Cost/Benefit Considerations in the Field Performance Testing of Small Turbines

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Abstract

For the past 50 years, the field testing of hydro turbines has generally been limited to units larger than 20MW – those units of a lesser capacity being considered too small to justify the cost of a field performance test. In recent years, due in part to the incentive to improve existing facilities through turbine upgrades, certain organizations have redefined the objectives of such field tests and, in the process, have extended the range of performance testing to units much smaller than 20 MW. Acres International has tested some 50 units over the past 8 years and has successfully utilized classical methods in combination with several innovations to provide its clients with cost-effective, reliable results. The paper focuses on the objectives, innovative aspects and benefits realized by the owners of small hydro stations and presents several case studies.

1. Introduction

The execution of field performance tests on hydroelectric turbines requires a great deal of experience and skill due to the significant difference that exists between generating station configurations. The methods that can be employed for these field tests may include traditional flow measurement methods (e.g., current meters or Gibson) or may utilize other methods depending on the plant layout, unit characteristics and objectives of the test. Modern data acquisition systems, when combined with innovative procedures, can be used to obtain high levels of accuracy without the high cost. Consequently, it is possible to justify the testing of small hydro units.

2. Objectives of a Turbine Field Test

Prior to deciding on the approach to be used for a field test, it is essential that the owner establish the objectives. The question, “What will the test results be used for?” is certainly one of the most important ones to be asked by the test engineer. The answer to this question can vary significantly. Some typical owner’s test objectives are listed below:

1. Optimization of energy production
2. Information for decisions on life extension such as rehabilitation or upgrade for older plants
3. Confirmation of performance guarantees after rehabilitation, upgrade or initial construction.

Once the objectives of the test have been identified, the field test program can be established. Some of the typical test parameters that depend on the objectives are:

- type of flow measurement (including relative vs. absolute)
- test procedures including instrument calibration

- number of test points
- number of testing personnel
- strict adherence to testing guidelines (IEC 60041, PTC 18)
- witnesses
- duration of test program.

Ultimately, the objectives and the test parameters will have a significant impact on the cost of the test and, therefore, the willingness of the owner to carry out the test.

The following sections address the primary issues that should be addressed prior to embarking on a performance test program for the three categories of test objectives defined previously.

Optimization of Energy Production

One of the most cost-effective ways to use turbine performance testing is in the optimization of the dispatch of units for the operation of one or more hydro plants. The accurate representation of the performance of all generating units in the system is essential in order to allow proper management of available water and dispatching of units in an optimum manner. Additionally, turbine performance data can be used to establish accurate river discharge information for environmental agencies or ministries.

Acres has conducted field test programs for a number of utilities for the purpose of providing input data to existing operations management tools. Information gained from such testing programs is also used for other purposes such as life extension decisions as discussed below.

When turbine performance testing is to be used for energy optimization purposes as described above, the scope of the field test is different from a field test used for the verification of new equipment guarantees. Since the absolute accuracy of the test is the primary objective (rather than documentation for contractual reasons) the time required to prepare for, execute and document the test can be reduced. The amount of test equipment required for field calibration and measurement as well as the number of persons required for the test can also be minimized, thereby resulting in substantial cost savings for the owner.

Further cost savings may be realized, without any reduction in the quality of the final product, if a limited number of absolute efficiency measurements are used to calibrate relative ‘index’ flow measurements. Typically, three or four absolute tests are adequate to demonstrate the accuracy of the index test readings.

For the case of double-regulated machines, the index test provides a highly cost effective means to optimize the correlation between the gate and blade positions. In Acres experience, the testing of generating units as small as 1 MW can easily be justified based on the improvement in performance achieved by the test. Such tests can usually be accomplished in one or two days with a team of two to three persons and with the use of automated data acquisition systems. Following analysis, the results provide a clear indication of the improvement possible by resetting the gate-blade relationship. Surprisingly, it is not uncommon to find relatively new units and upgraded units where the cam setting has not been properly adjusted following commissioning.

Information for Decisions on Life Extension

Owners of small, aging hydro stations are faced with difficult decisions regarding the future of their stations. Should they continue to operate the aging equipment and carry the penalty of reduced performance as well as the risks of a potential failure? Should the existing equipment be rehabilitated or should it be replaced? Should the entire station be replaced with a new development?

The answers to these questions are, to a large extent, dependent on the performance of the existing generating units. Cost-benefit analyses must take into consideration the anticipated improvements in efficiency and capacity before substantiated decisions on future capital expenditures (runner replacements, redevelopments, etc) can be made.

Compounding the problem, owners are often under the impression that the process of collecting meaningful turbine performance data is a process reserved for large turbines that can not be justified for small turbines due to the high cost of the testing. Consequently, owners often make critical life extension decisions without the information on which those decisions should be based.

Acres has successfully demonstrated to its clients that field performance testing of small turbines can easily be justified if testing is carried out in a scaled down, economic manner. High levels of documentation and instrument calibration are not necessary for these types of tests and certain procedures may be eliminated if they provide relatively little added value to the test objectives.

Confirmation of Performance Guarantees

Given the fact that there is a large amount of literature available in this subject area, the following discussion focuses on Acres experiences.

One of the key messages to convey is that accuracy and confidence in the field test results does not have to be expensive. As all test engineers are well aware, there are many different methods to measure turbine discharge. A list of standardized methods is given in IEC 60041, along with selection criteria and a detailed methodology. The selection of the most appropriate method(s) to be used for the test is often just as important as the actual execution of the test. Acres has found that comparative tests can be used in a cost-effective manner on small hydro units and provide a high level of confidence in the end results. Comparative tests are two or more independent, absolute methods of flow measurement used simultaneously or sequentially on one generating unit. Additionally, the use of relative flow measurements to supplement the absolute measurements provides further confidence in the accuracy of the results. The case study for such a field test has been included below.

3. Cost Effective Methods of Flow Measurement

The selection of the most appropriate method of flow measurement is likely the most critical decision of the test program planning. The proper selection requires the consideration of the owner's objectives, the station arrangement, the accuracy and the cost of the test. Table 1 provides a summary of the typical methods that have successfully been used for testing small turbines. This table is not intended to be exhaustive and it is worthwhile to note that there are other methods, including acoustic and thermodynamic, that are highly effective in certain applications.

Table 1

Features	**Method of Flow Measurement**			
	Tracer: Constant-rate-injection	Tracer: Transit-time	Pressure Time	Current Meters
Station arrangement	Requires at least 35 diameters of penstock length	Requires at least 150 diameters of penstock length	Requires at least 10 diameters of constant diameter penstock	Can be performed at intakes of close-coupled stations
Code Acceptance	Yes IEC 10.5.2	Yes IEC 10.5.3	Yes IEC 10.4	Yes IEC 10.2
Systematic Uncertainty (IEC)	1% to 2%	1% to 1.5%	1.5% to 2.3%	1% to 2% (Intake and Bell Mouth)
Relative Cost	Low-Med	Low	Low-Med	Med-High
Pro's	• Short set up and outage req'd • Constant diameter conduit not required	• Non-intrusive • Minimal set up and outage req'd • No laboratory analysis req'd	• Non-intrusive • Short set up and outage • Fast and accurate	• Non-intrusive • Applicable to close-coupled stations • Simple test procedure and analysis
Con's	• Laboratory analysis requires attention to detail • Environmental approvals •	• Requires long conduit of known cross-section	• Requires taps in penstock • Load rejection required for each test	• Each test can be lengthy during which time conditions may change • Accuracy highly dependent on intake entrance conditions

4. Case Studies

The following case studies pertain to actual field tests that have been carried out by Acres and are intended to help the reader gain a better appreciation for the concepts discussed above.

Case Study 1: MacKay G.S. Post Upgrade Performance Tests

The MacKay Generating Station is located in Ontario, east of Lake Superior and is the uppermost plant on the Montreal River. The station contains three generating units that were upgraded and tested to verify post-upgrade performance. Table 2 summarizes the unit characteristics:

Table 2

	Units 1 & 2	**Unit 3**
Turbine Rated Output	12.6 MW	33.5 MW
Net Head	69 m	69 m
Configuration	Unitized 260 m steel penstocks	260 m steel penstock with surge tank
Turbine Type	Vertical Francis S. Morgan Smith, Voith replacement runners	

Units 1 and 3 were tested using the pressure-time method of discharge measurement, Units 2 and 3 to constant-rate-injection tracer (dye dilution) tests and relative flow was measured on the Winter-Kennedy taps for all units. The choice of methodology was governed by the operational settings of the units, in particular the governor timing, and difficulties in placing a suitable injection rack in front of the deeply submerged intakes.

The tests on all three units were carried out November 8-13, 2000, using a team of four engineers including setup of equipment on the units, test execution, fluorometric analysis of the dye samples, preliminary analysis of results and demobilization.

Having redundant absolute discharge measurements on Unit 3 provided the valuable opportunity for a comparison of two independent methods as shown in Figure 1 and Table 3.

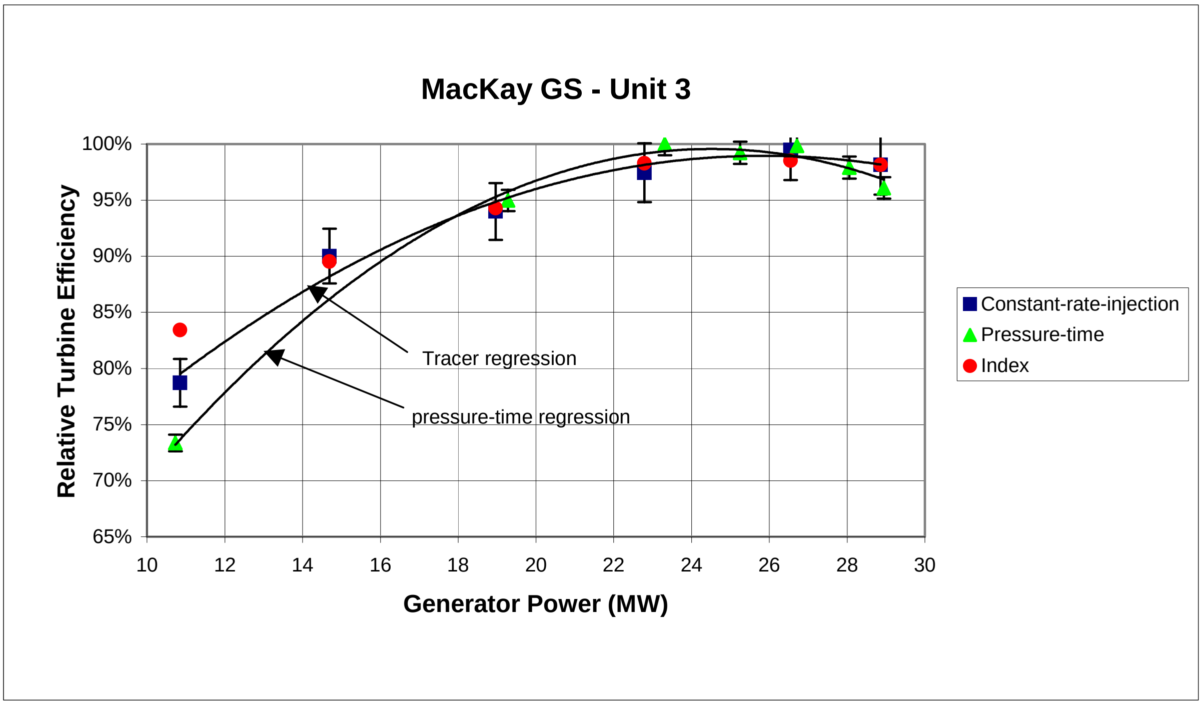

Figure 1: Comparative Field Test – Post Upgrade

Table 3

	Tracer: Constant-rate-injection	Pressure Time
Peak Efficiency (relative)	98.7%	99.5%
Power at Peak Efficiency	26 MW	25 MW

The performance tests demonstrate with a high degree of confidence that the replacement runners achieved the manufacturer's guarantees.

Case Study 2: Deer Lake Post-Upgrade Performance Test

The Deer Lake Generating Station is located in Newfoundland and contains several generating units in the same powerhouse. Units 1 to 7 are horizontal Francis units rated at 11 MW each and date back to the 1920s.

The units are currently being upgraded with a new runner, new wicket gates and several other improvements. Acres was hired by the owner to conduct a post-upgrade performance test to determine if the turbine supplier's guarantees were achieved.

The penstocks are approximately 2.75 m in diameter and more than 1200 m in length thereby making the station ideally suited to the use of tracers to measure flow. Both the constant-rate-injection and the transit-time methods were used during each test to provide two independent methods of measurement for improved confidence. The tracer used for the transit time test was the same as that used for the constant-rate-injection method thereby providing two independent methods with virtually no additional equipment and minimal additional time. The constant-rate-injection portion of the test followed immediately after the transit-time test. Multiple taps were used for sampling to ensure adequate mixing of the dye in the penstock.

Figure 2 shows the final results of the performance test. There is excellent agreement (generally within 1%) between the two tests. The index test also compares favorably with the other tests.

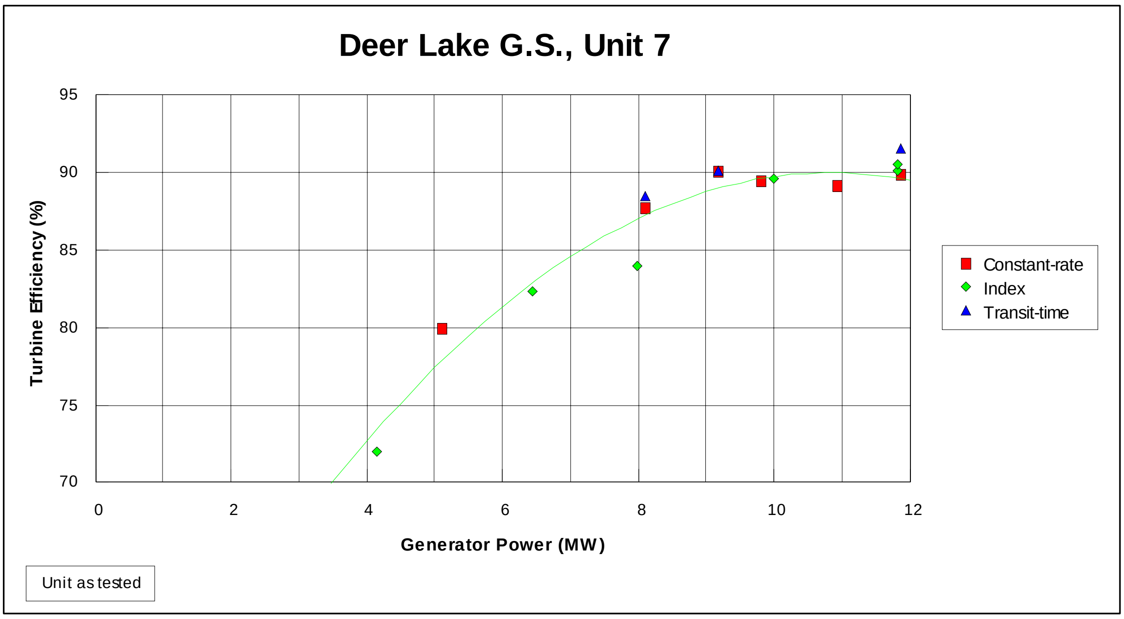

Figure 2: Comparative Field Test – Constant-Rate-Injection and Transit-Time

Case Study 3: Hogg Index Test

The Hogg Generating Station is located in Northern Ontario and contains one vertical 17-MW Kaplan turbine with a net head of 23.5 m (77 ft). The station was built in 1964 but was upgraded in 2000 through the replacement of the turbine runner as well as other improvements. An index test was conducted in November 2000 for the purpose of optimizing the gate-blade relationship. Relative flow measurements were obtained using the existing Winter-Kennedy taps on the semi-spiral case. The primary measurement data, including relative discharge, turbine inlet pressure, tailwater level and power were recorded using an automated data acquisition system that could later be analyzed using a spreadsheet.

One on-cam test (Test 1) was carried out on the turbine in the as-found condition. Following this run, seven more tests were carried out at blade positions ranging from 8% to 100%. For each blade position, five or six test runs were performed, each at a different wicket gate opening.

Figure 3 shows the relative efficiency as a function of relative flow for each test that was carried out. The on-cam performance (heavy line) is considerably lower than the optimum over the range of 50% to 80% of full flow. In fact, at the maximum efficiency point (8% blade, 70% gate), the optimum gate-blade position is approximately 7% greater than the maximum measured for the on-cam setting.

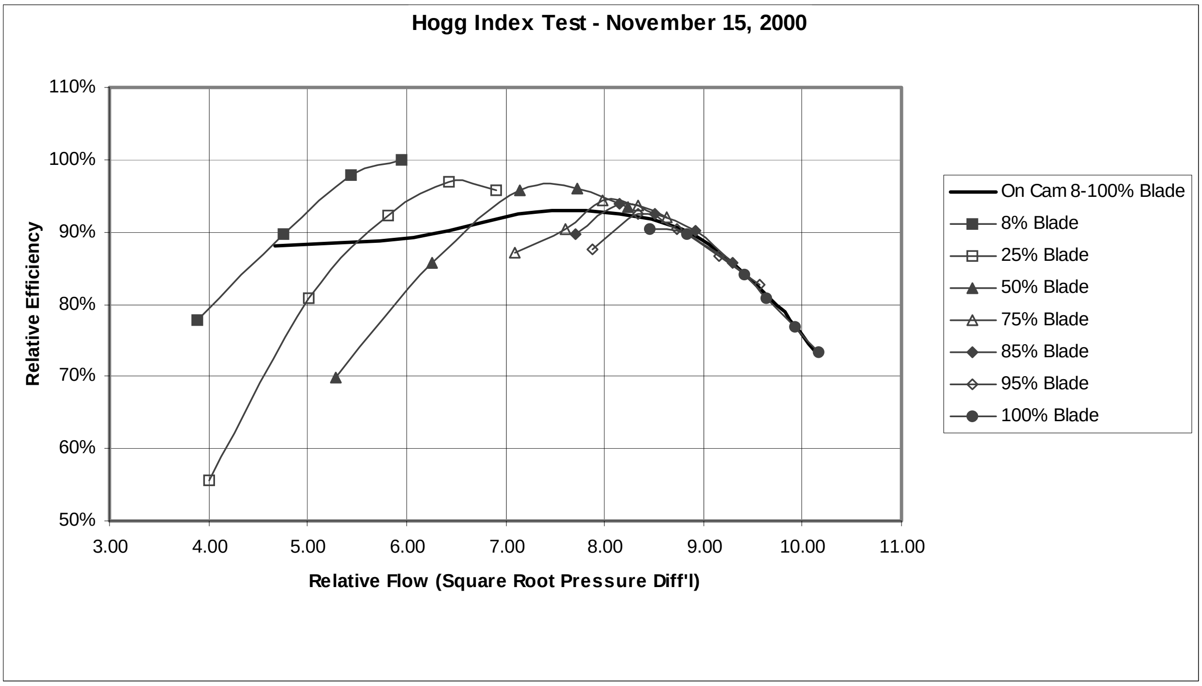

Figure 3: Index Test – Kaplan Turbine

Also of significance, the maximum power was measured at 85% gate and 85% blade. All other tests performed at higher gate openings (or different blade positions) resulted in a loss of power and a significant reduction in performance.

The results of the index test demonstrate that the turbine performance with the “on-cam” setting was not optimum and that a significant improvement in efficiency can be obtained by changing the gate-blade relationship to the optimum setting. For example, at a generator output of 15 MW, the optimum setting would result in a 3% improvement in the efficiency of the unit. Presuming that the unit is operated at this load for 25% of the time and the cost of energy is $40/MWh (peak), this improvement alone represents an annual benefit of $40,000. Meanwhile, the test was completed, including setup, in less than 1½ days with a team of four persons (including operator).

5. Conclusions

The field performance testing is often perceived by hydro station owners to be expensive undertakings reserved for large hydro units. Meanwhile, owners of small hydro stations need to make decisions on several issues that depend on the performance of their units, including unit dispatch, unit rehabilitation and unit retirement.

Acres has demonstrated that field performance testing can effectively be carried out and justified for small turbines when innovative methods and modern data acquisition systems are employed. It is important to identify the objectives of the test during the initial stages of the investigation.

6. References

International Electrotechnical Commission, International Standard, IEC 60041-1991 “Field Acceptance Tests to Determine the Hydraulic Performance of Hydraulic Turbines, Storage Pumps and Pump-Turbines”, Third Edition, 1991-11.

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