Performance Testing Experience at Mantaro Power Plant - Perú

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SANTIAGO ANTUNEZ DE MAYOLO (SAM) - MANTARO is located in the central region of Peru. The power plant is owned and operated by Electro-Peru S.A. The station has 7 vertical pelton wheel turbines operating under a normal head of 745 metres. Unit # 1 of Electroperu - Hydroelectric Mantaro was declared in-service in 1972.

On November 24, 2005 a performance test was carried out on unit # 1 following rehabilitation of the unit, including installation of an upgraded pelton wheel runner. Flow was determined by the Thermodynamic method. The performance characteristics of the turbine were also determined by the Thermodynamic method to evaluate whether the turbine met the guaranteed performance, as per the VA Tech specification.

The Performance Testing Team of VA Tech performed the test. Albert Mikhail of HydroPower Performance Engineering Inc., through a contract with Cenergia, supervised the test to ensure that the test was conducted in accordance with the IEC 60041 test code and with best practices.

This presentation describes the field test experience for evaluating the first upgraded unit at the Mantaro Power Plant. It includes a description of the test method, equipment, instrumentation, and the results achieved. The final results will be used as an acceptance test for the new turbines.

INTRODUCTION

SANTIAGO ANTUNEZ DE MAYOLO (SAM) - MANTARO is located in the central region of Peru. The power plant is owned and operated by Electroperu S.A. The station has 7 vertical pelton wheel turbines operating under a normal head of 745 metres. Unit # 1 of Electroperu - Hydroelectric Mantaro was declared in-service in 1972.

The turbines were replaced and upgraded to satisfy power production demands and improve turbine efficiency.

TURBINE PRE-TEST INSPECTION

Members of the test team and staff of VA Tech, Electroperu - Hydroelectric Mantaro, and Cenergia/HydroPower Performance Engineering Inc. carried out a site inspection on November 23, 2005.

A visual inspection revealed that the turbine pelton wheel appeared to be in very good condition. The nozzles and cones were in good condition aside from one (Nozzle # 3) that had plastic debris. After cleaning the plastic debris, the unit was ready for test.

The piezometers used for the test were in good condition. They were also flushed and a visual observation made to ensure there were no obstructions. Piezometers used during the test were periodically flushed to eliminate any trapped air.

Net Head Piezometers

- One piezometer was used to measure the pressure at the temperature probe cross-section, about 45 degrees from the temperature probe.
- A second piezometer was located inside the temperature probe instrument.

MEASUREMENT METHODOLOGY

The turbine flow was measured by the direct operating procedure using the Thermodynamic method in accordance with the IEC 60041-1991 standard.

TEST PROCEDURE

All instrumentation was calibrated at the VA Tech lab before the test. After they were installed, each one was checked properly on-site prior to the test.

The Temperature instruments were checked together in the same water bath to ensure that all instruments accurately read the same temperature. All instruments were adjusted accurately as per the zero check before and after the test (graph 3).

A total of 22 test runs were conducted covering the range of unit output from an approximately 42 MW to 100% of full unit output of 111 MW.

The Thermodynamic test runs were made at approximately 15 minute intervals. At the beginning of each run the nozzles were set at a fixed opening. Ten (10) minutes were allowed for conditions to stabilize. Each load point was measured twice.

The following simultaneous measurements were made over a 2 minute period:

- Temperature of flow at the turbine entrance immediately before the first nozzle bifurcation
- Temperature of flow at the turbine exit at the unit tailwater
- Unit tailwater elevation
- Pressure head elevation at the scroll case entry
- Generator output, power factor, turbine speed, and frequency
- Nozzle wicket gate opening

TEST PARAMETERS & MEASUREMENT PROCEDURES

Turbine Efficiency by Thermodynamic Method

General

The thermodynamic method is based on the application of the principal of conservation of energy (first law of thermodynamics) to transfer energy between water and the runner pelton wheel through which it is flowing (as per IEC 60041 Test Code Clause 14.1.1).

The specific mechanical energy at the runner is determined by measurement of the performance variables like pressure, temperature, velocity, and water level (as per IEC 60041 Test Code Clause 14.1.1). Figure 4 shows the disposition of the measuring instruments.

To determine the turbine efficiency, the need to measure the turbine flow is eliminated by using the specific mechanical energy together with the specific hydraulic energy. The turbine flow is calculated from the efficiency equation as per the IEC 60041 test code.

All the equations as presented and followed by VA Tech to measure the Specific Hydraulic Energy and the Specific Mechanical Energy are in accordance with the IEC 60041 test code and with the best performance testing practice.

Turbine Efficiency

Turbine Efficiency = $\eta = P/P_h = \eta_h \times \eta_m$
Where :
P = Mechanical power output = Turbine Output = Generator Output + Losses
P_h = Hydraulic power available for power production
P_m = Turbine runner mechanical power output at the runner coupling
Hydraulic Efficiency $\eta_h = P_m/P_h = E_m/E$
Mechanical Efficiency $\eta_m = P/P_m$

Specific Mechanical Energy Measurement

The specific mechanical energy is the mechanical power transmitted through the coupling of the turbine runner divided by the mass flow rate. The thermodynamic method allows direct measurement of the specific mechanical energy (E_m). The specific mechanical energy E_m deals with the specific energy exchange between the water and the turbine runner (IEC 60041 Item 14.2).

$$E_m = a \times (p_{abs11} - p_{abs20}) + c_p \times (\theta_{11} - \theta_{20}) + (v_{11}^2 - v_{20}^2)/2 + g \times (z_{11} - z_{20}) + dE_m$$

Specific Hydraulic Energy Measurement

The specific Hydraulic energy is the input energy to the turbine runner.

$$E = (p_{abs1} - p_{abs2})/\rho + (v_1^2 - v_2^2)/2 + g \times (z_1 - z_2)$$

The high temperature sensor was located downstream of the main valve and just before the first nozzle branch. The low pressure sensor was located at the tailrace. This setup is accordance with the IEC 60041 test code.

The pressure was also measured at the high pressure side and the free water surface level was measured at the tailrace in accordance with the IEC 60041 test code.

Generator Power Output Measurement

- The generator output was measured from the station information. It was recorded manually from the station information and assumed stable during the data collection time for each run (approximately 2 minutes each). By watching the generator output indicator, the power output was stable during the measurement.
- The Power factor was also recorded manually and it was also stable around 0.999, which is acceptable (it should be 1)
- The Vars on the unit was fluctuating within a very small range to assume that the power factor was stable during each test point.
- Turbine speed was recorded from the station information and it was stable during each test point.

- Frequency was also fluctuating within a narrow range, which is an indication that the runner speed was stable.
- The Turbine bearings were randomly checked and they were stable at normal temperature. This is an indication that the mechanical losses were stable and relatively small.

Measurement of Pressure

Before the test, the reference (zero) elevations of the unit were established at the centreline of the unit. All pressure elevations were referred to the turbine runner centreline.

The pressure was measured during each test run by the scanner. The pressure instruments were calibrated at the VA TECH lab before the test and were checked before and after the test.

The pressure measurement, calibration and checking is acceptable in accordance with the IEC 60041 test code.

Measurement of Temperature

- The temperature was measured by a PT 1000, which is a precision temperature instrument. The high pressure side temperature measurement apparatus is in accordance with IEC 60041 test code.
- One instrument was used to measure the high pressure side temperature, which is in accordance with the test code because the pipe diameter is less than 2.5 m.
- To ensure that there was no heat exchange between the temperature probe and the surroundings, a continuous flow of water was allowed around the probe.
- The location of the temperature probe was just before the first nozzle and before the first nozzle bifurcation, this location is acceptable and in accordance with the test code.
- The low pressure side temperature measurement was also performed by a precision instrument in accordance with the IEC 60041 test code.
- Two instruments were used at the tailrace to measure the water temperature.
- Both high pressure side and low pressure side instruments were checked and zeroed before and after the test in accordance with the IEC 60041 test code and testing best practices.

Determination of Turbine Flow

Turbine flow is determined from the efficiency equation as follow:
$Q = P_m/(\rho \times g \times H \times \eta_h)$

Measurement Repetition

- Eight (8) test points were measured with two (2) repetitions each. The best efficiency area and maximum output were repeated four (4) times.
- All repetitions were very consistent, which represents good temperature distribution, good flow velocity distribution, and stable generator output.
- Each test point was the average of 31 sample scans, excluding the power output and power factor.
- The consistency of the measurements is in accordance with the IEC 60041 test code.

Unit Tailwater Elevation

- The unit tailwater elevation was measured by a linear depth pressure transducer placed in a frame at the tailrace. This was done to determine the level and the velocity head at the exit for the determination of the specific mechanical energy.
- The transducer failed at run no. 14 and was replaced with manual measurement in accordance with IEC 60041 test code.

TEST DATA PROCESSING AND ANALYSIS

The test data processing from the raw data to the test results were reviewed in detail and were found to be in accordance with IEC 60041 test code.

MEASUREMENT UNCERTAINTIES

Measurement uncertainties were made immediately after the test in accordance with IEC 60041 test code. The efficiency uncertainties were calculated to be within ± 0.70%.

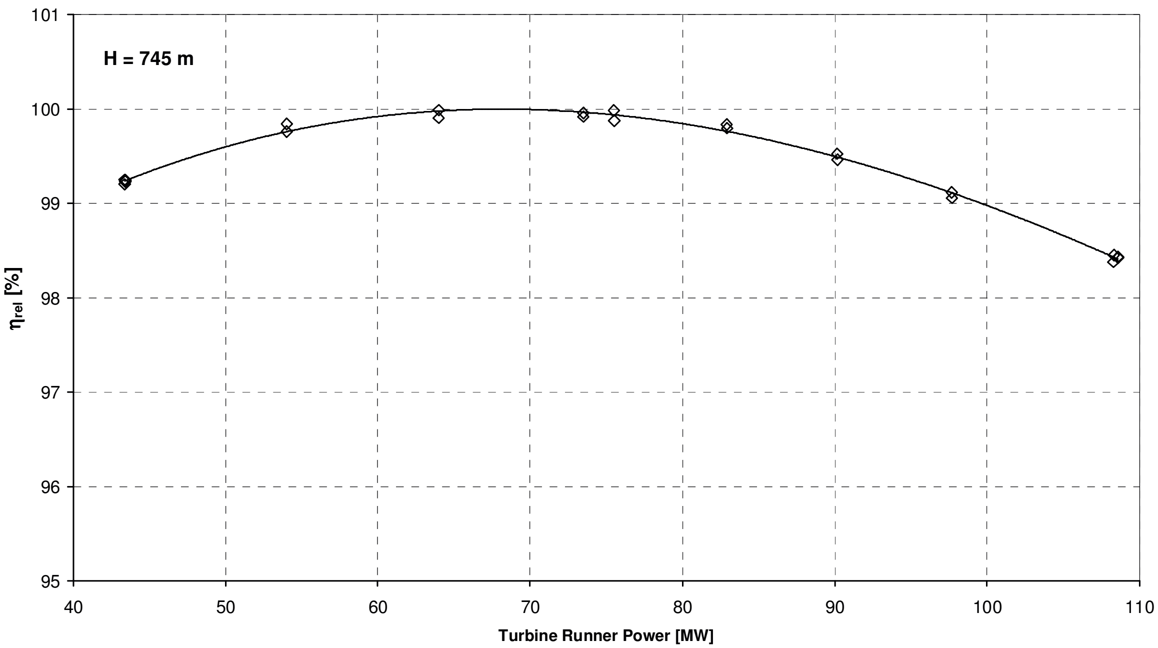
TEST RESULTS SUMMARY

The test results demonstrated in Figure 1 and 2 showed that the test points are very close to each other, and the collected data was accurately recorded.

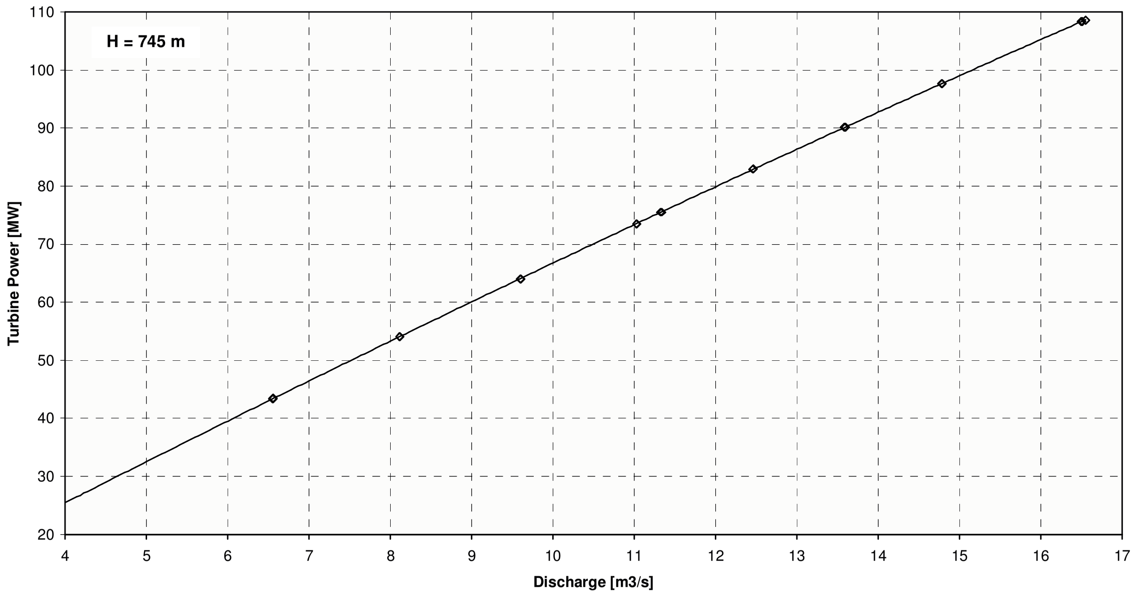
The turbine test results showed that the turbine runner performance is within the uncertainty band of the guaranteed performance and were accepted.

TEST CONCLUSION

- The test was carried out in accordance with the IEC 60041 test code.
- The test results showed that the turbine runner performance is within the guaranteed values.
- The turbine runner, after operating 2200 hours, is in very good condition without any cavitation or pitting damage.



GRAPH 1 **TURBINE OUTPUT – RELATIVE EFFICIENCY**

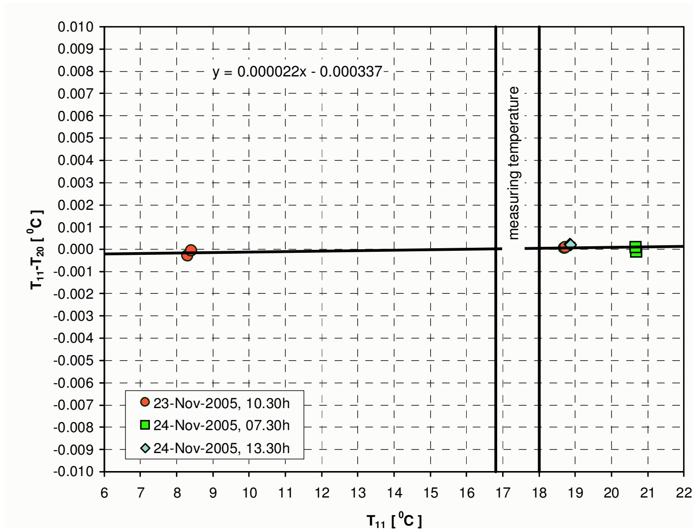


GRAPH 2 FLOW-OUTPUT

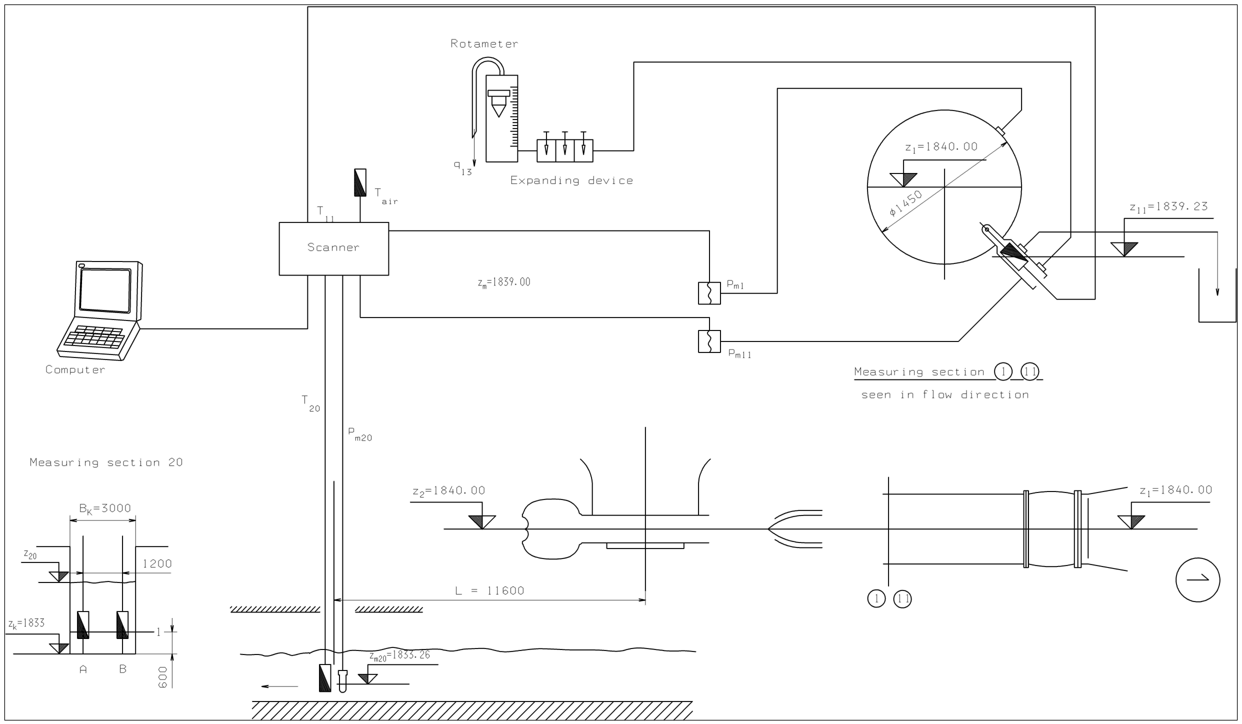
MANTARO
Thermodynamic Efficiency Test
Thermometer Zero Check

T_{11}	PT1000	number	05160613
T_{20A}	PT1000	number	05160616

T_{11} ^0C	T_{20} ^0C	T_{11}-T_{20} ^0C
18.7051	18.7051	0.0001
18.7223	18.7222	0.0001
8.3074	8.3077	-0.0003
8.4048	8.4049	-0.0001
20.6924	20.6925	-0.0001
20.6794	20.6793	0.0001
18.8518	18.8516	0.0002
18.8625	18.8623	0.0002



GRAPH 3 COMPARISON - TURBINE OUTPUT – EFFICIENCY



GRAPH 4 DISPOSITION OF MEASURING INSTRUMENTS