall performance of the units are an example of the information required to optimize dispatching of units.

During these tests, it was observed that changes in operation of units other than those immediately adjacent to the unit being tested (which were block loaded at approximately 70MW) can also have an effect on flow. It is recommended that coordination of the operation of all units with respect to the testing procedure be developed to promote optimal test accuracy.

Overall, the data collected is considered to be of high quality, and consistent with previous measurements. The data will serve its intended purpose of establishing performance baselines, and facilitate cam adjustments, which in the case of Units 3 and 4 were found to be relatively minor.

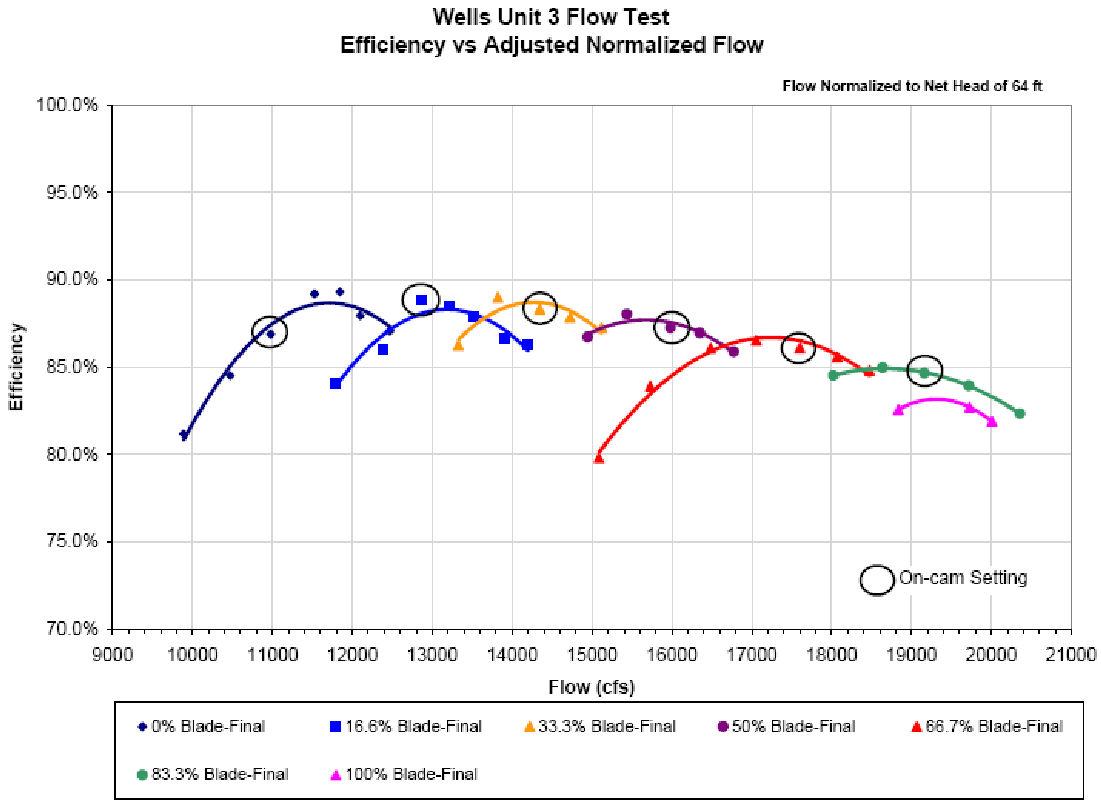

Figure #6: Unit 3 - 2004 Turbine-Generator Efficiency Curves

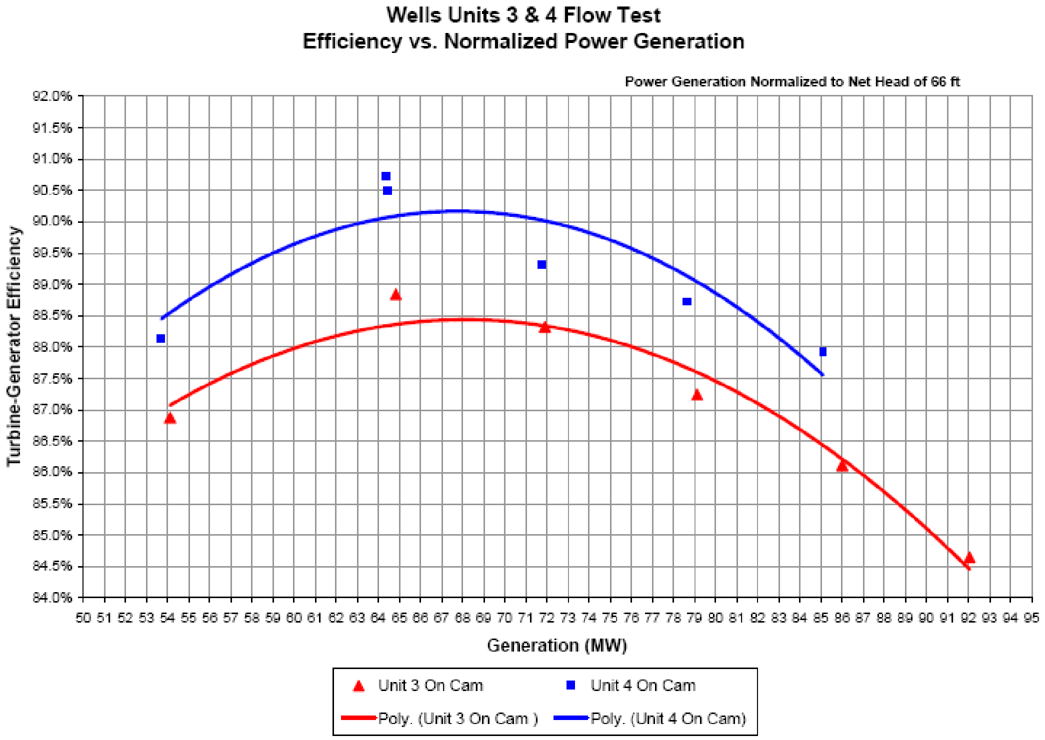

Figure #7: Unit 3 and 4 - 2004 Turbine-Generator Efficiency Curves

6. Conclusions

The August-September 2004 tests were the first in a planned program to test two units each year over five years for the purpose of developing performance baselines and potentially optimizing Kaplan cams for all units. Following these performance tests, which are expected to be completed for all ten units by the year 2008, a regular cycle of flow measurement and absolute performance testing is envisaged to continue cyclically into the future. With these tests, individual unit performance can be optimized by tuning the Kaplan wicket to blade cam relationship, the known performance can be used in dispatching units, and more accurate flow measurements can be used to improve the coordination of Mid-Columbia river system operations. In addition, a regular program of periodic performance testing on all ten units can be used to monitor trends in performance and predict the need for maintenance to make the best use of the Wells Project as a generation resource.

7. References

Farmer, D. M. and S. F. Clifford 1986. Space-time acoustic scintillation analysis: a new technique for probing ocean flows. IEEE J. Ocean. Eng., vol. OE-11, No. 1, 42-50.

Lemon, D. D., D. Billenness and J. Lampa 2003. The acoustic scintillation flow meter – a breakthrough in short intake turbine testing. Proc. Hydro 2003, Cavtat, Croatia

8. The Authors

Jan Buermans, P.Eng., graduated in Mechanical Engineering from Queen's University, Kingston, ON, in 1987 and has worked for ASL Environmental Sciences since 2001. He is ASL' Project Manager for the work conducted at the Wells Project. He is also responsible for the design of mounting frames and hardware for ASFM.

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David Lemon, M. Sc. graduated in Oceanography from the University of British Columbia, Vancouver, in 1975 and joined ASL in 1978. He has worked extensively on the application of underwater acoustics to measuring flow, and has been responsible for the development of the ASFM. He currently has responsibility for internal research and development at ASL.