Verbundplan
Tauernplan Consulting GmbH

20 Years Experience with the Thermodynamic Method

IGHEM - Montréal 96

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May 1996

Technical Paper

Summary:

This paper gives an outline of my personel relation to the Thermodynamic Efficiency Measurement, the history of evaluating the properties of water and the measurements done by Tauernplan Consulting with examples and special remark on the temperature distribution at the low pressure side section.

Rèsumè:

Ce rapport donne un extrait de mon relation personnel avec la Méthode Thermodynamique, l'histoire d'évaluation des propriétés thermodynamiques de l'eau et les mesurages faits de Tauernplan Consulting avec des éxamples tenant compte en particulier de distribution sur le coté de la basse pression.

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1. Introduction

My first touch with the Thermodynamic Method was in 1967 during my studies on the Technical University of Vienna. Prof. Schulz, the mentor for my dissertation, told me that there is possibility to determine the efficiency of a hydraulic machine by measuring the temperature difference between entrance and exit. I went home and calculated for some examples the temperature differences and was surprised about the very small rise. Then I started on the institute of Prof. Schulz, guided by Mr. Schedelberger (his assistant at this time) to develop a measuring device for such small temperature differences using thermistors.

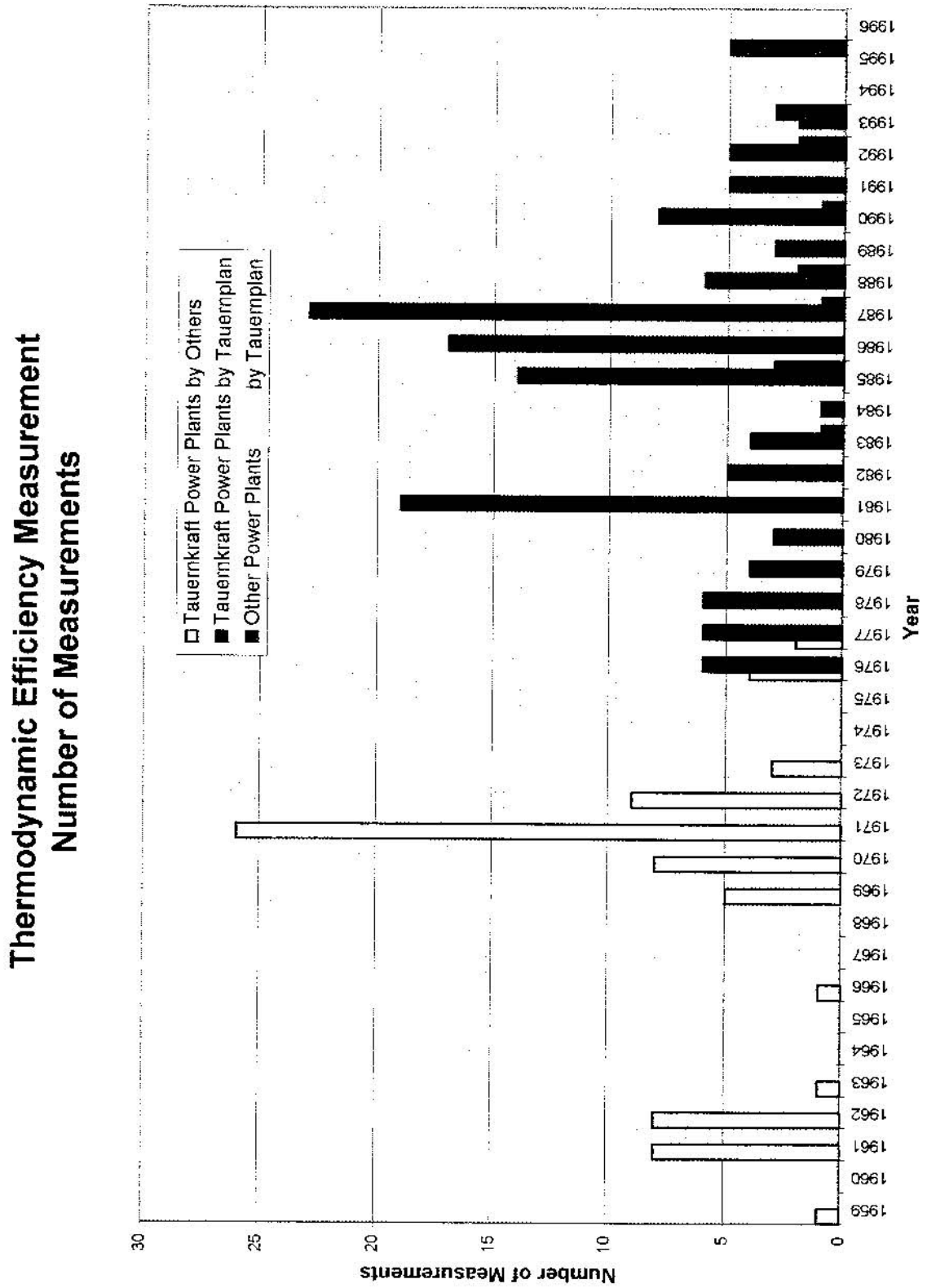
In 1968 when I began to work at Tauernkraftwerke AG I lost a little bit the contact to this method. But very soon I found out that there were also Thermo-dynamic Efficiency Measurements done for Tauerkraftwerke AG. Of course I was interested in participating in these measurements and after a short time we bought our own equipment and started with our measurements in 1976 - which means 20 years ago. During these last twenty years we carried out about 155 different measurements, most of them for Tauernkraftwerke AG but also for other companies (see also diagram on page 3).

A high amount of measurements was carried out around 1970. This was the time of commissioning of the Zemm-Development (Mayrhofen and Roßhag HPP) with total 11 new hydraulic machines. The number of measurements had to be increased to improve the hydraulic performance of some units.

Between 1981 and 1987 once again very detailed measurements of the units of the Zemm-Development had to be carried out. The reason was a contract with a German Electricity Company joining the use of water out of this system. Each partner had the right to use half of the inflow. As both parties operated the units at independent times and the amount of water per kWh is varying for different heads the storage had to be splitted imaginary into two halves. To divide the water in a fair way it was necessary to install a computer program to calculate the amount of water out of the produced and measured electricity and the imaginary head for each partner. One main input for this program was the efficiency of the hydraulic machinery and of course the head losses.

In 1986 respectively in 1987 the two units of the Häusling HPP were commissioned and acceptance tests had to be carried out for the turbines and the storage pumps.

Our experience is also spread over a very wide range of heads. We measured down to a minimum head of 114 m and up to a maximum head of 1025 m (see diagram on page 4).


Thermodynamic Efficiency Measurement
Number of Measurements
Tauernkraft Power Plants by Others
Tauernkraft Power Plants by Tauernplan
Other Power Plants by Tauernplan
Number of Measurements
Year
0
5
10
15
20
25
30
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
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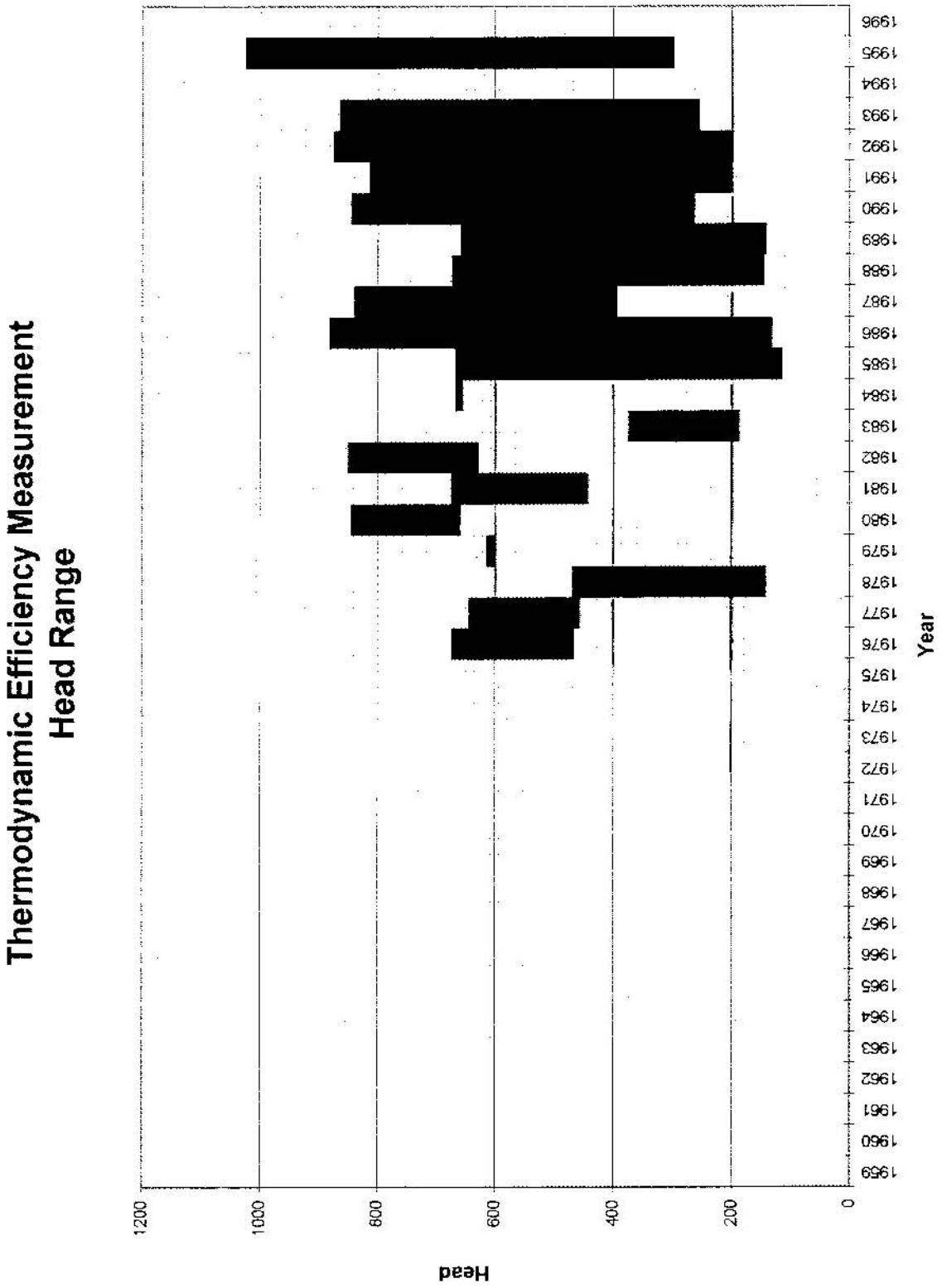
1996


Thermodynamic Efficiency Measurement
Head Range
Year
1996
1995
1994
1993
1992
1991
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1987
1986
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1982
1981
1980
1979
1978
1977
1976
1975
1974
1973
1972
1971
1970
1969
1968
1967
1966
1965
1964
1963
1962
1961
1960
1959
Head
1200
1000
800
600
400
200
0

2. The Equipment

Due to our good experience we are only using the partial expansion method. The expansion probes are still the same as we started in 1976, but because of the quick development in the electronic sector all other things have been improved several times. The main changes are

- platinum-thermometers with 1000 Ω instead of 100 Ω
- pressure transducers in parallel to the weight manometer
- modification of the low pressure sampling probe
- a new bridge
- electronic data acquisition
- on line evaluation with a PC

3. The Properties of Water

When I entered the Thermodynamic Group (GPMT) in 1978 a big discussion or more something like a competition about the properties of water was on the way. For me the use of the existing tables issued in the IEC-Code 607 „Thermodynamic method for measuring the efficiency of hydraulic turbines, storage pumps and pump-turbines" showing the properties depending on the temperature and the pressure seemed to be very clear.

Some time later when I received the report of the meeting at Heidenheim in 1976, I saw that the discussion about this matter had already started earlier. Prof. Borel on one side and Prof. Rögener on the opposite side had troubles finding a common understanding. At the meeting at Heidenheim Dr. Herbst presented the paper „Eine neue Zustandsgleichung des Druckwassers und ihre Anwendung auf das Thermodynamische Messverfahren für hydraulische Kraft- und Arbeitsmaschinen" (a new formula about the properties of pressurized water and its use for hydraulic turbines and pumps) from Dr. G. Herbst & Prof. Dr. H. Rögener. In this paper a spline-algorithm was used to calculate the enthalpy and the entropy. At the next meeting at Klagenfurt in 1978 both professors continued presenting documents about the properties of water. Prof. L. Borel together with Nguyen Dinh Lan introduced a simple formula using polynomes. At the meeting at Zermatt in 1980 I mentioned in my paper that we use for the evaluation of the results a new computer program now. This calculation was based on the formulas of Prof. Rögener. At the same meeting Prof. Rögener showed the comparison of the different methods using the values of

- IEC
- Herbst & Rögener
- Nguyen & Borel

- IFC
- Haar, Gallagher, Kell
- Pollak
- Rögener & Soll

At the meeting at Bergamo in 1984 Prof. Rögener as well as Mr. Nguyen Dinh Lan presented updated formulas. I was charged at the last meeting to show the difference in efficiency when using these different methods for the properties of water for measuring the efficiency of turbines. Prof. Borel's calculation was based on polynomes and Prof. Rögener was working with spline-algorithms. The conclusion of my paper was that in a very wide range of temperature (1 to 30 degrees Celsius) and head (100 to 1100 m) the difference in efficiency can be neglected.

At the meeting at Salamanca in 1986 both Prof. Borel and Prof. Rögener presented a paper dealing with the properties of water. But also Berra and Muciaccia mentioned in their paper the use of own formulas.

The publishing of the third edition of the IEC-Code 41 „Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines" in 1991 put an end to this story. The tables in Appendix E for the properties of water are there calculated according to the formulas of Herbst and Rögener, but it is also noted that the formulas of Borel and Lan or Haar, Gallagher and Kell are suitable for the calculation by means of a computer as they are all based on the same experimental values.

4. Temperature Distribution in the Low Pressure Side Section

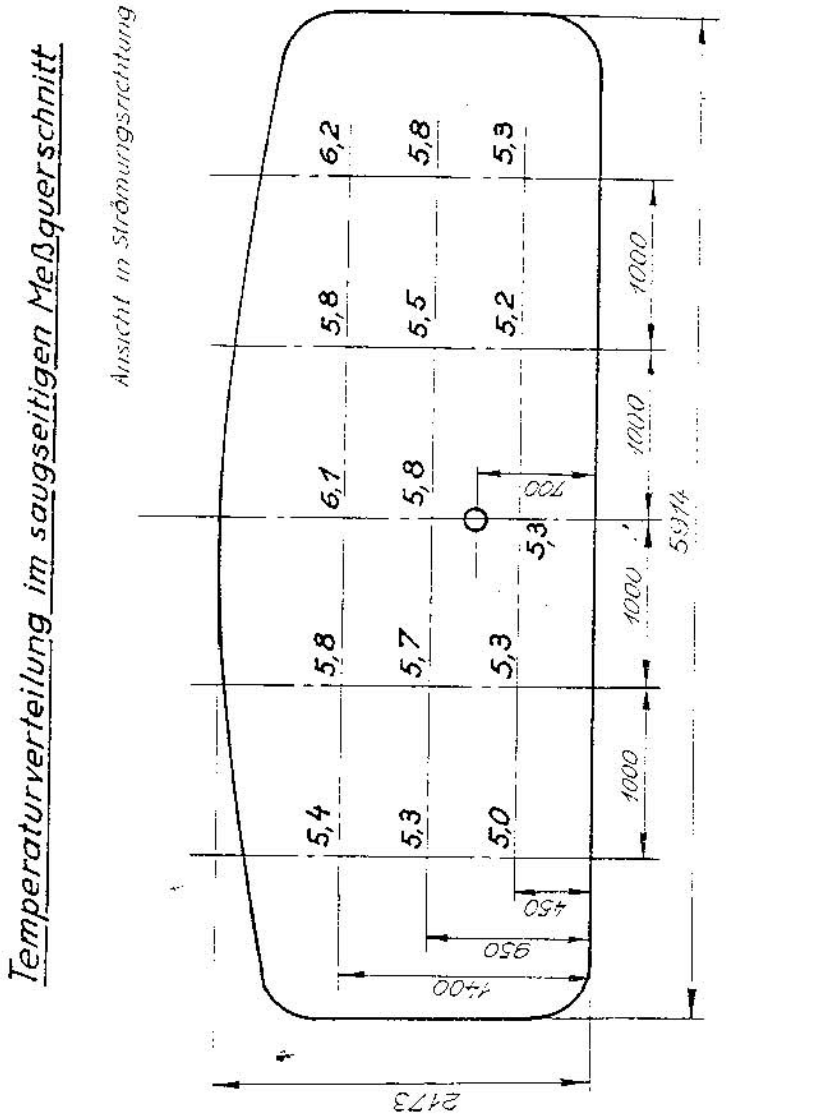
From our own experience I would like to show you some examples of the measurement and the influence of the temperature distribution in the low pressure side section of turbines.

4.1 Funsingau HPP (Low Head Francis Turbine)

Measurement by Technical University of Vienna in 1969
static head H-Tstat = 132.6 m

KW Funsingau
TD-Messung 69

Beilage 1



B - 415 Wien, 3.10.69 /Hg

The more or less rectangular draft tube was divided into 3 levels and 5 sections which means in total 15 measuring points. The difference in the readings of the bridge is shown in the sketch on page 7.

A change of 1 in the reading of the bridge is corresponding to a head difference of 1,73 m water column or 1.38 % in efficiency.

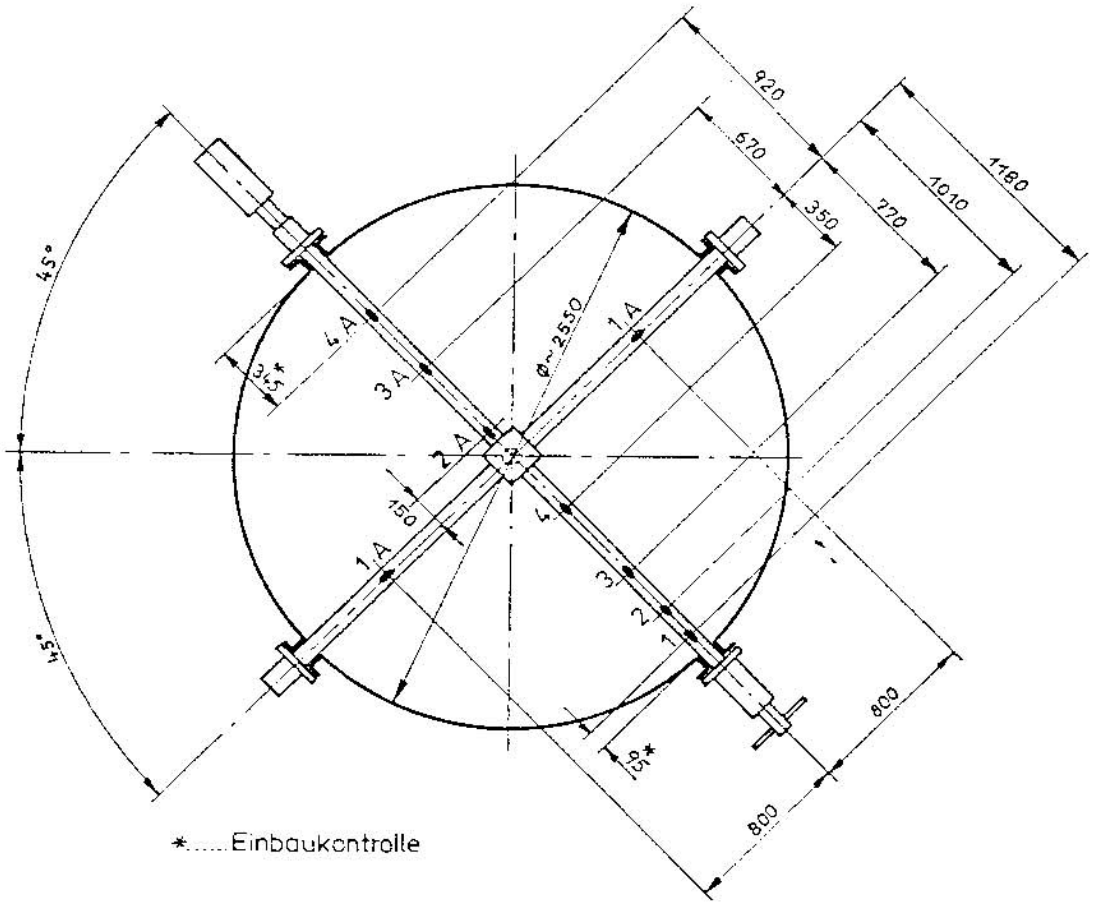
	Section	Reading bridge	average	deviation	$\Delta\eta$ [%]
level 1400	„1“	5,4		-0,167	-0,23
	„2“	5,8		+0,233	+0,32
	„3“	6,1		+0,533	+0.74
	„4“	5,8		+0,233	+0,32
	„5“	6,2		+0,633	+0,87
level 950	„1“	5,3		-0,267	-0,37
	„2“	5,7	5,567	+0,133	+0,18
	„3“	5,8		+0,233	+0,32
	„4“	5,5		-0,067	-0,09
	„5“	5,8		+0,233	-0,32
level 450	„1“	5,0		-0,567	-0,78
	„2“	5,3		-0,267	-0,37
	„3“	5,3		-0,267	-0,37
	„4“	5,2		-0,367	-0,51
	„5“	5,3		-0,267	-0,37
level 700	„3“	5,5		-0,067	-0,09

Finally the opening in the centre (section „3“) on a level of 700 was selected with an estimated reading of 5.5 which is very close to the average value.

- deviation -0,067 ⇨ -0,09 % in efficiency

4.2 Häusling HPP (High Head Francis Turbine)

Measurement by Tauernplan 1986
static head H-Tstat = 703.4 m



With the above shown arrangement each opening can be used separately to take off water from the draft tube. Only the two openings "1A" are connected and the water out of these two openings is mixed. The check of the different measuring point was done at 72 and 180 MW output. The differences in the reading of the bridge are a measure for the temperature difference.

A change of 1 in the reading of the bridge is corresponding to a head difference of 0,9 m water column or 0,129 % in efficiency.

	Opening	Reading bridge	all openings		without opening „1A“	
			average	deviation	average	deviation
72 MW	„1“	-5,5		-0,25		-0,57
p1-1=650 m	„2“	-4,5		+0,75		+0,43
	„3“	-5,0		+0,25		-0,07
	„4“	-5,0		+0,25		-0,07
	„1A“	-7,5	-5,25	-1,75	-4,93	-------
	„2A“	-5,0		+0,25		-0,07
	„3A“	-4,5		+0,75		+0,43
	„4A“	-5,0		+0,25		-0,07
180 MW	„1“	+2,5		-0,19		-0,78
p1-1=700 m	„2“	+2,0		-0,69		-1,21
	„3“	+2,0		-0,69		-1,21
	„4“	+2,0		-0,69		-1,21
	„1A“	-1,0	+2,69	-3,69	+3,21	-------
	„2A“	+3,5		+0,81		+0,29
	„3A“	+5,5		+2,81		+2,29
	„4A“	+5,0		+2,31		+1,79

The opening „1A“ which is different from all other openings showed the biggest deviation. As we could not find an explanation for this deviation we rejected the openings „1A“ for the selection of the best opening.

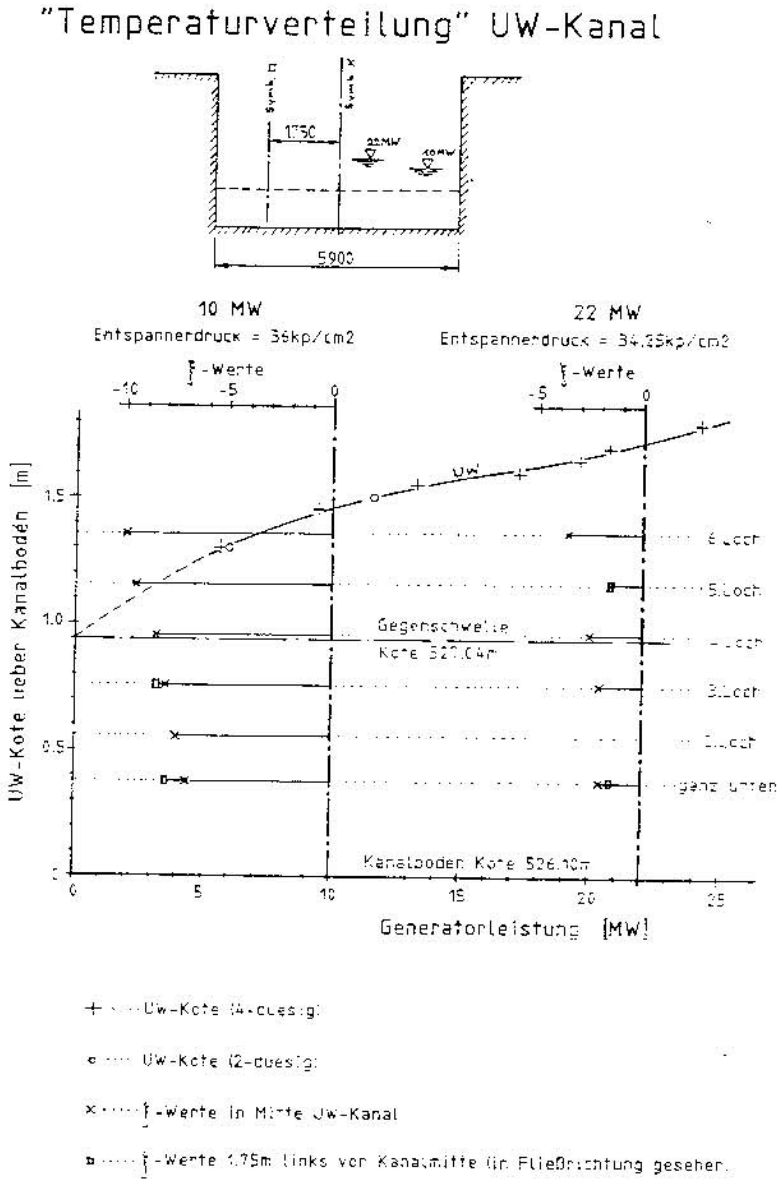
Finally the opening „2A“ which had the minimum deviation from the average value in both load cases was selected:

- 72 MW deviation -0,07 ⇨ -0,009 % in efficiency
- 180 MW deviation +0,29 ⇨ +0,037 % in efficiency

According to the high head, the difference of the temperature distribution in the draft tube has nearly no influence to the efficiency of the turbine.

4.3 Achensee HPP (Pelton Turbine with Open Channel)

Measurement by Tauernplan 1987
static head H-Tstat = 394.4 m



The open channel was measured in 2 sections and 6 levels.

A change of 1 in the reading of the bridge is corresponding to a head difference of 0,9 m water column or 0,228 % in efficiency.

	Section	Level	Reading bridge	average	deviation	Δη [%]
10 MW	centre	„1“	-7,0		+1,38	+0,31
p1-1=360.0 m		„2“	-7,5		+0,88	+0,20
		„3“	-8,0		+0,38	+0,09
		„4“	-8,5		-0,13	-0,03
		„5“	-9,5		-1,13	-0,26
		„6“	-10,0	-8,38	-1,63	-0,37
	1750	„1“	-8,0		+0,38	+0,09
		„2“				
		„3“	-8,5		-0,13	-0,03
		„4“				
		„5“				
		„6“				
22 MW	centre	„1“	-2,0		+0,17	+0,04
p1-1=342.5 m		„2“				
		„3“	-2,0		+0,17	+0,04
		„4“	-2,5		-0,33	-0,08
		„5“				
		„6“	-3,5	-2,17	-1,33	-0,30
	1750	„1“	-1,5		+0,67	+0,15
		„2“				
		„3“				
		„4“				
		„5“	-1,5		+0,67	+0,15
		„6“				

Finally the level „4“ in the centre position which had the minimum deviation from the average value in both load cases was selected:

- 10 MW deviation -0,13 ⇨ -0,03 % in efficiency
- 22 MW deviation -0,33 ⇨ -0,08 % in efficiency

5. Our Last Measurement (Lünersee HPP)

Lünersee is a pumped storage power plant in the Western part of Austria. In the power house are 5 units of several manufacturers with vertical shaft installed. Each of the units consist of one Pelton-turbine with 4 jets and a storage pump with 5 stages. Lünersee HPP was commissioned in 1958.

After this long period of operation the owner was interested in knowing more about the condition of his units.

For one storage pump the change of the runner of the first stage was already fixed. The measurement in October 1995 was a basic one and should be repeated after having changed the runner in autumn 1996 to check the success in increase of efficiency.

The reason for the efficiency test of the Pelton-turbine was mainly to examine the condition of the runner. A comparison with a measurement in 1959 shows nearly the same efficiency (diagram next page). The control mechanism of the nozzles was modified in the meantime to allow an operation with 2 jets only. As for partial load an operation with 2 jets is of interest, it was necessary to know the efficiency also in this mode. To measure the efficiency and to determine the switching point, measurements were also done with 2 jets in operation only.

Wirkungsgradmessung KW-LÜNERSEE, Turbine 3

Messung am 12.10.1995

Bezugshöhe: 970 m