COMPERATIVE THERMODYNAMIC EFFICIENCY MEASUREMENTS USING PT-100 SENSORS AND "SEABIRD 38"

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ABSTRACT

During the winter of 2002/2003 the efficiency at a new power plant was measured independently by Norconsult AS and Sweco Grøner AS (former Statkraft Grøner AS). The power plant has a rated head of 438 m, and the rated power is 97 MW.

The measurements were performed using two different measuring equipments. Norconsult used PT100's with a Hewlett Packard Data acquisition/switch unit, and Sweco Grøner used Seabird 38 thermometers, communicating directly with the computer using RS485. The sampling vessels at the inlet were different, and the sampling frame at the outlet was the same. This outlet frame was set to different levels during the measurements to determine the energy distribution at the outlet.

Sweco Grøner:	A measuring vessel operating on the "Direct operating procedure." "Seabird 38" temperature sensors with RS485 communication through fiber-optic cable.
Norconsult:	A measuring vessel operating on the "Direct operating procedure." PT100 temperature sensors connected to a HP 34970A Data acquisition / switch unit

The results from the measurements are shown in figure 1 below.

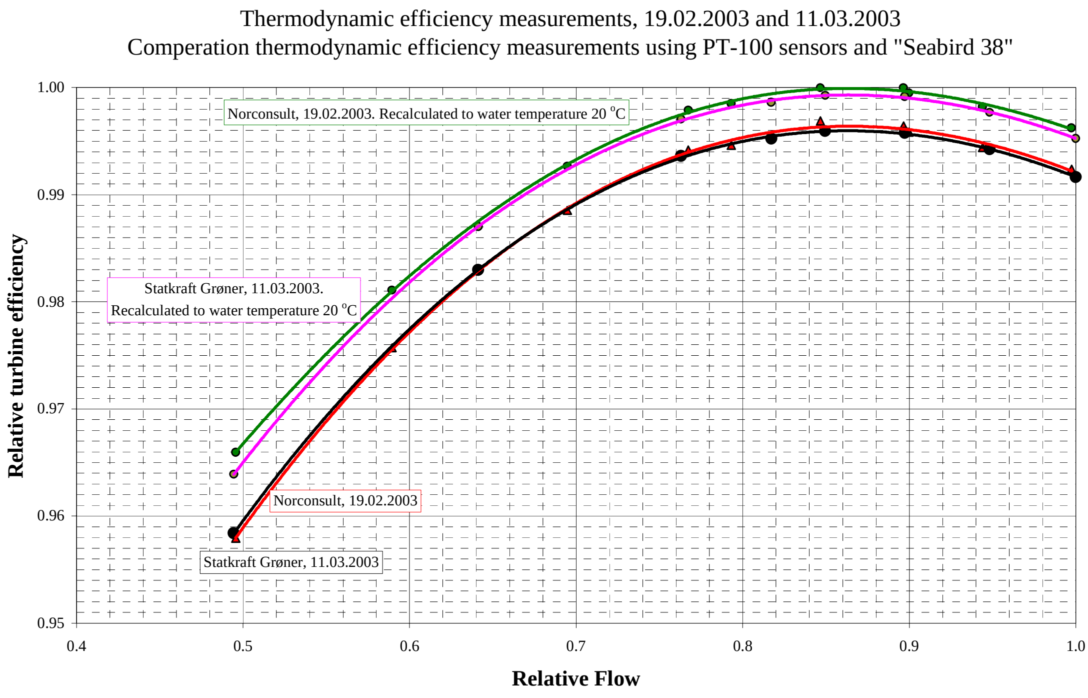


Figure 1 The measured turbine efficiency

1. INTRODUCTION

The first measurements of the turbine, performed by Norconsult, showed a somewhat different efficiency curve than expected. It was therefore decided to repeat the measurements using different instrumentation, and Sweco Grøner performed this. Norconsult was present at the repeating measurements.

The results of the measurements were, as shown on figure 1, a remarkable merging of the results. Calculating the 5^{th} degree polynom for each set of measurements and comparing the fitted curves in the range of 0.5 to 1.0 in relative flow, the average differences between the two measured efficiencies are 0.01 %.

Performing comparative measurement like these – using different instrumentation and personnel – is of great value, as it will increase the reliability of the measuring method. Also, it is of great assurance for the involved measuring crew.

2 THE MEASUREMENTS

2.1 The Measuring Method

For both measurements the thermodynamic method using the direct operating procedure was utilized, and the measurements were performed according to IEC41.

2.2 The measuring equipment

The measuring instruments used are given in table 1.

Table 1. Measuring Equipment

	Sweco Grøner	Remarks	**Norconsult**	Remarks
Measuring vessel at inlet	Sweco Grøner design	Enclosure 1	Norconsult design	Enclosure 1
Sampling frame at outlet	Norconsult design (fitted to Seabird)	Enclosure 3 Picture 3	Norconsult design	Enclosure 3 Picture 1 and 2
Pressure measurements p_1, and p_{11}	Parosientific Mod. 3000 psia Mod. 900 psia 6015A (p_{atm})		Parosientific Mod. 1000 psia	
Temperature measurements Φ_{11} og Φ_{21} Temperature measurements $\Phi_{leakage}$.	SeaBird 38 Dostmann P500 PT-100		HP 34970A PT-100 HP 34970A PT-100	
Flow measurements, $Q_{leakage}$	ELIS, Flomag Comfort and Fuji Portaflow		ELIS, Flomag Comfort	
Water level, z_2 (for p_2, p_{21})	Measuring tape Yamayo		Measuring tape Yamayo	

2.3 Measuring Arrangement

The different measurement arrangement is shown below.

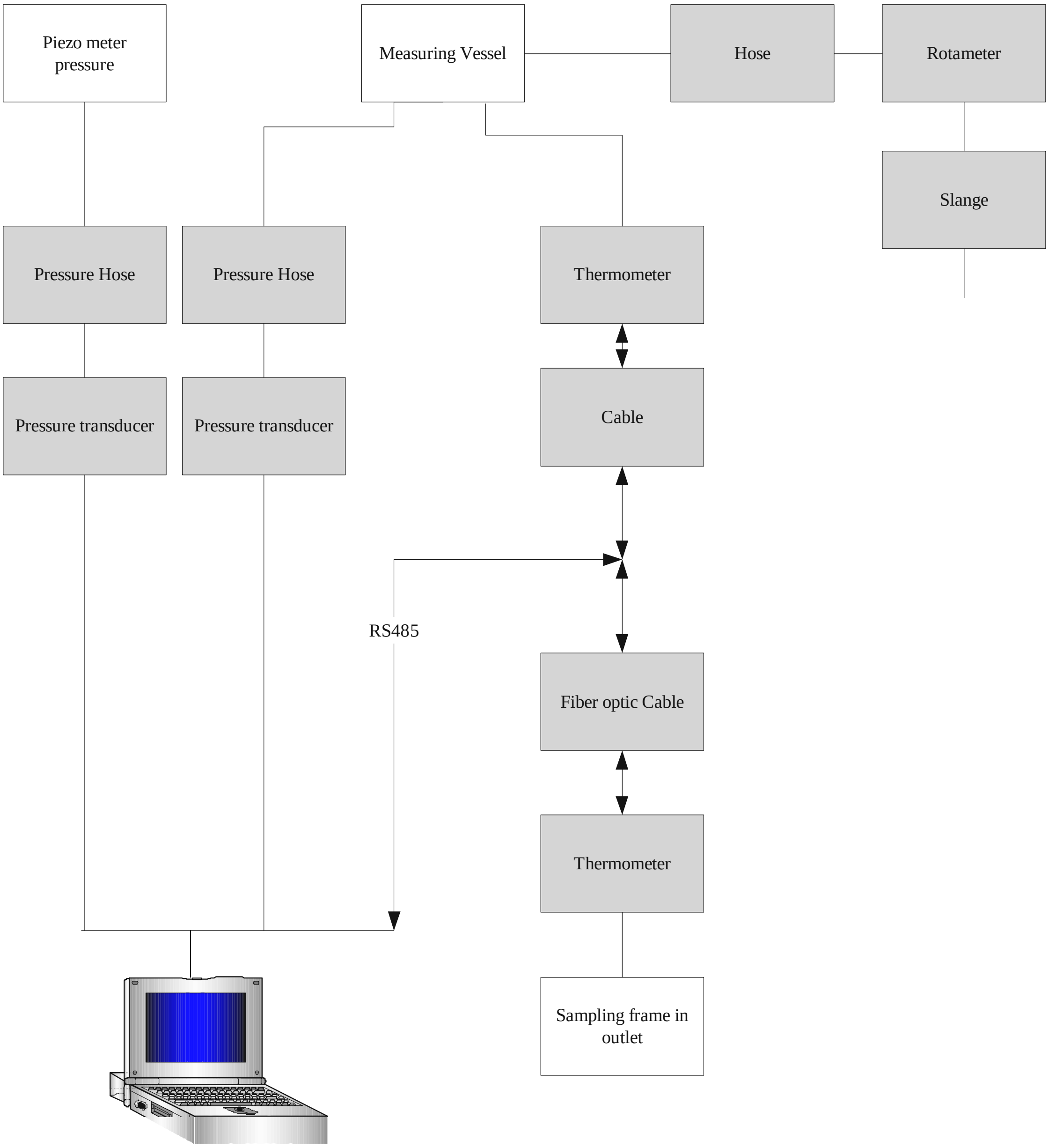


Figure 2. The measurement arrangement Sweco Grøner

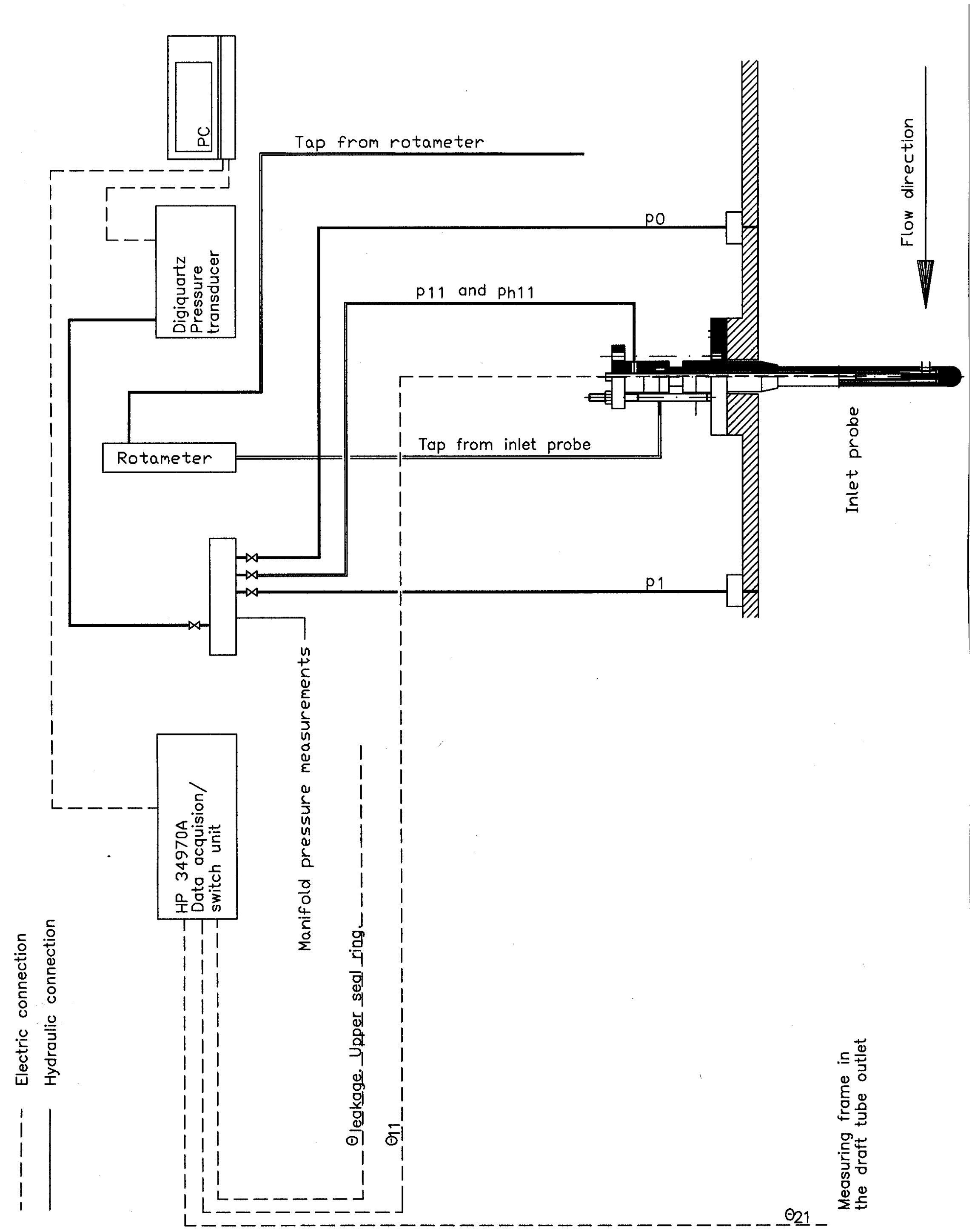


Figure 3. The measurement arrangement Norconsult

2.4 Measurement procedure

The following measurement procedure were used:

2.4.1 General procedures

Both measurements were performed using the thermodynamic method according to IEC41.

8/10 test points (Norconsult/Sweco) were measured, approximately on the same loads.

2.4.2 The temperature measurements

At each load the temperature at the outlet was measured at 3 different levels, achieved by lifting/lowering the measurement frame. At each level the temperature was logged for 3 minutes. In the calculation of the efficiency the average of all three measurements are used.

2.4.3 The pressure measurements:

Sweco Grøner performed the temperature and the pressure measurements p_1 and p_{11} simultaneously. Norconsult performed the measurement of the inlet pressure, p_1, just before and after the measurements of the temperature and the measuring vessel p_{11}. The temperature and the measuring vessel pressure were performed simultaneously. The pressures at the outlet, p_2 and p_{21} were calculated from the tail water level. The tail water level was measured using a measuring tape from a reference point.

2.4.4 Power measurements.

The power was measured using on the units MWh-meter (class 0.2) in the same period as the temperature and pressure was measured.

2.4.5 Upper labyrinth leakage water

The leakage water flow was read on the unit’s flow meter (see table 1). Sweco Grøner measured also the flow using a clamp-on ultrasound meter

3 THE CALCULATIONS

The calculations were performed according to IEC 41, 3. ed. 1991-11 [1]

Both Norconsult and Sweco Grøner shared the data, checking each other in their own spreadsheets. All calculations were in accordance with each other.

4 THE RESULTS

4.1 Turbine efficiency

The turbine efficiencies are shown in figure 5.

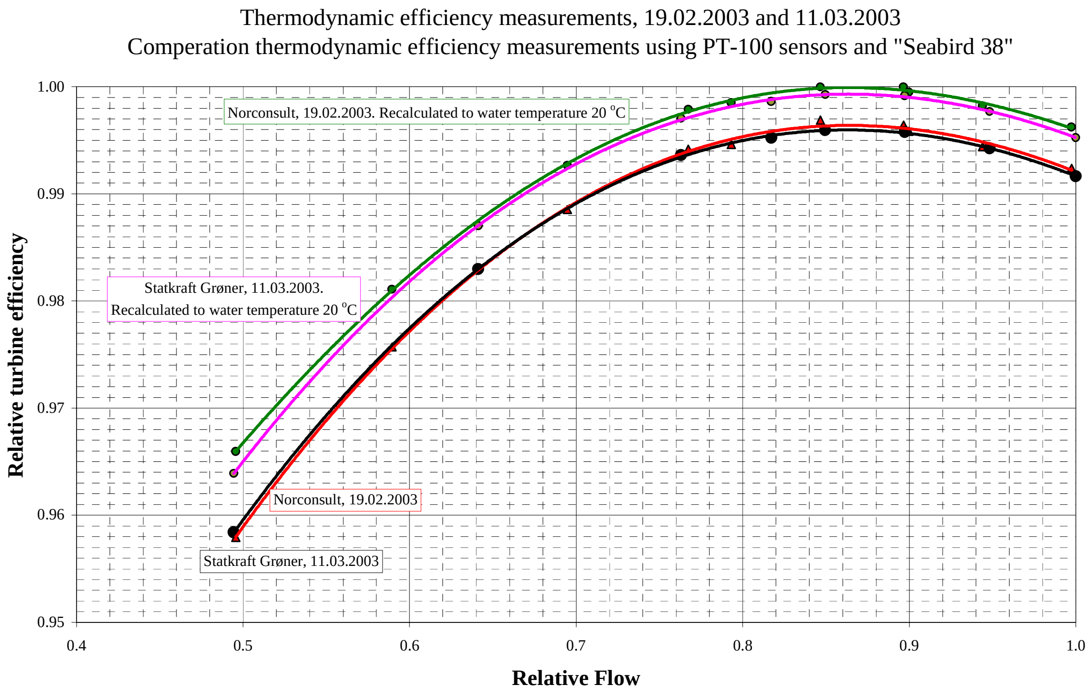


Figure 4 The turbine efficiencies

4.2 Losses through the upper labyrinth

The losses through the upper labyrinth were measured separately, and are shown in figure 5.

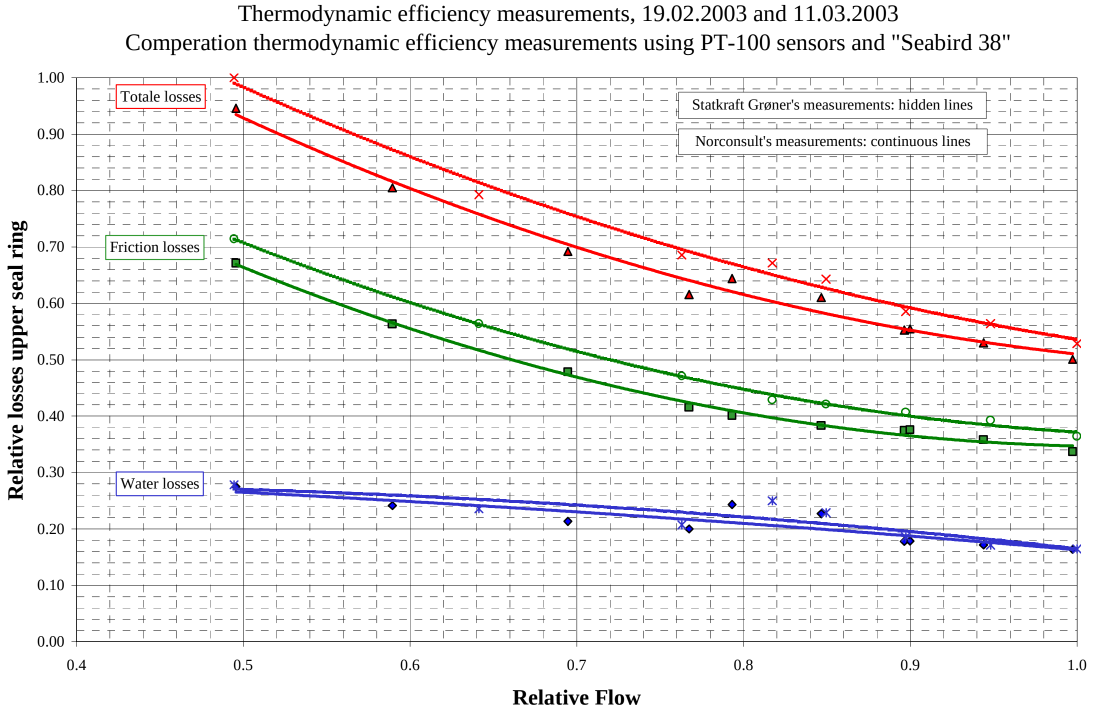


Figure 5 Losses through the upper labyrinth

5 SOME REMARKS ABOUT THE TEMPERATURE MEASUREMENTS

5.1 The Hewlett Packard HP 34970A and PT-100

The PT100s use a well-known technology developed over many years, and it is possible to buy high accuracy thermometers relatively cheap. The HP 34970A is also quite inexpensive, under 2500 Euro – a little more than one sea-bird thermometer. Due to its size, it is possible to place the measuring vessel thermometer pocket so that there is a minimum of expansion and heat transfer with the surroundings. The uncertainty of the temperature measurement is thereby minimized.

The main problems with the PT100 is

- Long time stability
- The response time

5.1.1 Long time stability

When using the PT100 it is essential that the thermometers are zero-checked before and after the measurements. If possible in practical terms, it is also an advantage that a zero-check is performed in the middle of a test. Nevertheless, the maximum zero change ever observed during a measurement was 1.5 mK.

5.1.2 The response time

The PT100 has a relatively large mass and when the inlet temperature has big gradients, it is necessary to correct for the time constant of the thermometers – in addition to the correction for the time the water to pass through the machine. Thus, the time constant of each thermometer has to be determined.

5.2 The Seabird 38

The most positive about the SBE38 is the long term stability – within 1 mK a year – and that the RS485 communication make the signal uninfluenced by surrounding electrical and magnetic noise. Also, cable length is of no problem, as the RS485 signal easily can be converted to utilise fiber-optics. The response time is very short, making it possible to handle quite large temperature gradient during measurements.

There is necessary to address three problems especially for the SBE38. These are:

- The heat transfer between the main body and the sensor tip (Conduction)
- The viscous heating of the sensor
- Heat transfer with the surroundings

5.2.1 Conduction (heat transfer)

According to Seabird Inc, for each degree C variation between the body and the tip, the conduction give rise to an error (heating or cooling of the tip) of 1 mK. It is therefore essential that the temperature of the body be under control.

We considered several solutions for achieving this, and finally ended with the thermometer body fully embedded into the measuring vessel – into the water flowing from the pitot tapping, so that the thermometer body has approximately the same temperature as the sensing tip.

5.2.2 Viscous Heating Of Sensor Tips

The problem with viscous heating has been addressed earlier at IGHEM. (See Nordeen Larson & Arthur M. Pedersen (Sea-Bird Electronics, Inc.), "Temperature Measurements In Flowing Water: Viscous Heating Of Sensor Tips".) There seems to be no direct solution to this other than trying to avoid the high velocities where viscous heating becomes a problem. By monitoring the flow through the vessel and keeping the velocity below 1.0 m/s to 1.5 m/s this problem is minimized.

5.2.3 Measuring Vessel Heat transfer

Placing the thermometer so far away from the pitot inlet will inevitably lead to problems with heat exchange with the surroundings. The best way to correct for this is to insulate the vessel properly. Some other solutions may also be considered, for instance to have some water-cooling arrangement (tapped from the penstock) around the vessel. [1)]

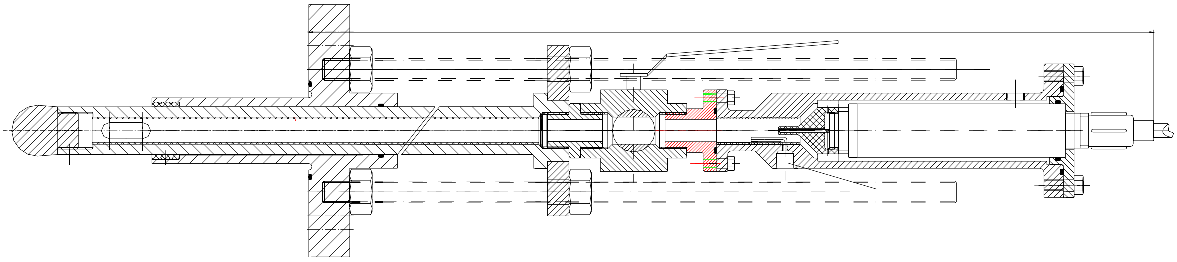
6 CONCLUTIONS

The results of the measurements were, as shown on figure 1, a remarkable merging of the results. Calculating the 5th degree polynom for each set of measurements and comparing the fitted curves in the range of 0.5 to 1.0 in relative flow, the average differences between the two measured efficiencies are 0.01 %.

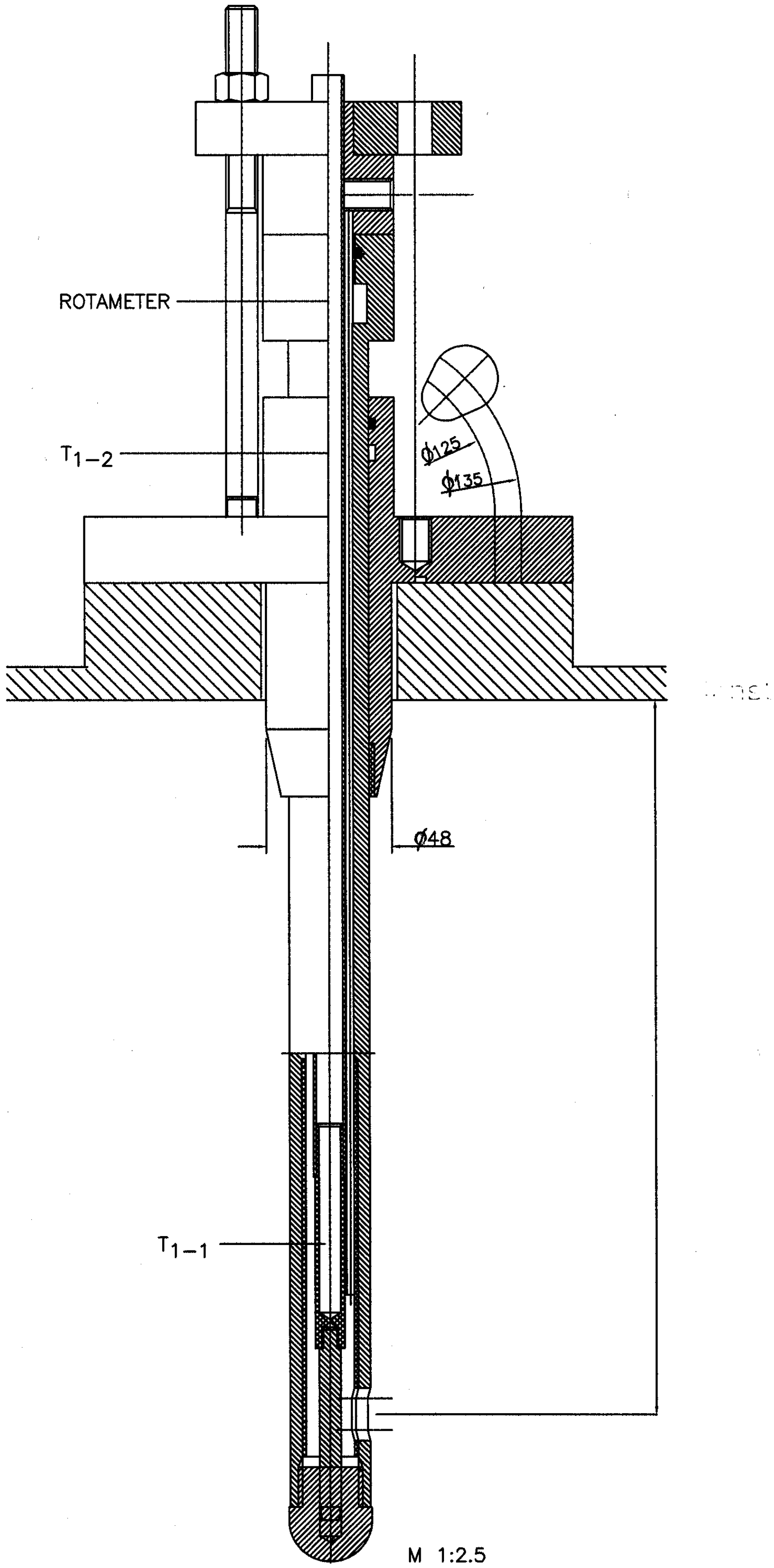
The measurements show that if the measurement conditions are good, the results will agree if the following conditions are fulfilled:

- Measurement equipment and instruments are in accordance with the claims and recommendation given by IEC 41
- Both procedures for measurements and calculations are in accordance with IEC 41.

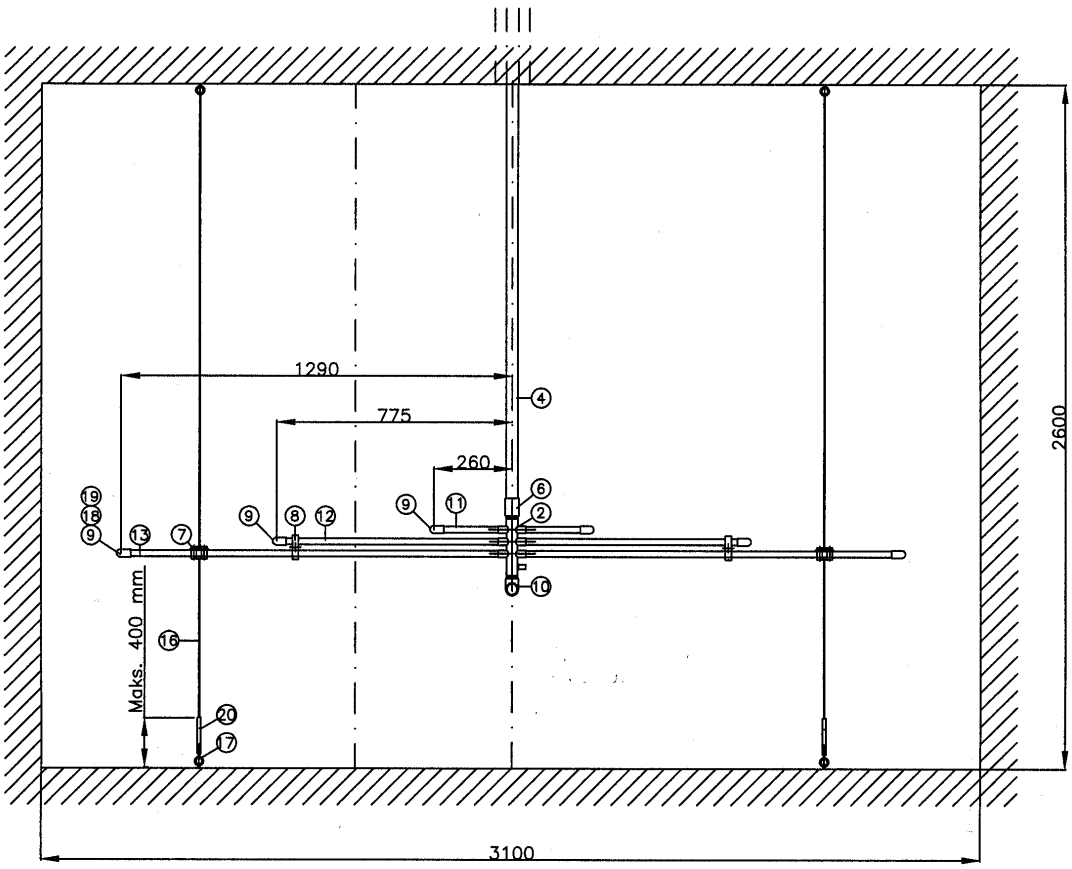
[1)] Earlier comparisons between Seabird and PT100s (See The IGHEM 1998 paper by E. Paquet, "Thermodynamic Method: Comparison of Sea-Bird and Pt 100 Temperature Probes") shows that Seabird thermometers systematically gives a better efficiency than PT100. This may be due to heat exchange between the measuring vessel and the surroundings and/or conduction from the main body and the sensor tip – both phenomena will cause measurement of too high temperature at the inlet, thereby a smaller temperature difference and better measured efficiency. (Assuming that the temperature in the power house is warmer than the water).

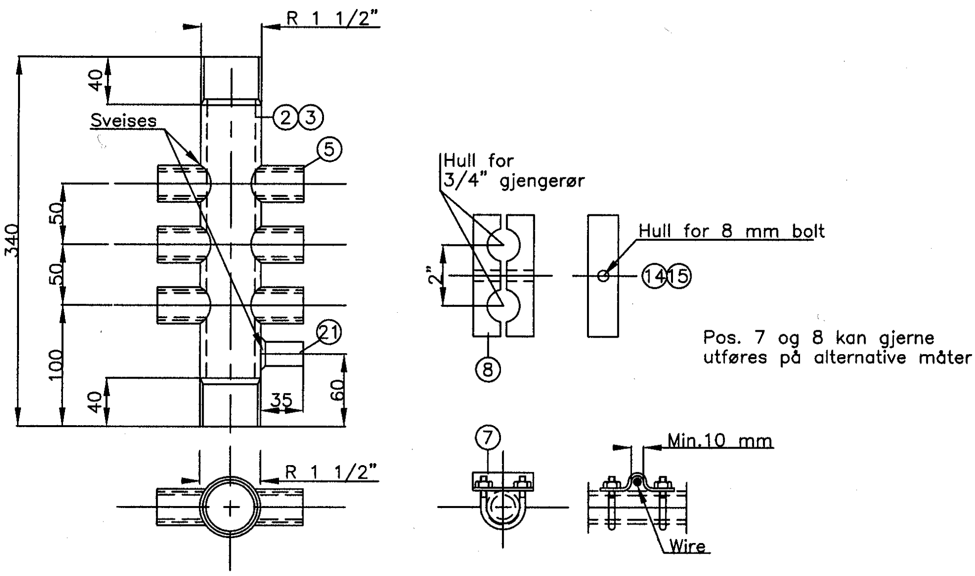


Enclosure 1. Statkraft Grøners measuring vessel



Enclosure 2. Norconsults measuring vessel

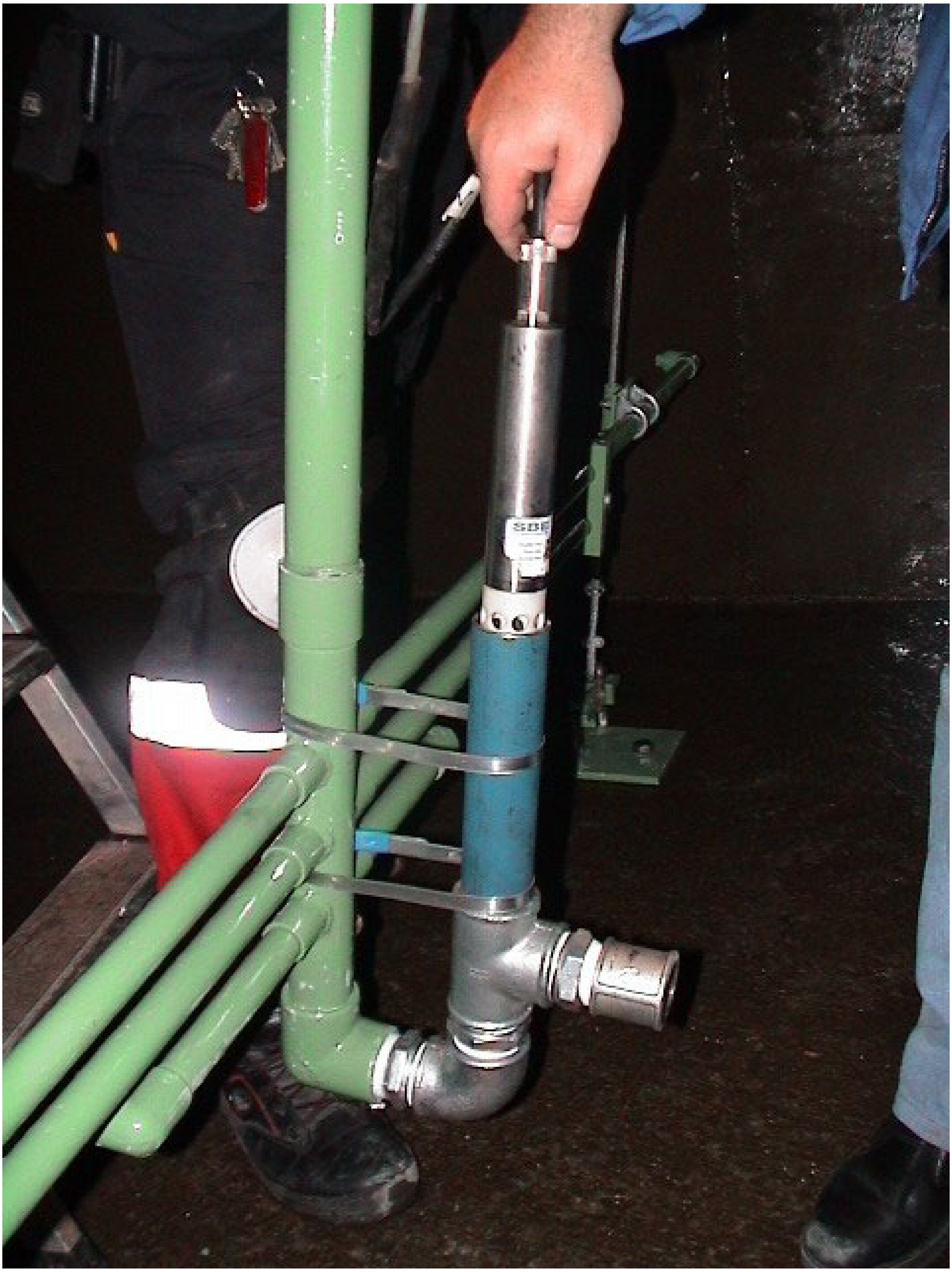




Enclosure 3. Measuring frame in the draft tube outlet

Picture 1. Measurement frame in the outlet

Picture 2. Measuring frame, mixing chamber. Norconsult measurements



Picture 3. Measuring frame, mixing chamber. Sweco measurements