TURBINE EFFICIENCY MEASUREMENT FOR LOW HEAD UNITS USING ULTRASONIC TRANSIT TIME METHOD

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Abstract

Low Head Hydroelectric units usually are smaller in size and typically with no penstock. It is extremely difficult to carry out turbine performance tests for verifying the contractual guarantees and operational optimization due to the unit configuration and performance test cost.

The rate of contractual guarantee failures for small and low head Hydroelectric turbine during upgrading turbine is on the rise. Contractual performance tests will determine the actual "as installed" turbine performance and will determine if the contractual turbine performance guarantees (rated output and turbine efficiency) were met.

The main issue in carrying out the contractual performance tests for small and low head is the cost of conducting absolute performance tests.

This new acoustic flow measurement application was developed to carry out performance tests on low head units economically and accurately.

This acoustic test application uses 6-12 cross paths to determine the flow at the entrance of the turbine. The setup is simple and requires a short setup time and delivers accurate results, with expected uncertainties between ±2% to ± 2.75% and with cost slightly higher than Index tests, but significantly less than typical absolute tests.

The test procedure was enhanced to capture the acoustic method capabilities and to fit in any unusual unit configuration.

This application was used in Canada and Turkey to successfully measure the turbine flow for low head units.

This presentation will describe the test setup, test equipment, and test results of two units at two different power stations Fort Frances and Kenora generating stations in Ontario Canada

This new methodology uses proven acoustic flow measurement techniques which was approved by the test codes.

1. Introduction

Fort Frances Generating Station is located on the Rainy River in the town of Fort Frances, Ontario, Canada. The power plant is owned and operated by H2O Power LP. The station has 8 vertical fixed blades propeller turbines operating under a rated net head of 8.839 m (29 ft) and gross head of 9.100 m (29.855 ft). The hydroelectric station was installed and declared in-service in 1909, then was converted from horizontal units to vertical units in 1954. The units were upgraded in 2016-2018 with new turbine runners.

The October 19, 2017 performance test was carried out on Unit # 3 at the Fort Frances Generating Station. The purpose of this test was to determine overall unit and turbine performance characteristics for unit operation, and to determine if the turbine manufacturer achieved the contractual guarantees. The post-upgrade performance test would then establish a performance benchmark for the upgraded units.

Kenora Generating Station is located on the Winnipeg River, at the outlet of the Lake of the Woods in the town of Kenora, Ontario, Canada. The power plant is owned and operated by H2O Power LP. The station had 10 vertical fixed blades propeller turbines operating under a normal head of 5.700 m. The hydroelectric station was installed and declared in-service in 1906, then was converted from horizontal units to vertical units in 1921-1926.

Six units (units 3, 4, 5, 6, 7, and 8) were upgraded in 2018-2019 with new turbine runners and new generators. The remaining 4 units (G1,2,9,10) were permanently shut down and those turbines and generators were removed.

The September 17-18, 2019 acoustic performance test was carried out on Unit # 8 and capacity tests on units 3, 4, 5, 6, and 7 at the Kenora Generating Station. The purpose of unit 8 test was to determine overall unit and turbine operating characteristics after the unit upgrade. The acoustic method was used to compute the turbine performance. The post-upgrade performance test will establish a performance benchmark for the upgraded unit.

This presentation describes the field test experience to determine the turbine performance and evaluating the turbine upgrade. It includes a description of the test method, equipment, instrumentation, and the results achieved. The results were used to evaluate if the turbine manufacturer achieved the contractual guarantees.

2. Description of Water Supply Passages

The Fort Frances units are vertical fixed blades propeller turbines: The water supply passages to the turbine consist of one rectangular reinforced concrete supply intake opening with no penstock or spiral scroll casing (Figure 1 and 2)

The Kenora units are vertical fixed blades propeller axial flow turbines: The water supply passages to the turbine consist of one rectangular reinforced concrete supply intake opening with no penstock or spiral scroll casing (Figure 3 and 4).

The Fort Frances units operate at a normal rated gross head of 9.100 m (29.855 ft) The flow available for power production varies from 0 m3/sec 0 ft3/sec) to 23 m3/sec (706.3 ft3/sec). The total unit power output varies from 0 MW to 1.7 MW.

The Kenora units operate at a normal rated gross head of 5.700 m (18.700 ft). The flow available for power production varies from 0 m3/sec 0 ft3/sec) to 20 m3/sec (812.2 ft3/sec). The total unit power output varies from 0 MW to 0.825 MW.

3. Selection of Acoustic Method for Flow Measurement

Analysis of several test methodologies were carried out to select the most appropriate test method for the unit configuration. The test methodologies we checked are the pressure-time method, acoustic method and the velocity area using the intake current-meters. An Index test was not feasible due to the lack of pressure taps in this unit configuration.

The pressure-time method (Gibson method) can not be used as there is no penstock. The current-meters at the intake were problematic as the removal of the stoplog would have been an expensive procedure and left the unit without overspeed protection during the test period.

It was determined that the acoustic method was the most suitable for the unit configuration to measure the turbine flow accurately and economically, based on the following criteria:

- The expected test accuracy (±2.20% - ±2.80%) is acceptable and it is economical relative to other alternative test methods.

- The acoustic method is approved by the International Test Code IEC-60041 and ISO 6416 test codes and is suitable for the unit configuration with some enhancements (see Figure 1 and 2).

- Suitability of unit geometry (Test code requirement relative to actual unit configuration)

- Economic factors (Unit outage, test set-up cost, test cost, and test equipment removal)

4. Flow Measurement Instrumentation

EIGHT cross paths acoustic flow measurements were used. Systec-Controls 500 kHz 3 Bar g with path length 0.5-40 m instrument were used. (see figure 3-4-5-6)

Turbine flow velocities were measured and turbine flow was calculated by the Acoustic Method using ISO 6416 Mean Section Method. This multipath Algorithm, which divide the cross section in 5 weighted areas. The sum of the area-flow is the total flow in the cross section.

The average flow velocity was determined by the section flow divided by the hydraulic area. using HPPE 8-cross-path acoustic system.

Number of measuring points	=	8
Number of intakes	=	1
Total number of measuring points	=	8

The acoustic system was 8-cross path at the turbine pit see Figures 4, 5, and 6.

The metering section width and height were obtained from construction drawings and verified by actual measurements on site. The elevation of the bottom of the intake was checked by closed loop survey from the official benchmark. The elevation of the water level was measured by two accurate depth transducers.

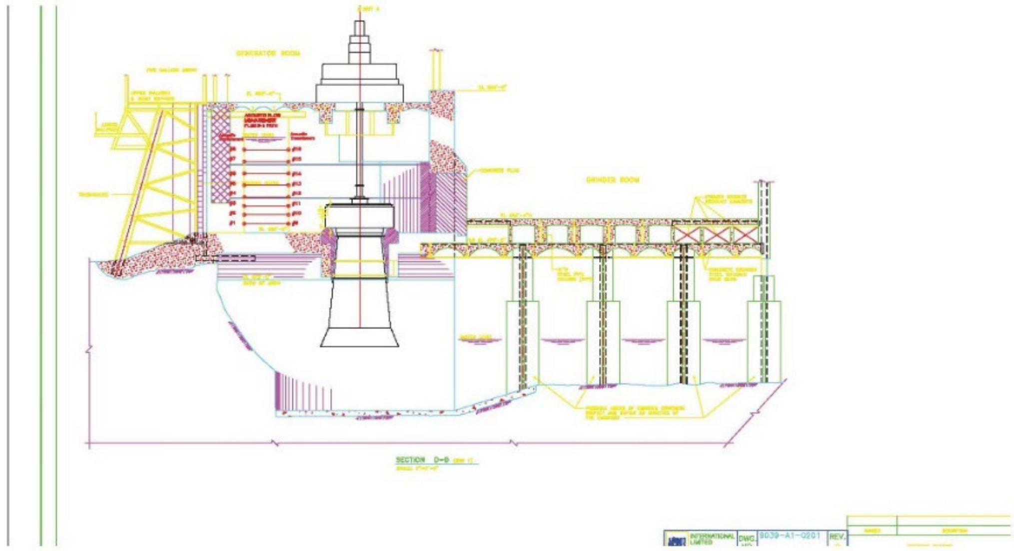

Figure 1 – Fort Frances Unit Cross Section Showing 8 Cross Paths Acoustic Instruments Setup

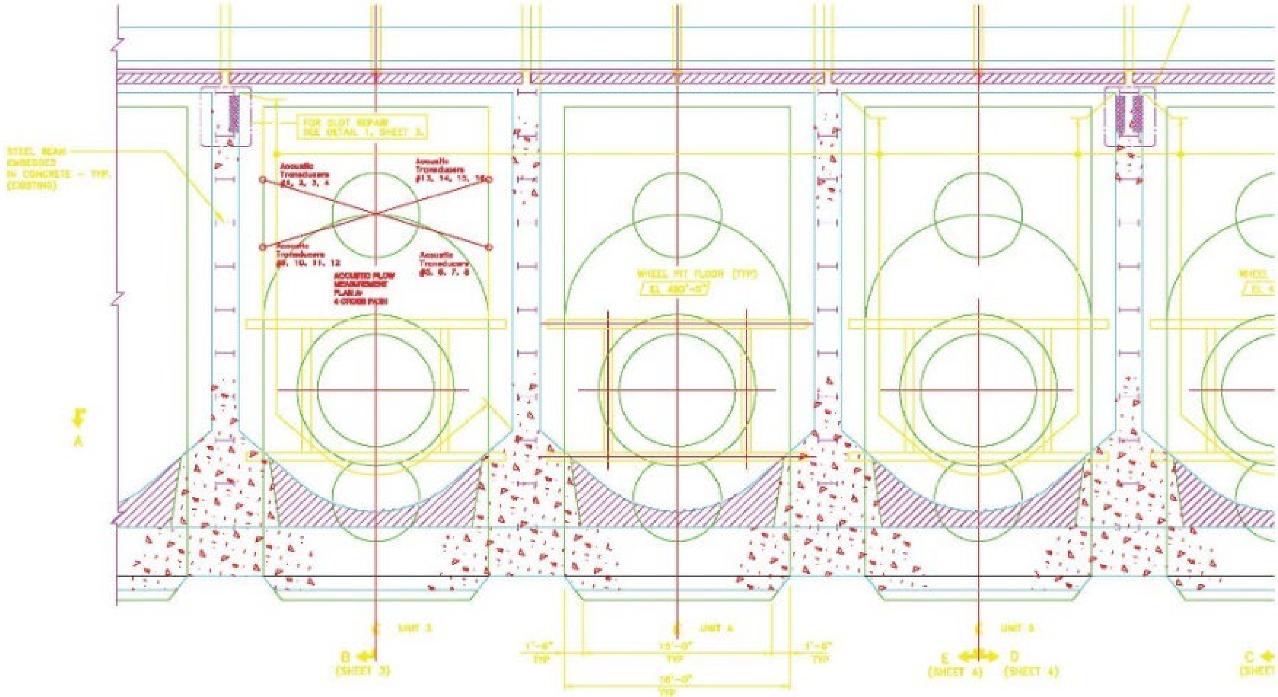

Figure 2 – Fort Francis Unit Plan View Showing Acoustic Cross Paths

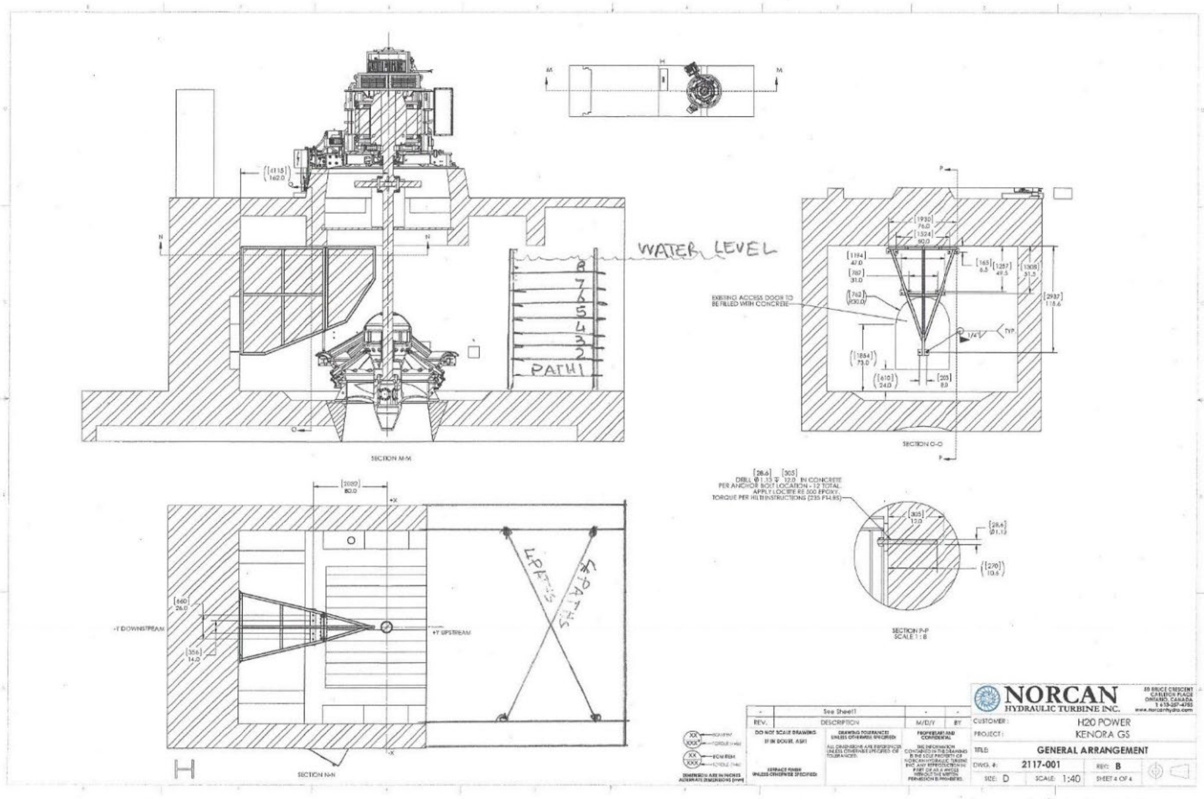

Figure 3 - Kenora Turbine Plan and Cross Section showing Acoustic Flow Meter Setup

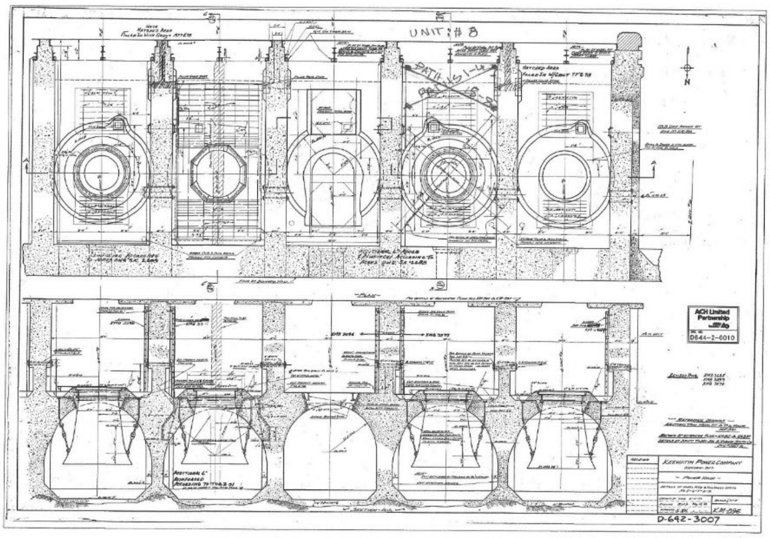

Figure 4 - Kenora Plan View showing Acoustic Flow-Meter Setup

Figure 5 - Acoustic Instruments Setup

Figure 6 - Acoustic Instrument

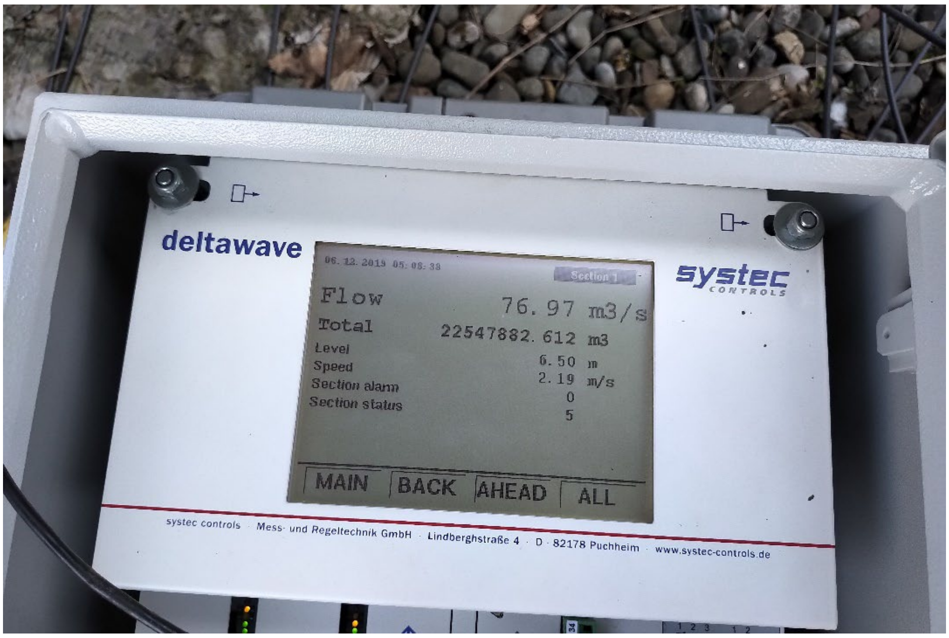

Figure 7 - Acoustic Flowmeter Controller

5. Ultrasonic Transit Time Method – Test Procedure

The test procedure was developed to ensure accuracy, consistency, and compliance with the international test codes.
Test procedure was reviewed and approved by all stakeholders (Owner, Turbine Manufacturer, Turbine Tester)

6. Ultrasonic Transit Time Method – Test Equipment Setup

Acoustic instrument supporting frames (quantity of 4) were assembled to fit the unit entrance opening. Acoustic instruments were installed on the supporting rods, with 4 instruments per supporting rod, each checked and connected to the test control centre. Acoustic instruments spacing measured and documented. Intake opening dimensions were measured and verified (width and height).

Test Control Centre was set up with computers, data acquisitioning, signal cables, communications between each measuring point and computer centre.

Installation of servomotor stroke, wicket gate angle and runner blade angle measurement instrumentation, calibration of instruments and verification of measurements.

Installation of power-meter measurement instrument, verification of measurements.

Temporary stilling wells were installed to measure the static water level of the unit headwater and tailwater elevations. The wells were made of 2 inch diameter aluminium pipe open at the top and capped on the bottom with a 3/16 inch diameter hole to minimize water level variations caused by turbulence. The wells were fixed to the concrete wall. Temporary benchmarks were established on the top of each well. One well was installed in each intake, while two wells were installed in each of the two tailrace slots.

Survey from the official station benchmark to each headwater and tailwater measurement to verify gross head and net head measurements was completed. Temporary benchmarks were established at each measuring location including station headwater and station tailwater measurement locations.

With the exception of power and flow velocity measurement instruments, all instruments were calibrated on site prior to the start of the test. The power meter was calibrated off-site by independent laboratories to national standards.

7. Ultrasonic Transit Time Method – Field Tests

The absolute test using the HPPE Acoustic system determined the flow and efficiency.
One full Acoustic test was carried out. The test runs were selected between speed no load to maximum gate opening. Each test run was repeated three times for determining the test uncertainties.
Several iterations of test repeats were made to confirm the best efficiency point and maximum output

7.1. Turbine Flow Measurement

Turbine flow was measured by the Acoustic Method by the ISO 6146 Mean section method using HPPE Acoustic System.

The average flow velocity was determined by measuring the 8 velocity cross paths acoustic system.

The acoustic instrument supporting rods consists of 4 rods each rod has 4 acoustic instruments spaced to measure the average flow velocity at the measured cross-section

Each acoustic transducer (total 16) is Systec-Controls 500 kHz (3 Bar g with path length 0.5-40 m instruments.

The performance test consisted of 49 test runs covering a range of wicket gate openings from 20% (speed-no-load) to 100% of full servomotor stroke. Turbine flow was measured and computed using the acoustic method. The test runs were made at 10-minute intervals. At the beginning of each run the wicket gates were set at a fixed opening. About 3 minutes were allowed for conditions to stabilize.

During the remaining 5 minutes, the data acquisition system measured all parameters simultaneously at a rate of 100 scans/30 seconds.

7.2. Unit Output Measurements

Generator output was measured by watt-hour instrument and validated by the station recording meters.

7.3. Head Measurements

Station headwater elevation, unit headwater elevation, station tailwater elevation, unit tailwater elevation, pressure elevation at the turbine entrance were measured using high accuracy instrumentation.

7.4. Servomotor Stroke and Wicket Gate Angle Measurements

The servomotor stroke opening was measured by linear displacement transducer was installed on the servomotor stroke piston rod.

The wicket gate angle opening was measured by linear displacement transducer that was mounted on a protractor on the operating rod.

8. Test Results

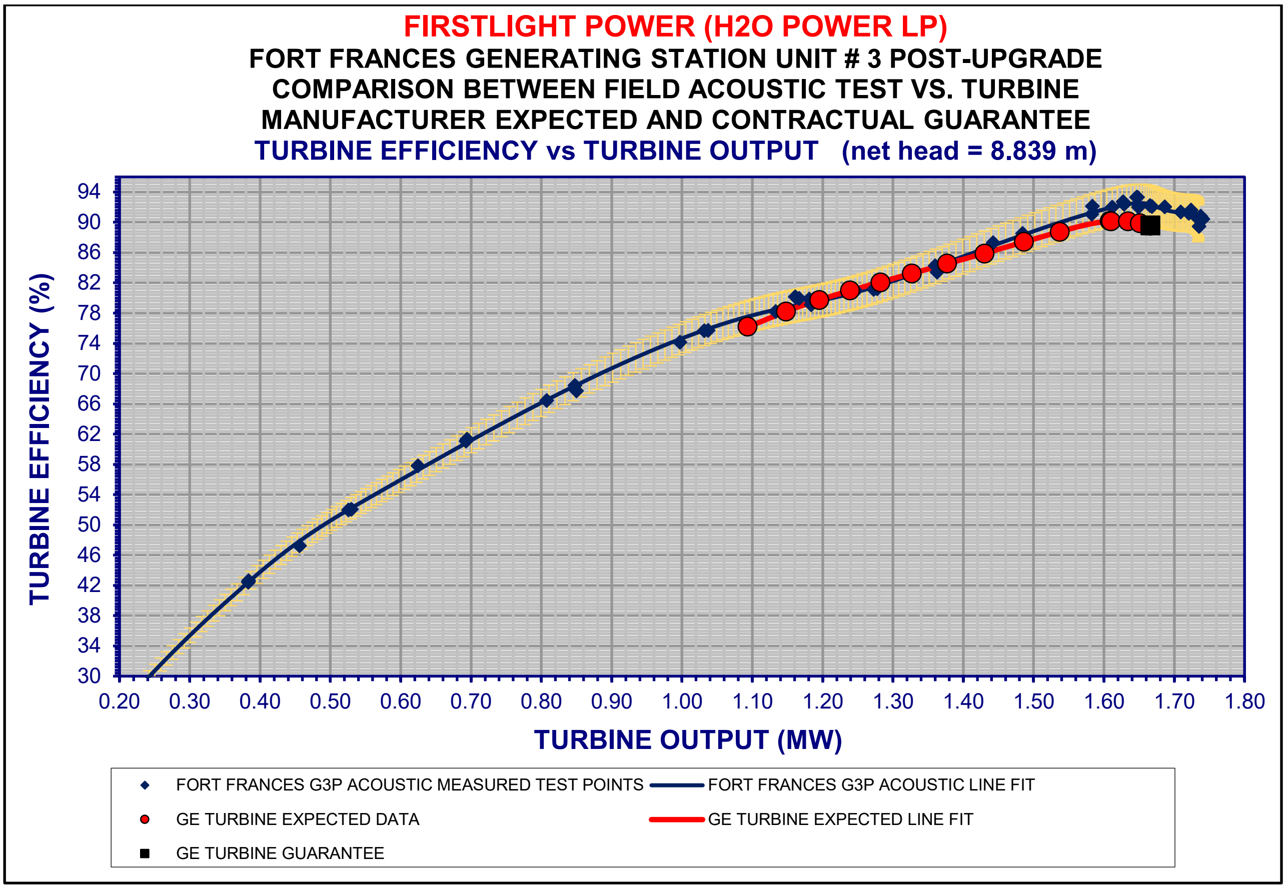

Figure 9 - Fort Frances Test Results

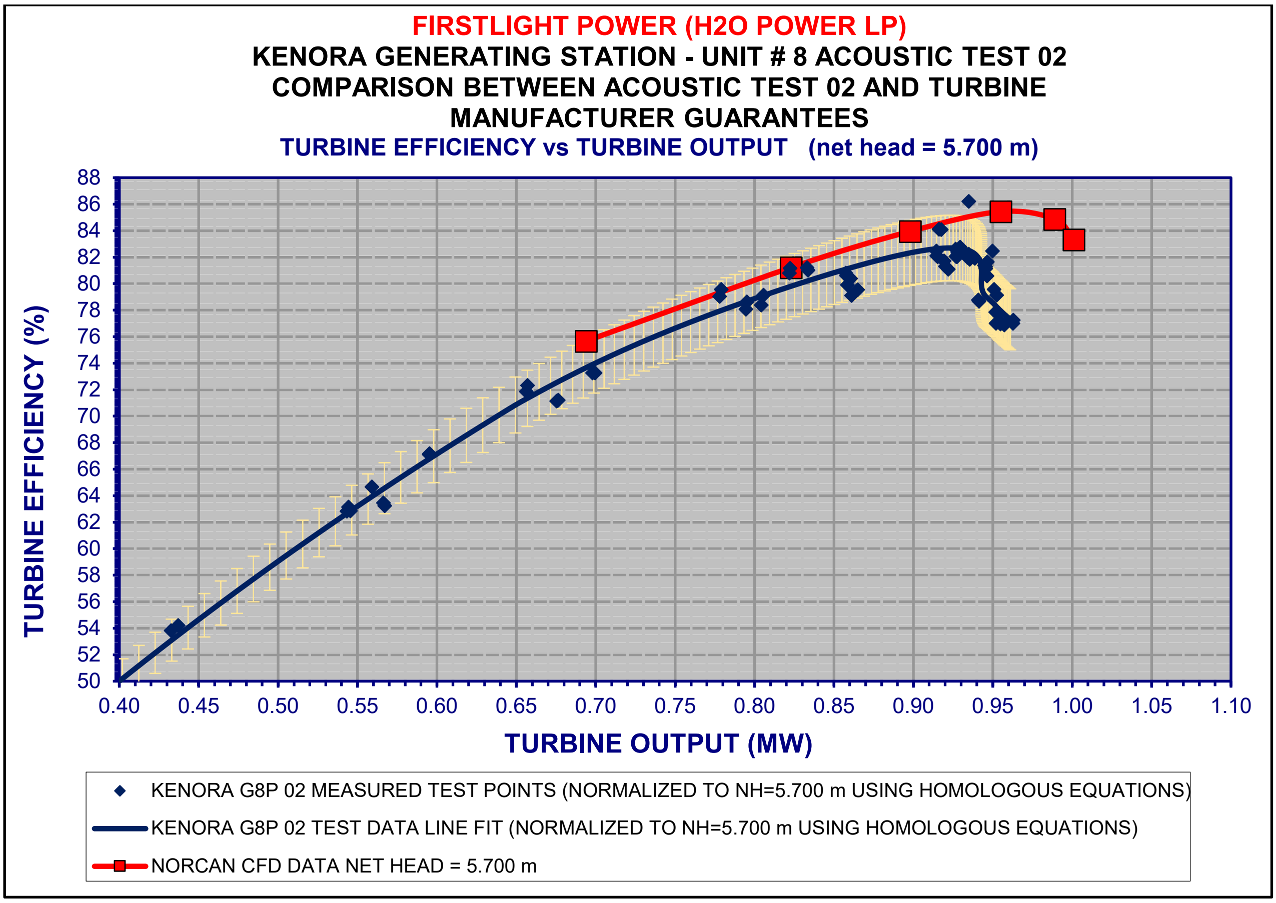

Figure 10 – Kenora Test Results

9. Test Conclusions

- The present operating characteristics of the turbine and overall unit performance relationships of Fort Frances Unit #3 and Kenora Unit #8 were determined by this test procedure using the acoustic flow measurement method to determine the turbine flow and efficiency.
- For the Fort Frances unit, the turbine manufacturer achieved its contractual guarantees.
- The uncertainty values of the efficiency were calculated to be ±2.77%.
- The test was conducted safely, successfully and in a relatively short time compared to other methods.
- Fort Frances turbine manufacturer did achieve the committed contractual guarantees.
- Kenora turbine manufacturer did not achieve the committed contractual guarantees on output and efficiency.

10. Acknowledgements

Special thanks for the staff of H2O Power for assisting and supporting the test to get it completed successfully as per schedule.

Special thanks to Systec-Controls for assisting and supervising the equipment design, test procedure, test setup and test.

11. References

12.1. IEC 60041 – Field Acceptance Tests to Determine the Hydraulic Performance of Hydraulic Turbines, Storage Pumps and Pump-Turbines
12.2. ASME PTS-18-2020 – Hydraulic Turbines and Pump-Turbines – Performance Test Codes
12.3. ISO 6416 – Hydrometry – Measurement of Discharge by Ultrasonic Transit Time (Time of Flight) Method