TURBINE EFFICIENCY MEASURED BY THERMODYNAMIC METHOD AGAINST USING ULTRASONIC FLOWMETER

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ABSTRACT

Company OSC performed efficiency measurement at two original and one modernized Pelton turbines in HPP Caoria (Italy) in autumn 2013 using the thermodynamic method. Because the advanced 8-paths ultrasonic flowmeter is installed on the penstock in front of HPP also its data output was used for efficiency determination by using other independent method. Description of the methods used as well as measurement results comparison for both the methods are presented in this article.

1. INTRODUCTION

Fig. 1 *HPP Caoria general view*

The HPP Caoria (Italy) is high pressure power plant located close to village with the identical name. There are installed three identical units, each consisting of horizontal one nozzle Pelton turbine directly coupled with synchronous generator. Performance tests were carried out on the original units U1 and U2 as well as on the unit U3 equipped with the new runner and nozzle. The average head during the tests was approx. 536 m.

It is necessary to say that the power plant is perfectly maintained and suitable for thermodynamic measurement.

Turbine data	
Manufacturer	ESCHER WYSS Schio
Type	Pelton, one nozzle, horizontal
Manufacture year	1942 (U1, U2), 1954 (U3)
Runner diameter	2.47 m
Number of buckets	21
Rated head / head range	542 m / 470 ÷ 523 m
Maximum flow through turbine	2.9 m^3/s
Rated turbine output	12.7 MW
Rated speed	375 rpm

Tab. 1 *Main turbine data*

2. THERMODYNAMIC METHOD

Unit longitudinal section with marked positions of the main sensors used for performance tests is presented in Fig. 2 with the following instrumentation used for thermodynamic measurement:

1. **Data acquisition unit HP 34970A + multiplexer HP 34901A:** Precise instrument with resolution 6.5 decades and 20 channels multiplexer with very low thermoelectric voltage.
2. **Thermometers Pt1000, class A.** Total number – 4 pcs, th_{11} in sampling probe, th_{21} ÷ th_{23} located in discharge channel.
3. **Thermodynamic sampling probe** (OSC design) with adjustable expansion element and cooling water circuit in the high pressure cross section (details see Fig. 3).
4. **Electromagnetic flowmeter Badgermeter,** DN 15 for flow rate determination through sampling probe (Q_{11}).
5. **Sampling frame in discharge channel** (see Fig. 4).
6. **Pressure sensors BD Sensors DMP333**, range 6 MPa for pressure measurement in turbine inlet cross section (p_1) and also in sampling probe after expansion (p_{11}).
7. **Submersible probe BD Sensors LMP308i** for water level measurement in discharge channel (Z_2)
8. **Contact thermometer TESTO845** for auxiliary measurement (surface temperature etc.)
9. **Data acquisition unit BMC USB AD16f**, resolution 16 bit, 16 channels, accuracy class 0.05 was used to measure non-electric quantities as flow rate, spear position, all pressures and also auxiliary quantities used for correction of the thermodynamic method results (e.g. ambient pressure, water level in discharge channel, etc.). This unit was used also for data acquisition as necessary for indirect efficiency determination.

Above described instrumentation represents one of the two most commonly used sets for thermodynamic method. Usage of Pt thermometers requires very careful adjusting of zero temperature difference before and after the site tests. Such zero calibration has to be performed under stable temperature close to real water temperature. Zero calibration is performed in spacious thermos with special cooper block, where the thermometers are inserted into prepared holes. The thermos is filled with water which temperature was adjusted using pieces of ice. The efficiency calculation was performed in accordance with standard [1].

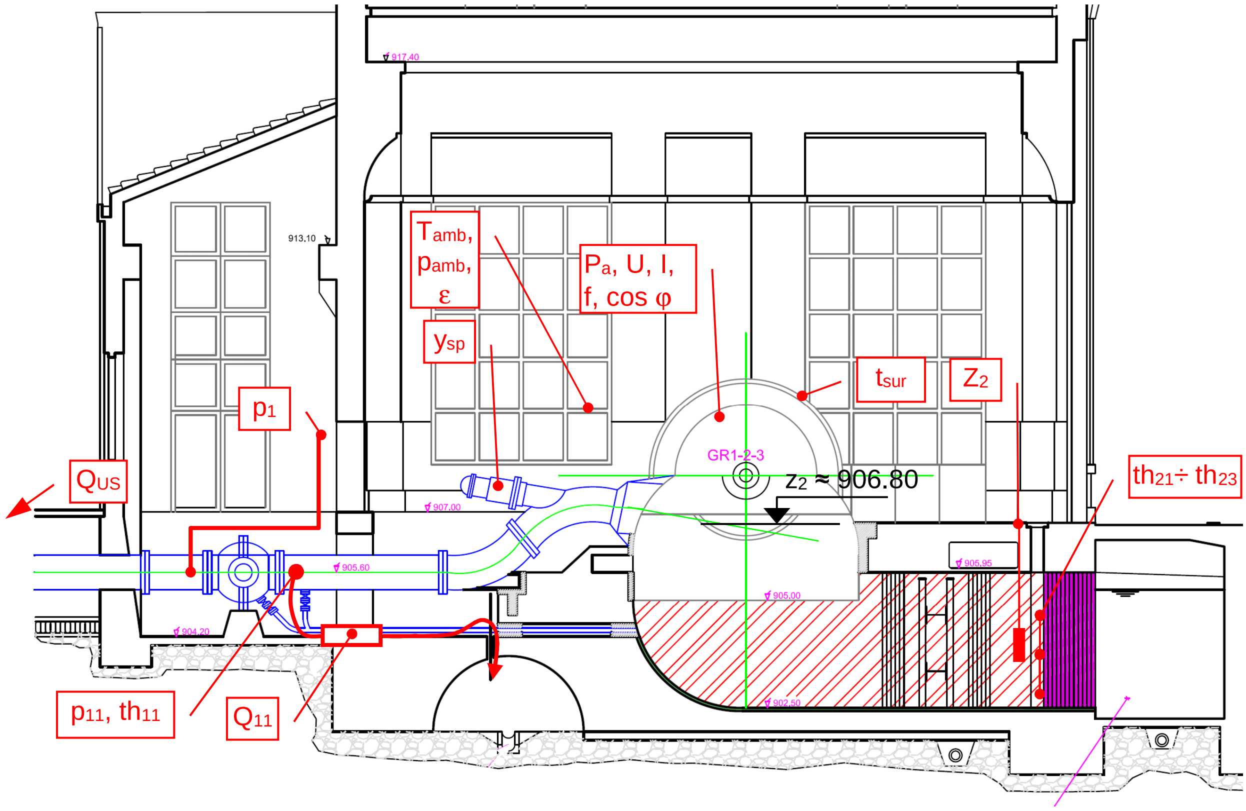

Fig. 2 Location of the main sensors used for the unit performance tests

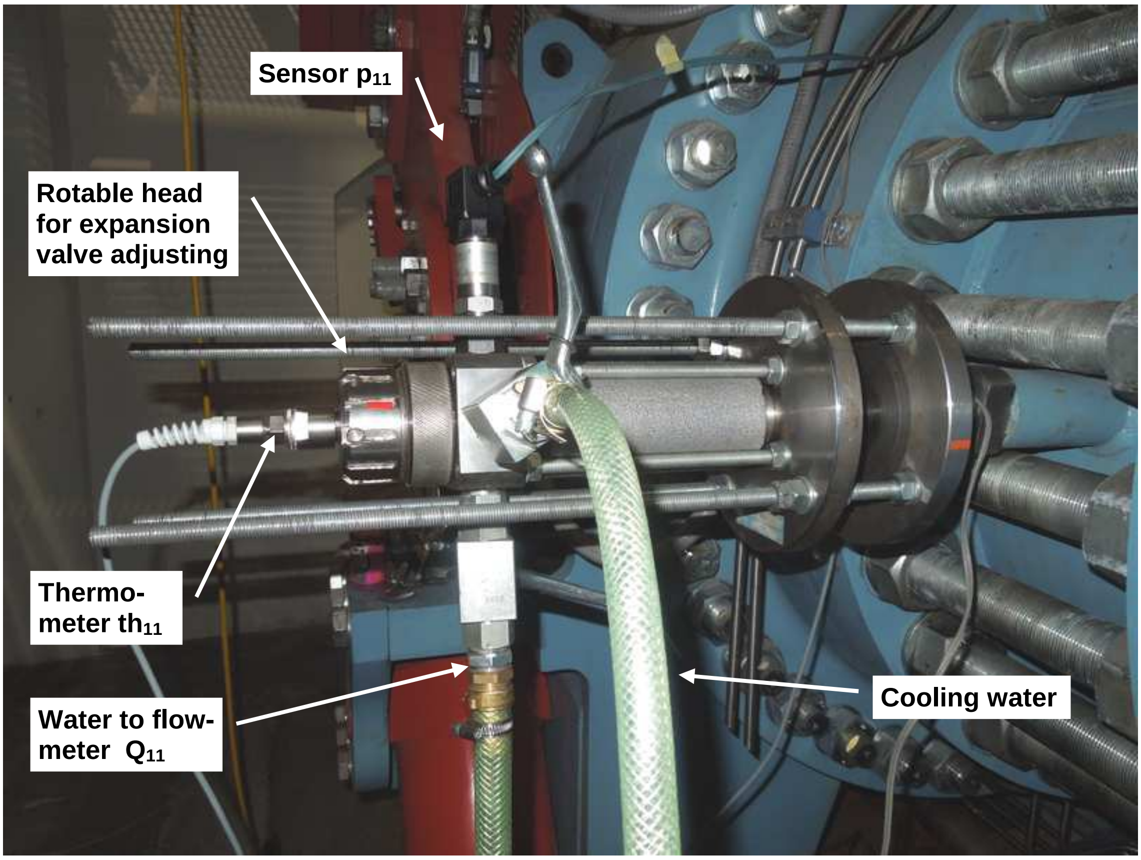

Fig. 3 Thermodynamic sampling probe in the high pressure profile

Fig. 4 Structure with thermometers and collectors in turbine discharge channel

3. EFFICIENCY INDIRECT DETERMINATION

Some additional complementary quantities were scanned parallel to the thermodynamic measurement for turboset efficiency evaluation by indirect method. Among the most important quantities are:

1. **Flow rate in penstock.** Output signal 4 ÷ 20 mA from the plant operational flowmeter RITTMEYER Risonic 2000 was led into OSC data acquisition unit BMC.
2. **Power on generator terminals.** Temporarily installed digital power meter YOKOGAWA WT230 was used for this purpose. This instrument provides exhaustive set of grid parameters as phase currents, voltages, power factor, frequency etc. which can be used for generator losses calculation.

Primary result of the indirect efficiency determination is the total turboset efficiency. To extract the turbine efficiency the generator efficiency knowledge is necessary. For this purpose the generator efficiency data based on ENEL document from site test performed in 1993 were used. The evaluation of turbine efficiency based on ultrasonic flowmeter data was performed in a standard way in accordance with [1].

4. MEASUREMENT RESULTS

Relative efficiency of all the three HPP turbines determined by thermodynamic method is presented in Fig. 5. Relative efficiency of all the three turbines relates to the best efficiency point of upgraded unit U3.

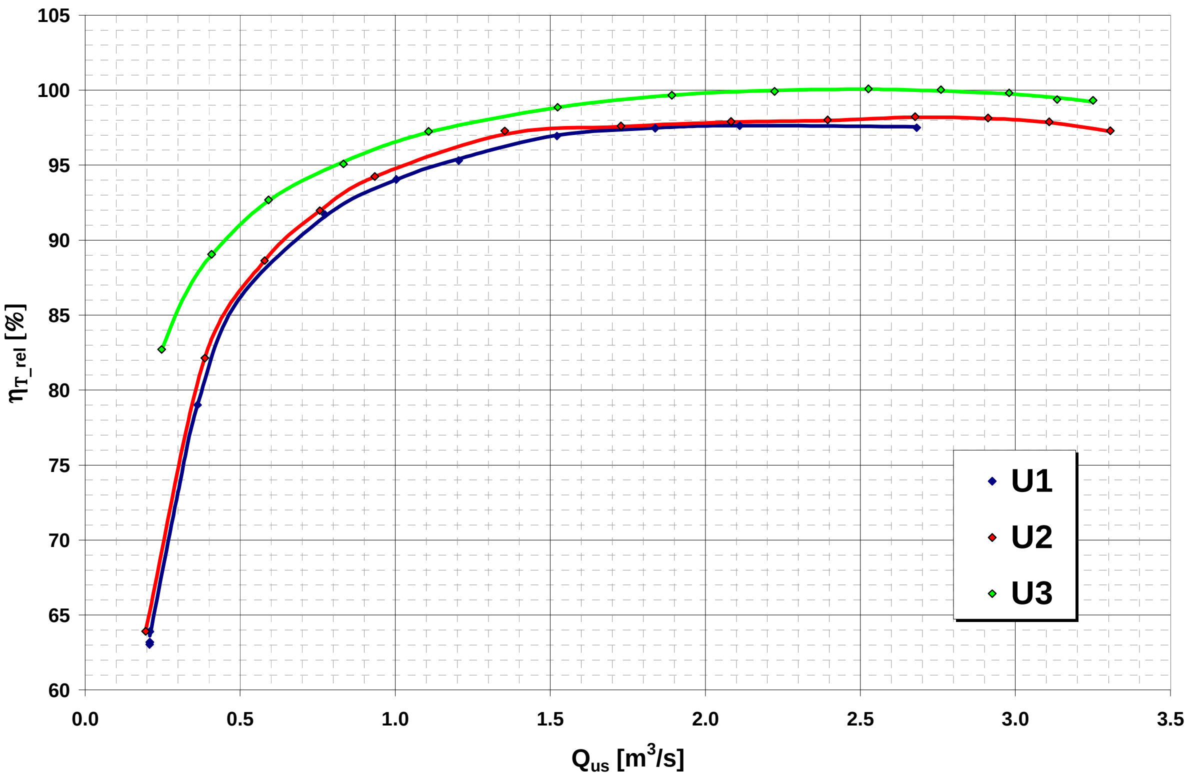

Fig. 5 *Turbine efficiency determined by thermodynamic method*

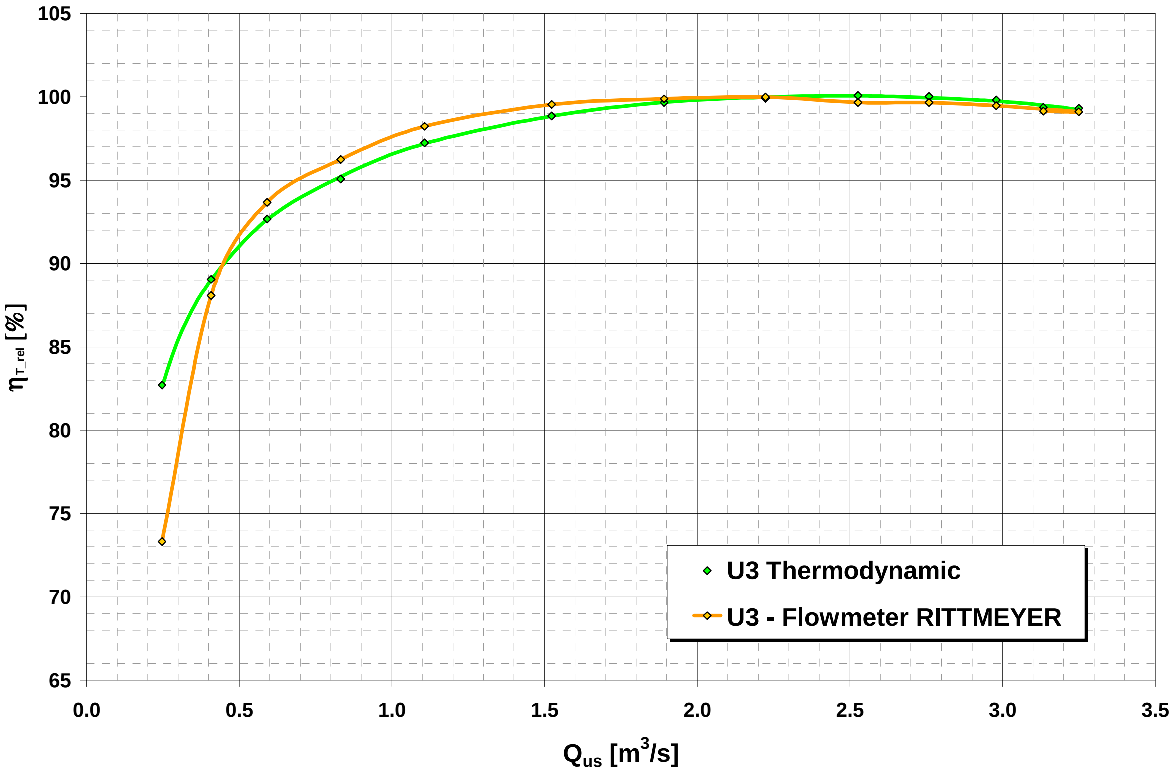

Fig. 6 *Efficiency curves as determined by thermodynamic and by indirect method*

Comparison of the turbine efficiency measured by thermodynamic method and efficiency determined by flow rate measured by ultrasonic flowmeter on unit U3 is presented in Fig. 6. It is evident that correlation between both efficiency curves is very good in the part approximately above 50 % of the unit maximal power, while the efficiencies differ significantly for the low power. This situation is similar also by the two other units U1 and U2.

Difference between shapes of efficiency curves is according to author's experience typical for the results provided by the thermodynamic method against the indirect measurement. Similar results exist also for comparison of thermodynamic method and Gibson flow measurement performed e.g. on HPP Sapuncica, Macedonia [3].

To explain this discrepancy, we can consider following issues:

1. Not appropriate corrections applied in thermodynamic method. Probability of this reason is however low, because impact of such a kind corrections on the final efficiency is very low.

2. Not well defined generator efficiency for the low load range. The generator efficiency data defined by generator supplier are indicated in the Fig. 7 by big magenta curve. The efficiency is defined only for power above 4 MW while the curve below this value is just polynomial extrapolation. This reason may be considered as the factor with much more probability impacted above mentioned discrepancy.

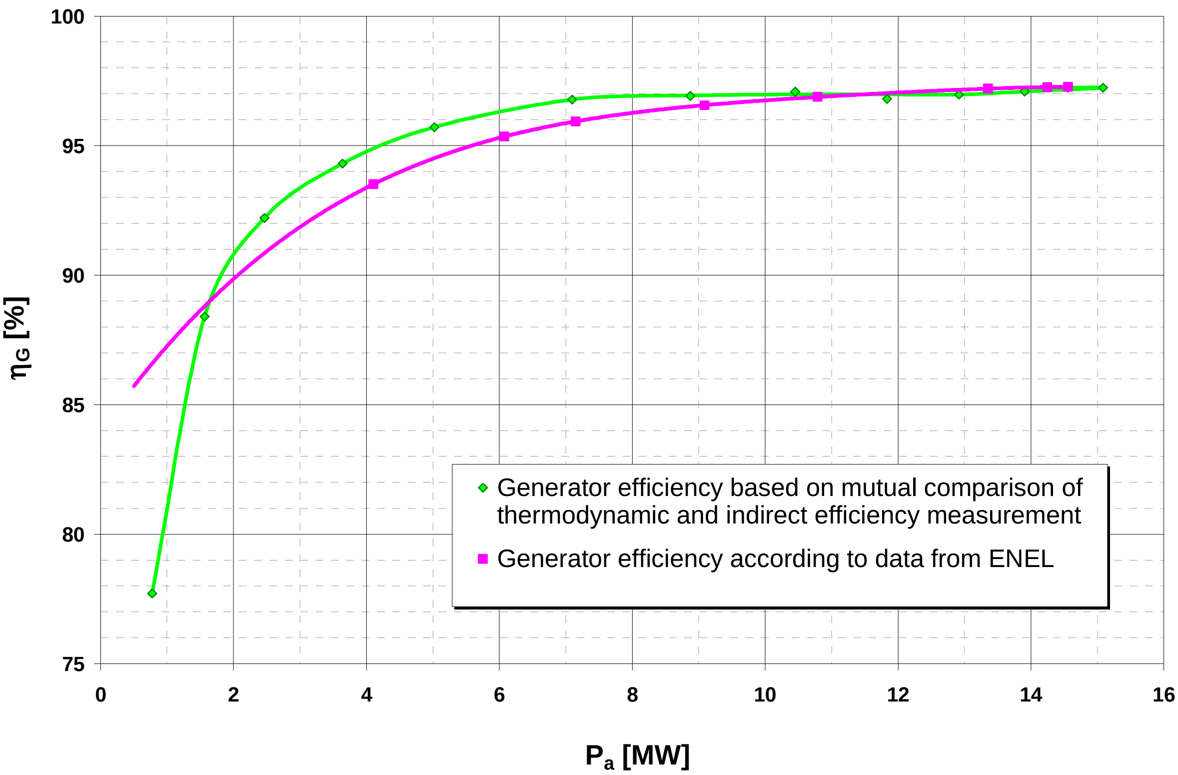

Fig. 7 *Comparison of generator efficiency curves*

While the thermodynamic method provides turbine efficiency η_T the indirect method evaluates the turboset efficiency η_{set} according to equation (1). The real generator efficiency can be then determined in accordance with formula (2) and this efficiency curve is presented also in Fig. 7 – green curve.

$$\eta_{set} = \frac{P_a}{Q \cdot \rho \cdot g \cdot H} \tag{1}$$

Where P_a = generator output
Q = turbine discharge
ρ = water density
g = gravity acceleration
H = head

$$\eta_G = \frac{\eta_{set}}{\eta_T} \tag{2}$$

5. SUMMARY

Experience gained with turbine efficiency measurement using two different and independent methods can be summarized as follows:

- The almost identical results taking into account uncertainty tolerance field can be achieved for the load above 50 % of the unit maximal output if the measurement is performed carefully.
- Efficiency curves determined by thermodynamic method and by indirect measurement differ usually for the low load.
- The probable main reason for this phenomenon may be suspected insufficient determination of generator efficiency for the low load.

6. REFERENCES

[1] *Standard IEC 41: „Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump turbines“, standard issued by CEI, year 1991.*

[2] *Ševčík P.: „HPP Caoria – Performance tests”, report OSC TZ 2069/3000, December 2013.*

[3] *Ševčík P.: „Small HPP Sapuncica - Measurement by thermodynamic method”, report OSC TZ 1843/3000, June 2009.*