

Thermodynamic Efficiency Measurement on a Pelton Turbine before and after Rehabilitation

Werner Schitter¹⁾ and Werner Mayr

Summary

The following paper is dealing with several efficiency measurements before and after the rehabilitation of one twin Pelton turbine at the Rothenbrunnen HPP in Switzerland. VA TECH HYDRO VEVEY (HYDRO VEVEY) carried out a thermodynamic efficiency measurement with the direct method already in 1996. In 1997 and 1998, also before rehabilitation Verbundplan GmbH (Verbundplan) did additional thermodynamic efficiency measurements with the partial expansion method - first using the same taps as being taken for the previous measurements. The result of one runner was in very good accordance with the HYDRO VEVEY measurement. The measured efficiency of the other runner was to our big surprise even too high. After modifying the installation the values were in accordance with the other previous measurements.

After the replacement of the two runners Verbundplan carried out acceptance tests in 1999. At the same time Rittmeyer tested an equipment for operational efficiency measurements by means of an acoustic flow measurement.

We will describe the differences between the measurements and give more information on the results.

¹⁾ Verbundplan GmbH, Branch Office Salzburg, Rainerstr. 29, A-5020 Salzburg, Austria
Tel.: +43/662/8682-22275 * Fax.: +43/662/8682-22275 * e-mail: SchitterW@verbundplan.at

Description of the Hydro Power Plant (HPP)

The Kraftwerke Zervreila AG was founded in 1952. The company runs 4 power plants (Zervreila, Safien Platz, Rothenbrunnen and Realta) with a total output of 245 MW and an annual production of about 560 GWh.

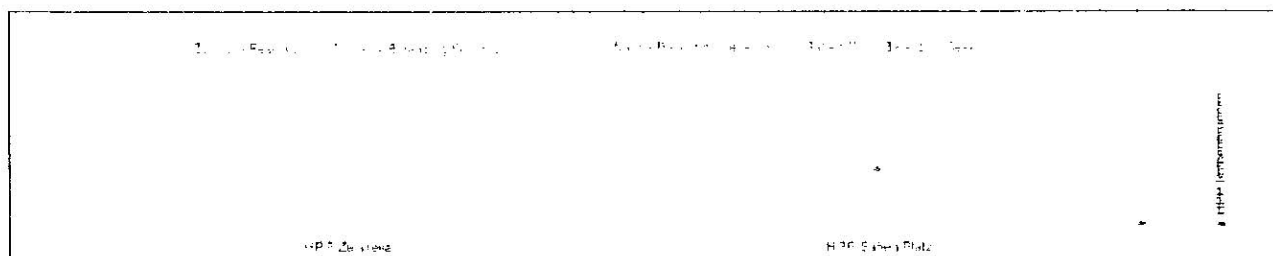


Figure 1. Kraftwerke Zervreila AG, hydroelectric development

The power plant Rothenbrunnen is supplied with energy out of the balancing reservoir Safien Platz that is mainly fed with water from the annual storage Zervreila (capacity of 100 mio. m³) via the balancing reservoirs Zervreila and Wanna.

In the power plant Rothenbrunnen there are 3 units with the following rated data installed:

Type	Twin-Pelton turbine
Jets per runner	1
Shaft	horizontal
Rated head	662 m
Rated flow	7,35 m ³ /s
Rated turbine output	42 MW
Rated speed	428,6 1/min

Table 1. Technical data Rothenbrunnen HPP

The turbines of the Rothenbrunnen HPP are in operation since 1958 and the installed Pelton wheels at unit II had already 100.000 operating hours until 1996. Therefore the Kraftwerke Zervreila AG thought about buying new runners.

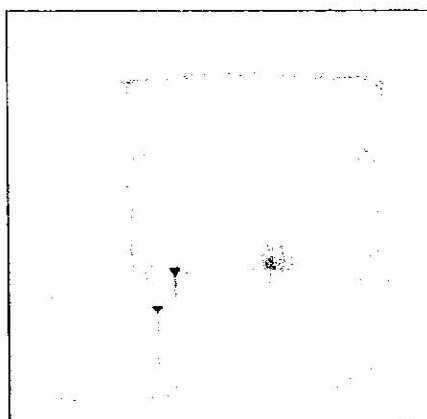


Figure 2. Rothenbrunnen HPP

The machines of the Rothenbrunnen HPP are very suitable for a thermodynamic efficiency measurement. On the one hand the head is with about 650 m quite high and on the other hand every partial turbine has a separate outlet channel with a slot for erection of the stop locks and very useful for installing the tailwater thermometer. As the distance between the downstream measurement section and the runner is only about 2,5 times the runner diameter this is not corresponding with the IEC 41 code. Nevertheless the measurement was possible without any problem and very stable.

The Measuring Company and the Equipment

Verbundplan GmbH was founded in 1959 as an independent consulting company. In 1976 we started with our first measurement using the thermodynamic method. Now we are looking back to nearly 25 years of practical knowledge with more than 170 measurements (1). Due to our good experience we are still using the partial expansion method.

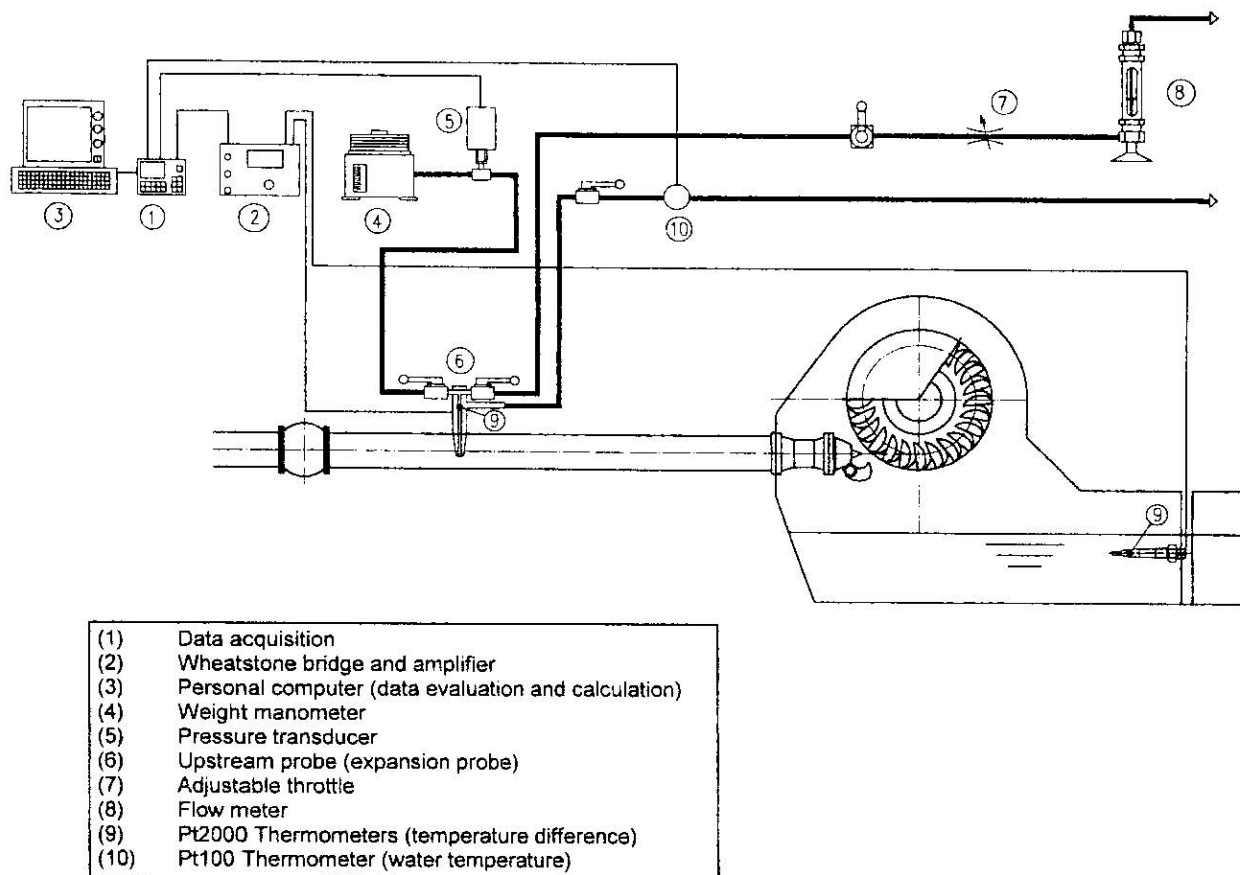


Figure 3. Scheme of Verbundplan measurement

Measurements before Rehabilitation

To measure the efficiency of the old renewed runners on the one hand and to get a more detailed knowledge of the possibility of measuring the efficiency by means of the thermodynamic method on the other hand, HYDRO VEVEY got an order for measurements in 1996. HYDRO VEVEY

was using the direct method with 3 thermometers in the outlet channel. Due to this measurement and the received offers of new runners an improvement of efficiency of about 2 % could be expected.

According to the wish that the measurements for the confirmation of the given guarantees (acceptance tests) should not be done by a manufacturer, possibly by a competitor, the order for further measurements of the old Pelton wheels was handed to Verbundplan in 1997. The aim of this measurement was as follows

- to prove the suitability of the measuring method used by Verbundplan as well as of the existing measurement equipment,
- to check the existing measuring taps for the acceptance test,
- to give the manufacturer the change to get better knowledge of this method.

Verbundplan is using the method of partial expansion, which means that only one thermometer is installed in the outlet channel. Mainly the measuring taps used for the measurement of 1996 remained the same for the measurement in 1997.

Measuring the partial turbine II A the results of HYDRO VEVEY could be reproduced very well and there was a maximum deviation of 0,2 %. The installation of the high-pressure probe of the partial turbine II B was not in accordance with our recommendations. Due to the wish of the customer thus a measurement was carried out. The measured values were clearly about 1,5 % higher then the results of HYDRO VEVEY and higher then the values of the partial turbine II A.

How could this result be achieved ? Verbundplan is using a special double body probe.

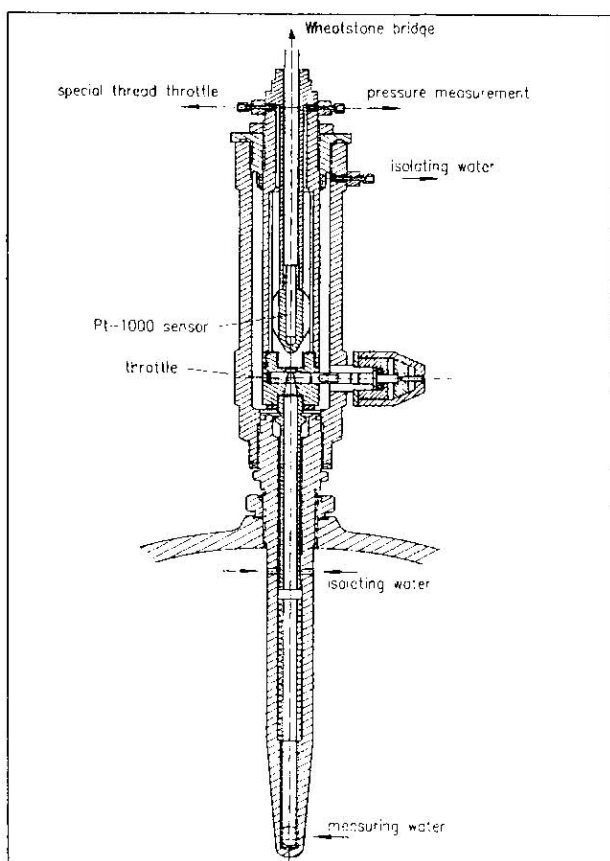


Figure 4. Probe with partial expander

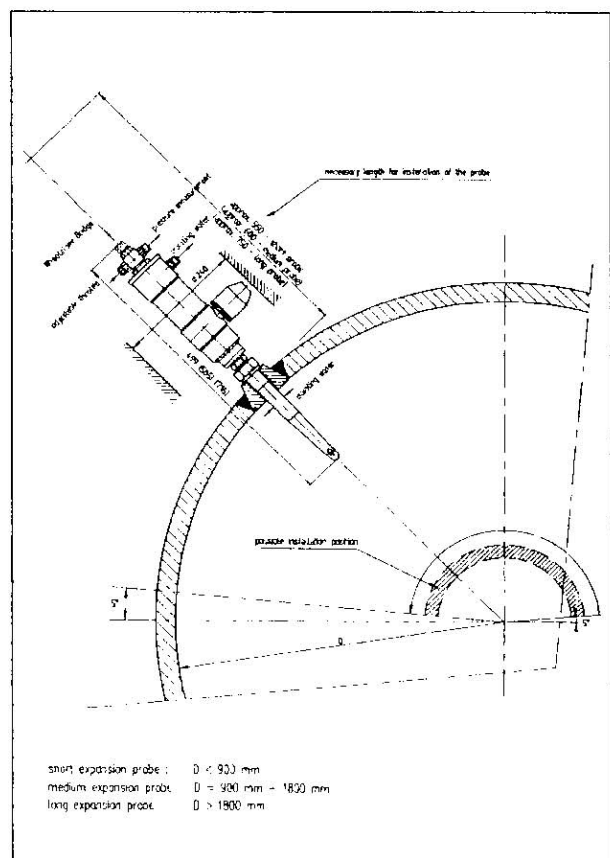


Figure 5. Recommendation for the installation of the probe

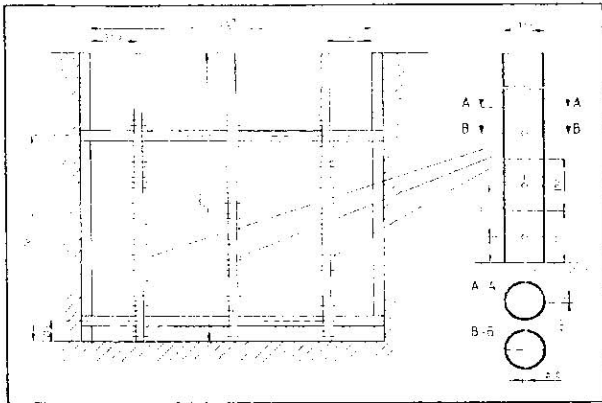


Figure 7. Tailwater installation during test HYDRO VEEVEY and Verbundplan 1997

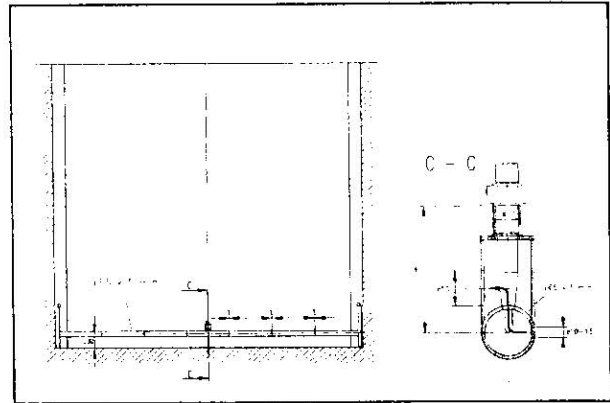


Figure 8. Tailwater installation during test Verbundplan 1998 and 1999

The new measured efficiency values showed only very little differences to the results of HYDRO VEEVEY similar to those of the partial turbine II A in autumn 1997. To assure that the changed tailwater installation had no negative influence on the result of the measurement also a few measurements with the partial turbine II A were done at the same time. The deviations were in a range smaller than 0,1 % and the measurements could therefore be assumed to be identical.

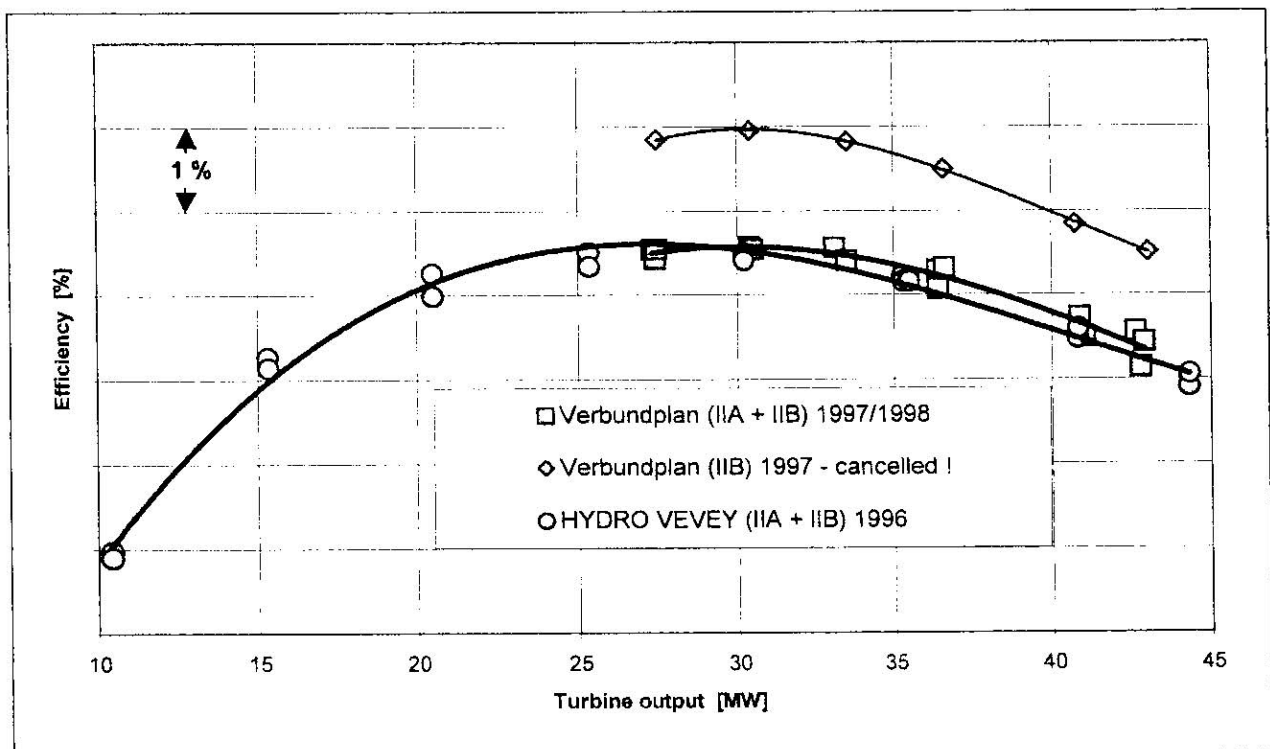


Figure 9. Comparison of the efficiency measurement by HYDRO VEEVEY and Verbundplan before rehabilitation with the thermodynamic method.

Measurements after Rehabilitation

The acceptance tests done in May 1999 showed up an indeed pleasant result for the operator Kraftwerke Zervreila AG and the guaranteed values were clearly within the contractually fixed tolerance of $\pm 0,8 \%$. The actual measurement accuracy was ascertained to be $\pm 0,69 \%$. The

reason for the mean variation of the measuring points in Figure 10 is the fact that the partial turbine II A has a slightly higher efficiency than the partial turbine II B.

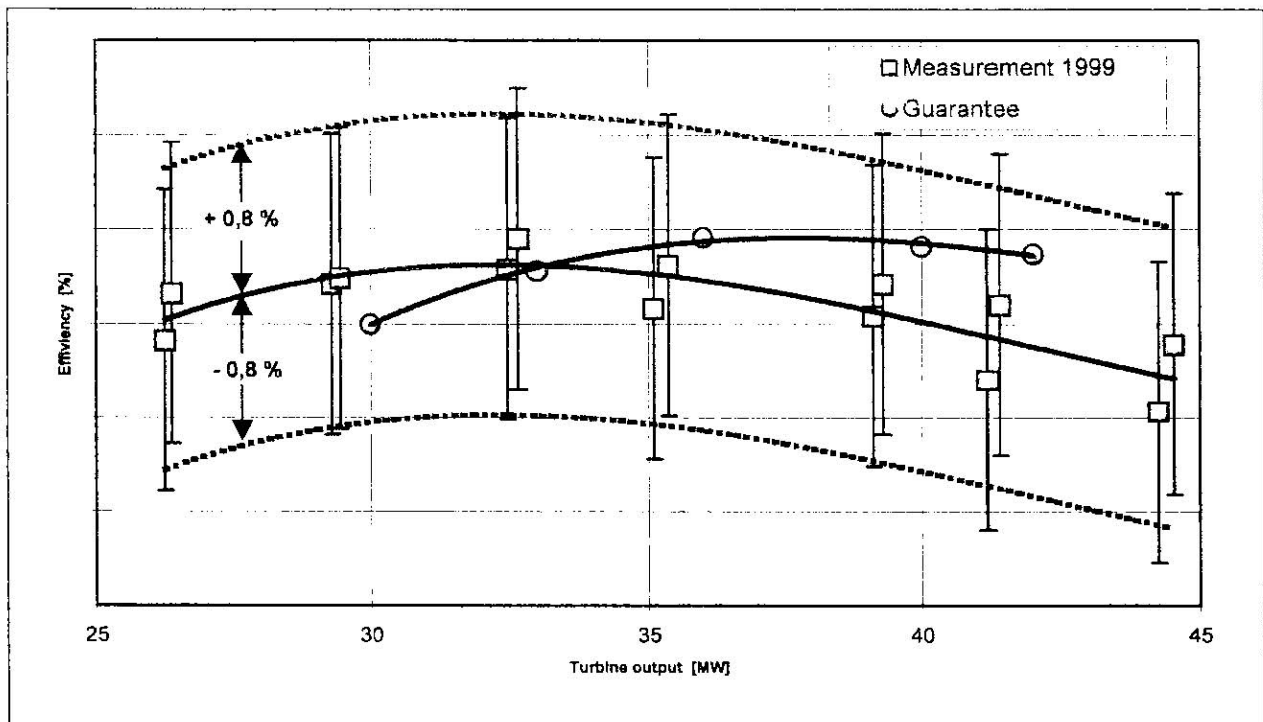


Figure 10. Result of the acceptance test and comparison with the guaranteed values

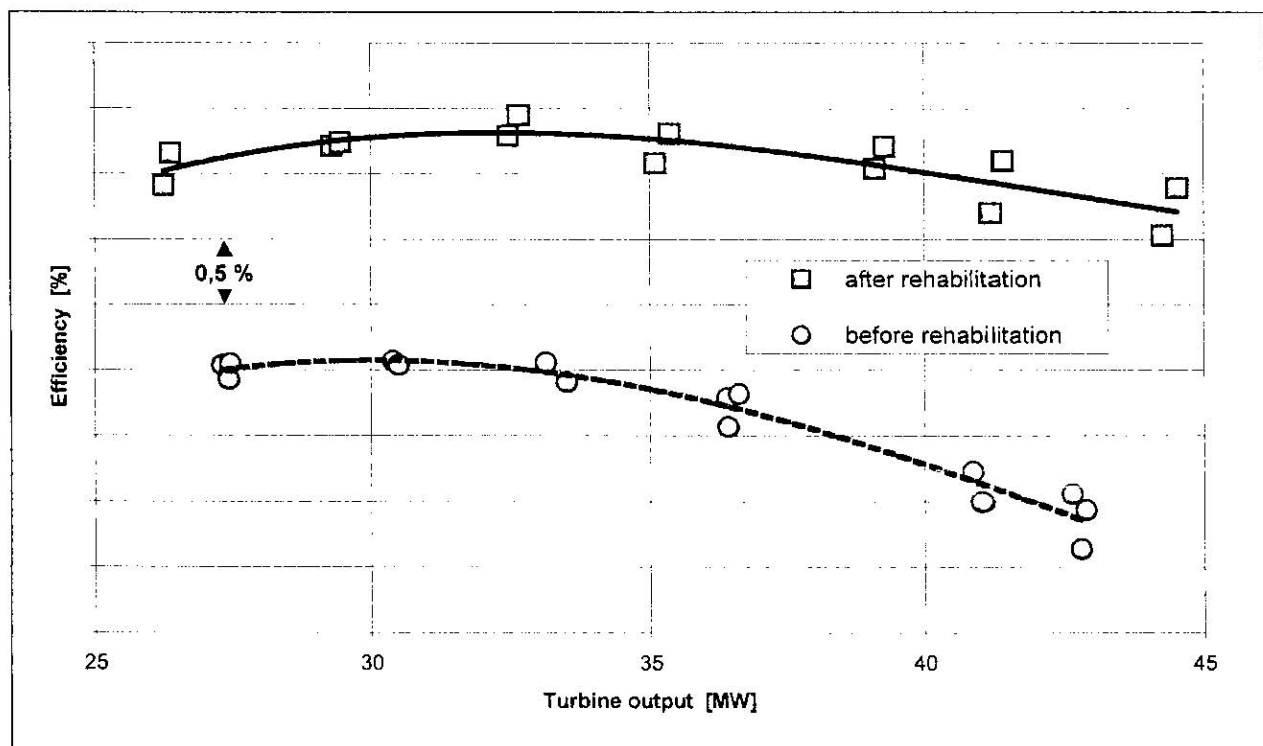


Figure 11. Overall result of the efficiency measurement by Verbundplan before and after rehabilitation with the thermodynamic method

The increase of the efficiency varies between 1,5 % at half load and 2,5 % at full load.

At the same time as Kraftwerke Zervreila AG has bought the new Pelton wheels, they ordered an equipment for an operational efficiency measurement at Rittmeyer. The basis for this measurement is as follows

- a permanently installed ultrasonic flow measurement,
- a pressure measurement at the entrance of the turbine (one partial turbine only) for determination of the head,
- a power measurement at the generator.

The later installation of an ultrasonic measurement is mostly difficult and only possible at very few locations. At the Rothenbrunnen HPP the only suitable place for this purpose was the removable pipe in the valve chamber Balveins. The valve chamber is situated at the end of the pressure tunnel and the beginning of the pressure shaft and is equipped with a butterfly valve. This measuring section is not appropriate as it is close to the butterfly valve and immediately before the bend to the pressure shaft. To achieve thus rational measuring values an 8-path installation has been chosen. This equipment has been set in operation in parallel to the acceptance tests done by the thermodynamic method.

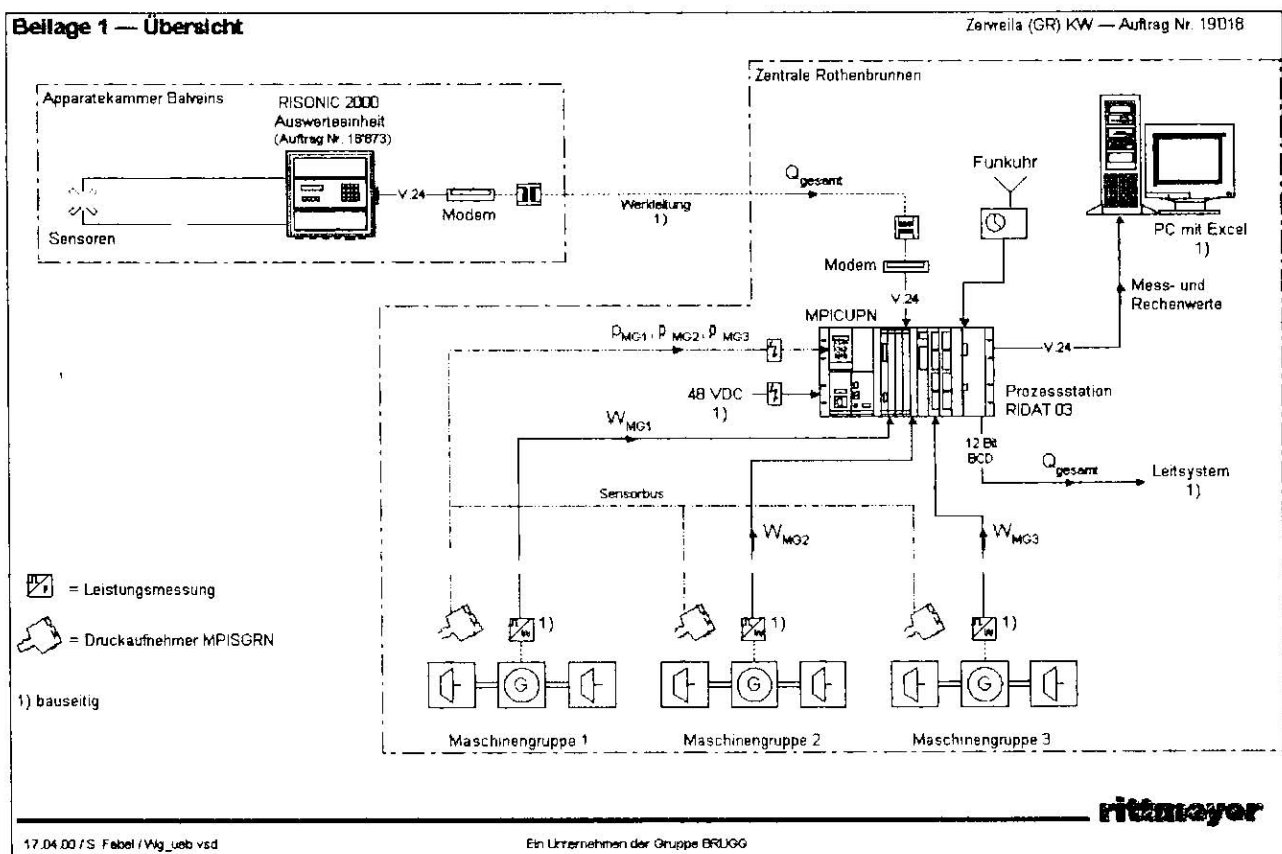


Figure 12. Scheme of operational efficiency measurement

The thermodynamic measured efficiency is an internal efficiency of the turbine and does not include any external losses (bearings, governor etc.). The efficiency determined by using an ultrasonic flow measurement as described above leads first to an overall efficiency. It is also not possible to distinguish between the two runners. If you know the efficiency of the generator and all external losses between generator output measurement and turbine runner, you can calculate a comparable efficiency also for the whole turbine (both Pelton wheels).

The efficiency can be calculated by means of the following formulas:

$$\eta_{US} = \frac{P_{turbine}}{P_{hydraulic}}$$

$$P_{turbine} = \frac{P_{generator}}{\eta_{generator}} \quad (+ P_{losses})$$

$$P_{hydraulic} = Q * \rho * g * H_n$$

$$H_n = \frac{p}{\rho * g} + \left(\frac{\frac{Q}{2}}{d_i^2 * \pi} \right)^2 \frac{1}{2 * g}$$

$$\begin{array}{l} P_{generator} \Rightarrow MW \\ Q \Rightarrow m^3 / s \\ p \Rightarrow bar \end{array}$$

$$\begin{array}{l} \eta = f(P_{generator}) \\ \rho = 1002 \text{ kg} / m^3 \\ g = 9,80665 \text{ m} / s^2 \\ d_i = 0,75 \text{ m} \end{array}$$

In the case of Rothenbrunnen HPP the available values for the generator efficiency are based on the acceptance tests of the generator somewhat round 1959 and do not include any mechanical losses like bearings, ventilation losses in the generator and so on. Therefore it is not possible to compare the results directly but the difference of about 1 % shown in Figure 13 seems to be plausible taking into account the missing losses (fixed losses and losses as a function of the output).

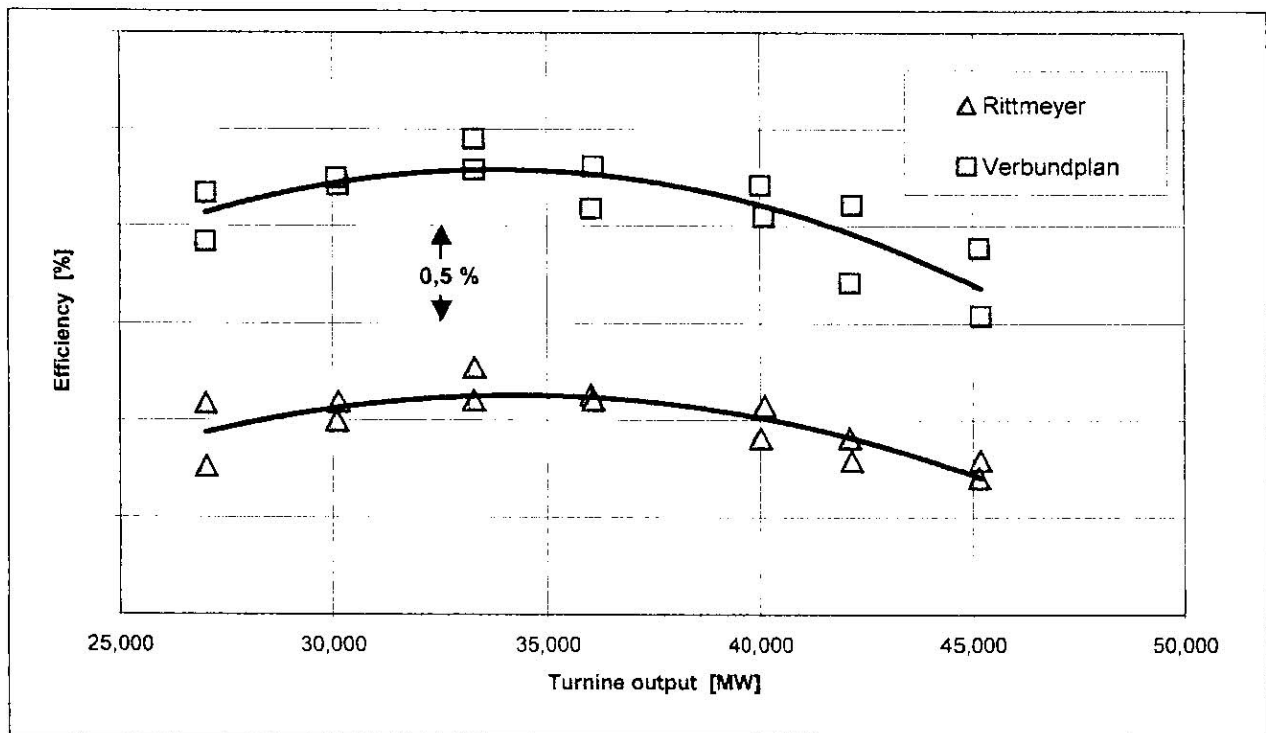


Figure 13. Comparison of ultrasonic measurement by Rittmeyer and thermodynamic efficiency measurement by Verbundplan

Conclusion

The measurements of two completely independent measuring teams by means of different methods have shown that using a correct installation leads to equivalent results.

It was also proved that with a rather simple, fix installed ultrasonic flow measurement combined with pressure and output measurements, a very useful operational relative efficiency measurement is possible.

We would like to thank Mr. Capatt and Mr. Bleiker of Kraftwerke Zervreila AG as well as Mr. Wolf of Rittmeyer for their active support, which enabled us to prepare this report.

References

- (1) Werner Mayr, *20 Years Experience with the Thermodynamic Method*, IGHEM Seminar – Montréal '96, Montréal, Canada