**INTERNATIONAL GROUP FOR HYDRAULIC EFFICIENCY MEASUREMENTS**

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# A Comparison of the Thermodynamic Method at the Beginning and at Present.

by

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*CONTENTS*



## *SUMMARY*

*This report compares thermodynamic efficiency measurements made on a new turbine in 1963/64 and on the same, completely overhauled turbine in 1995. A new runner of stainless steel had been installed. The old runner was made from ordinary mild steel. Both runners were of exactly the same hydraulic design. The power station discharges directly into seawater and the first runner was soon heavily attacked by rust.*
*The first two measurements (63/64) were made with the original Neyrpic instruments and equipment using the partial expansion procedure. The measurements in 1995 were made with modern equipment using the direct procedure.*
*From these measurements very interesting conclusions are drawn, both regarding the quality of the test methods and the effect of seawater and rust on the turbine performance.*

## *RÉSUMÉ*

*Ce rapport compare des essais thermodynamique de rendement d'une turbine neuve en 1963/64 avec des essais sur la même turbine complètement réparé en 1995. Une roue nouvelle en acier inoxidable a remplacé l'ancienne roue en acier ordinaire. Les deux roues ont exactement le même géométrie hydraulique. L'usine hydoelectrique aboutit directemaent à la mer, et la première roue avait eté tres fortement attaquée par la rouille.*
*Les deux premiers essais (1963/64) ont eté fait avec les appareils originales de Neyrpic pour la mode opératoire de "détente partielle". L'essais de 1995 ont été effectués avec un appareil modern selon le mode opératoire "directe". Il resulte des conclusion très intéresante de ces essais concernant la prècision les metodes de mesure et l'effet de l'eau de mer et de la rouille sur le rendement de la turbine.*

## 1. Introduction

During the first half of the 1950'ies G. Willm and P. Campmas developed the theory and the practical measurement instrumentation of the Thermodynamic method and presented it in an article in "La Huille Blanche"(1954) Ref. [1]. The instrumentation and equipment was marketed by Neyrpic, Grenoble, and during the 1950'ies a great number was sold and was in practical use. In 1961 Mr. J. Coffin took the initiative to form an international measurement group (Groupe des Praticiens de la Method Thermodynamique) and GPMT was inaugurated in Grenoble at the beginning of October, and hase been in existence until the new group (International Group for Hydraulic Efficiency Measurements) now will take over.

An interesting comparison is made between measurements performed with that particular Neyrpic equipment on a turbine in 1963 (and '64) and recent measurements (1995) with modern equipment on the same, completely overhauled turbine. All the measurements were made at Grytåga Powerplant on a 48 MW vertical Francis turbine with a head of 180 m. The comparison gives a good indication of the basic quality of the method and its usefulness and development until today. The only change made was that the original turbine runner made from ordinary mild steel was replaced by a new one of stainless steel. As the old runner had a very good efficiency, the new one was made as close as possible with the same physical shape as the old one. The reason for the change of material to stainless steel was that the old runner was heavily corroded. The turbine discharges directly into seawater with several meters difference between high and low tide, and it had proved impossible to prevent seawater to fill the turbine when it was closed down,even with fast moving gates.

## 2. The Measurements

The first set of measurements at Grytåga in October 1963 were made as Field acceptance tests with the original Neyrpic instruments and equipment apart from a strengthening of the inlet probe. The partial expansion procedure was used. There were no problems with the measuring instruments and equipment apart from the calibration of the temperature sensors. The sensors were connected to the measuring bridge with only 3 different electrical circuits, and the calibration was influenced by the small variation in electrical resistance with variation of the outside temperature of the cables used.

The hydraulic measuring conditions were mostly good apart from the problems caused by the seawater with another density and temperature, setting up a reverse flow at the bottom of the draft tube outlet, see **Fig. 1**. This resulted in a very large scatter in the measured turbine efficiency points dependant upon the seawater level (high and low tide) and temperature. Some very high efficiencies were found because the seawater was colder than the turbine water. This was the first time we met this seawater problem, but later we have seen it many times even with long outlet channels.

After viewing all testpoints with scrutiny and eliminating all doubtful ones, a probable efficiency curve could be drawn (using 10 points out of 22). It was decided, however, to repeat the acceptance test next year in 1964 when one could be more prepared for the difficulties. All the data from the 1963 and 1964 measurements are found in the personal notes and the report from the acceptance test mentioned in Ref [2].

The measurements in 1995, after the turbine had been completely overhauled, were made with new instruments and equipment as a result of the experience during the more than 30 years since the first tests. We are today able to measure the water temperatures very accurately with 100 ohm platinum resistance sensors with a high sensibility, and can use the direct procedure which is now accepted by the IEC test rules. One of the main advantages of the direct procedure is that the measuring time for each test point can be kept short, and that the best moment for the measuring can be selected. This gives better measurements with lower total efficiency uncertainty ($f_n$). For temperature measurements one now only uses temperature sensors directly mounted in the inlet probes and in outlet tapping arrangements.

The 1995 measurements were made by E. Bøkko with equipment from Norconsult International with K. Alming present during the tests, and the results are found in the report, Ref. [3]. One main improvement to this last measurement was that a threshold was fitted in the outlet channel in the slots for the stoplogs to prevent backflow of seawater. Instead of using heavy stoplogs of wood, light stoplogs of extruded aluminium were now used, which could be mounted without the help of lifting device. The stoplogs are shown on **Photo 1.**

## 3. Hydraulic and physical measuring conditions in general

The measuring conditions play an important role with the thermodynamic method as for all the other methods. The method is by its nature best suited for higher heads.

Suitable instruments and equipment have been developed. It is sufficient to mention thermometers to measure directly the water temperature difference, electronic computers, continuously recording equipment for temperatures, pressures etc.

From the beginning a lot of thought and work was concerned with the different measuring conditions and their effect on errors and the total efficiency uncertainty. Up to about 1972 F.L.Brand was the leader of an editing group within GPMT (see ref. [4]) with the purpose of preparing an instruction book for the method. The different chapters were given to members of GPMT to write, but although quite a lot of work was done, it proved impossible to finish the work.

Some of the following figures concerning measuring conditions are taken from the notes of this editing group. **Fig. 2** points out some influences on the measuring conditions, mainly stability and the correct value of the water temperature. Sunshine on an exposed pipeline, especially if it varies, and also heavy rain can make proper temperature measurements impossible. Other sources of error, specially for underground power plants, can be brook intakes to the headrace tunnel bringing in water of higher temperature (sometimes also containing lots of air), which will disturb the temperature measurements. Silt can also be brought in blocking the sampling circuits and measuring equipment both for temperature and pressure. As alredy mentioned, if the outlet tunnel discharges into seawater, backflow will cause difficulties if it is not prevented, for instance with stoplogs.

If there is a long headrace tunnel to a large powerstation with several units, the whole powerplant must be under full control during the efficiency measurements. In **Fig. 3** temperature and pressure measurements for such a powerplant are shown. There is a variation in power output causing a variation in turbine net head and in the inlet water temperature (even when the temperature for total throttling is constant). One can also see the large temperature variation that occurs when a sudden load increase takes place, which will prevent proper measurements for a long period of time.

## 4. Influence of the measurements on the measuring conditions in general

The manner in which the total efficiency tests are carried out also influences the measuring conditions. For good conditions the water temperature should be as constant as possible over time to prevent any extra corrections, as the water will need some time to flow from the inlet measuring probe section to the outlet measuring section. In the inlet supply conduit the water temperature will vary along the conduit because of the history of changing friction losses. The variation will alter with the flow. Every change in the flow discharge will give a different temperature gradient along the conduit, and a long time may elapse before a new constant state of temperature is achieved. This can be seen from **Fig. 3**, but is better illustrated in **Fig. 4**. With an increase from half to full discharge the water temperature at the measuring section before the turbine will rise steadily, to begin with having a gradient of about 0,004 °C/min. (the limit in the IEC test code is 0,005 °C/min). The turbine inlet pressure also changes due to water hammer, but will usually reach a steady state quickly although surge tank oscillations may last longer.

## 5. Instruments and equipment

As mentioned earlier the two first **tests at Grytåga (1963 and 64)** were made with the original Neyrpic equipment with its deficiencies. The main one was the long measuring time because at the inlet of the turbine the calorimeter with temperature sensor was placed in a separate vessel outside the turbine and the water was drawn from the inlet probe through a flexible insulated tube. The heat exchange with the surroundings was compensated for by measurements with different flowrates through the apparatus. This could take a long time, and with continuos changes both in water and air temperatures the accuracy of the measurements would be effected. In addition the detrimental effect of airdraft on the equipment was present. The DC measuring bridge with a very sensitive galvanometer was of very high quality, but using only three electrical connections to the platinum sensor was a drawback, especially since a relatively high current was used for the measurements. The 100 ohm platinum sensors were very good, but had to be paired thoroughly for equal heat capacity.

The dead weight manometer for the pressure measurements was of good design with an additional continuous variation of the load on the piston from the imersion of a cylinder dipped into mercury. The variation could not be recorded, and one had to be very careful with the slow surge tank oscillations.

At Grytåga in 1963 and '64 the turbine outlet temperature was measured with only one temperature sensor which was moved up and down along a vertical wire in the middle of the outlet section.

For the **measurements in 1995** new electronic instruments were used, both for temperature and pressure measurements. The pressure transducers could be calibrated against a dead weight manometer. The temperature sensors were of the 100 ohm platinum resistance type, but with less mass in the sensors and connected to the bridge with 4 electrical copper wires, using a much lower measuring current than used for the two first measurements. Using electronic instruments for both temperature and pressure, the signals could be recorded continuously and fed into a computer. The design of the inlet tapping probe was with the temperature sensor build right into it, i.e. no heat exchange.

At the outlet of the turbine the temperature sensor was mounted in a collection chamber picking up water from 4 pitots across the width of the outlet channel, **Photo 2**. It all formed a mounting frame which could be moved up and down the outlet area. The measuring arrangement can be seen on **Fig. 5**, showing the measuring sections and also the "stoplogs" preventing backflow of seawater at the bottom of the outlet channel. **Fig. 6** shows the outlet measuring frame with the positions of the pitots.

## 6. Measurement results

In **Fig. 7** the efficiency curves are shown giving the results of all three tests. The first test in 1963 and the last one in 1995 give practically the same efficiency curve. This was a little surprising as the first test was regarded as doubtful because of difficult measuring conditions. When studying and comparing the measurements now in a new light, it seems that the lower efficiency values in 1964, after one year of operation, may be caused by the badly corroded runner. Increasing the friction losses through the runner by around 1% is not unrealistic. The turbine runner was not inspected before the test in 1964, as everything was in order during the test in 1963. See **Photo 3** of the turbine runner in 1963.

In the graph on **Fig. 7** is shown the differences between the measured efficiencies in 1963 and 1964. $(\eta_{63} - \eta_{64})$ and the similar curve for $(\eta_{63} - \eta_{95})$.

Near the best turbine efficiency point, with probably the lowest risk of backflow along the bottom of the tail race channel, the efficiencies are practically the same. At higher and lower turbine outputs the differences will be larger, and specially for the lesser outputs when the backflow will mix with a lower turbine discharge. The measurements therefore indicate that the old and the new runner are of the same very good hydraulic design, and that the thermodynamic method for measuring turbine efficiency is reliable and capable of measuring small changes in the turbine efficiency. The development in both instruments and equipment has also made the method more capable of mastering difficult measuring conditions. This is expressed by the total efficiency measuring uncertainty $f\eta$ which for the 1964 measurements was: $f\eta_{64} \approx 1{,}4$ % and for the 1995 measurements was: $f\eta_{95} \approx 0{,}6$ %

## 7. Conclusions

The comparative turbine efficiency measurements treated in this paper show that the original instruments and equipment designed by G. Willm and P. Campmas with good care is capable of producing accurate and reliable measurements and one should pay high tribute to Willm and Campmas for their work. The method is improved by a number of people since it was introduced, and it can today be used for field measurements under good measuring conditions to improve turbine design in a better way than small scale laboratory model tests can do.

***Figures and Photos***

Fig. 1 Turbine discharge directly into salt seawater.

Fig. 2 Influence on thermodynamic measuring conditions.

Fig. 3 Influence of power plant output on water temperature and head.

Fig. 4 Variation of energy in supply conduit.

Fig. 5 Test arrangement.

Fig. 6 Outlet sampling arrangement.

Fig. 7 Measurement results.

Photo 1. Extruded aluminium stoplogs.
Photo 2. Outlet pitots with measuring chamber (slightly bent after measurements).
Photo 3. Outlet of turbine runner after efficiency tests in 1963.

***References***

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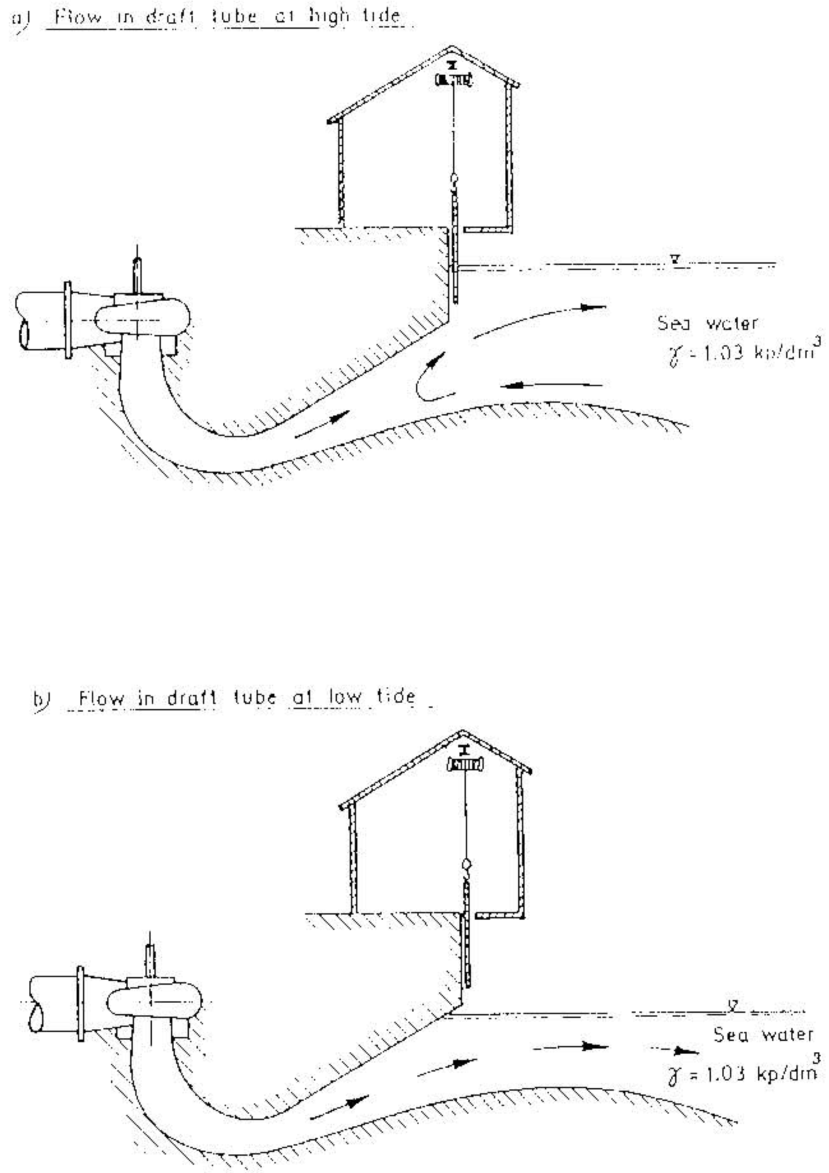



**FIG.1 Turbine discharge directly into sea water**

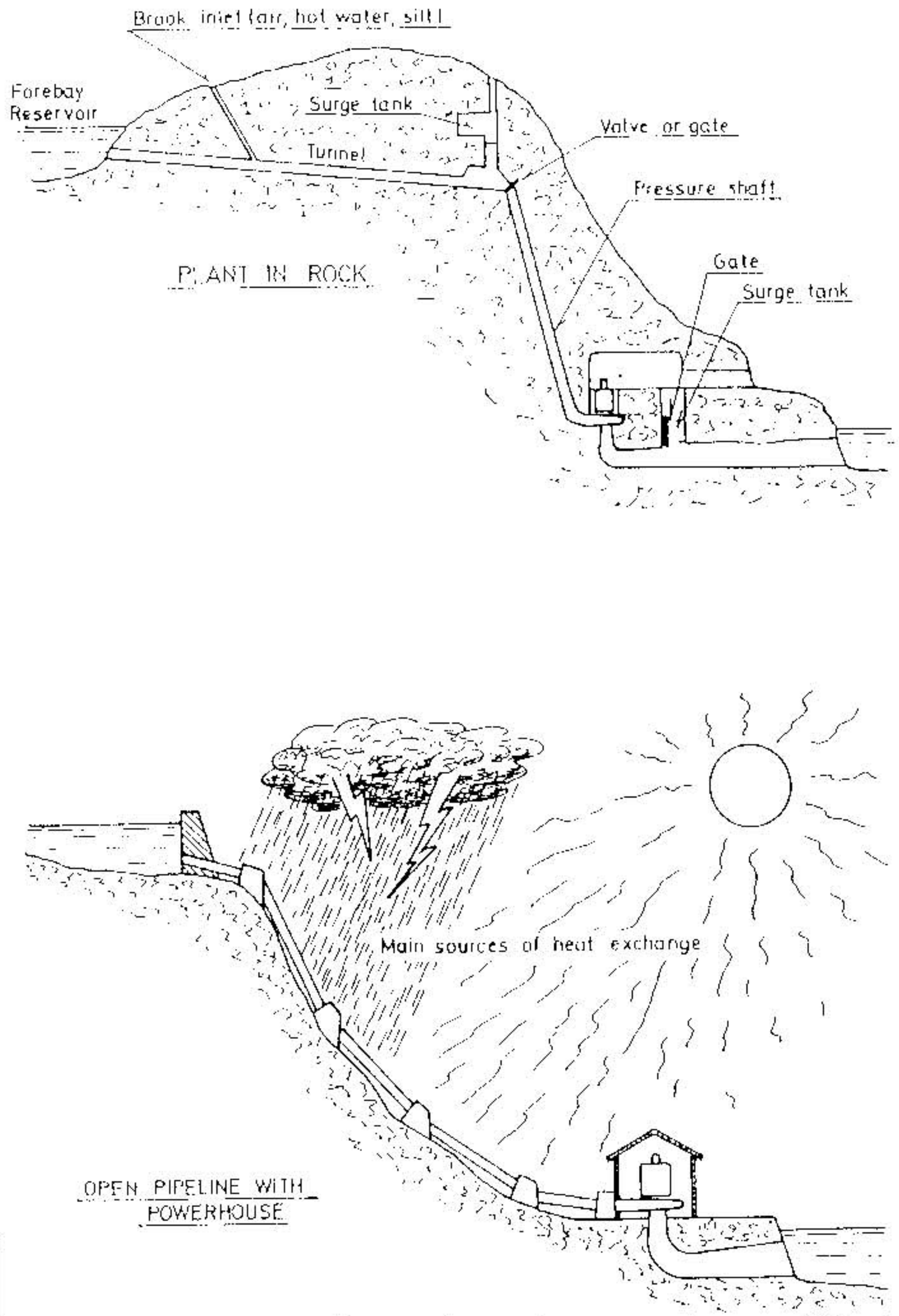



**FIG.2 Influence on thermodynamic measuring conditions**

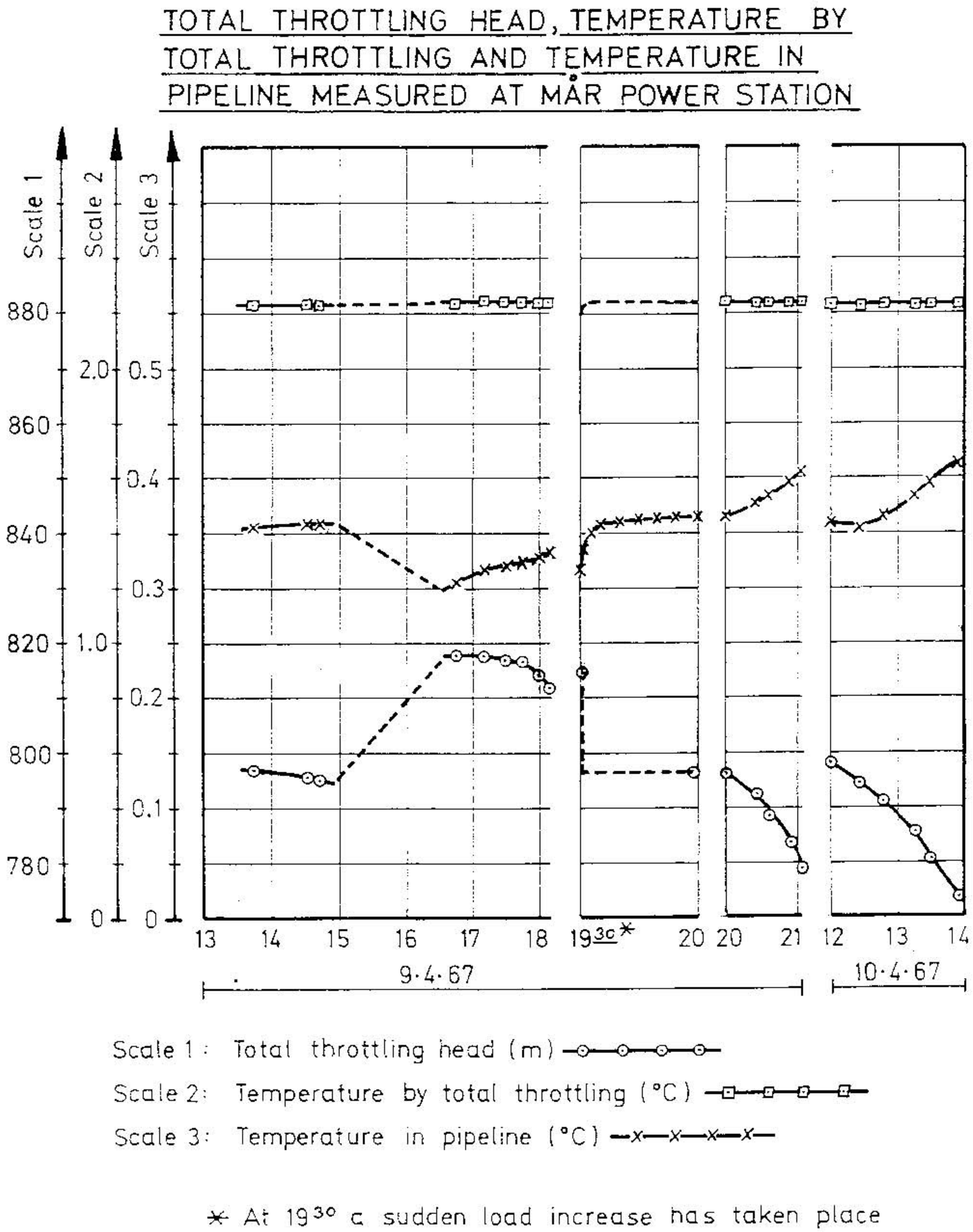



**FIG.3 Influence of total power plant output on water temperature and head**

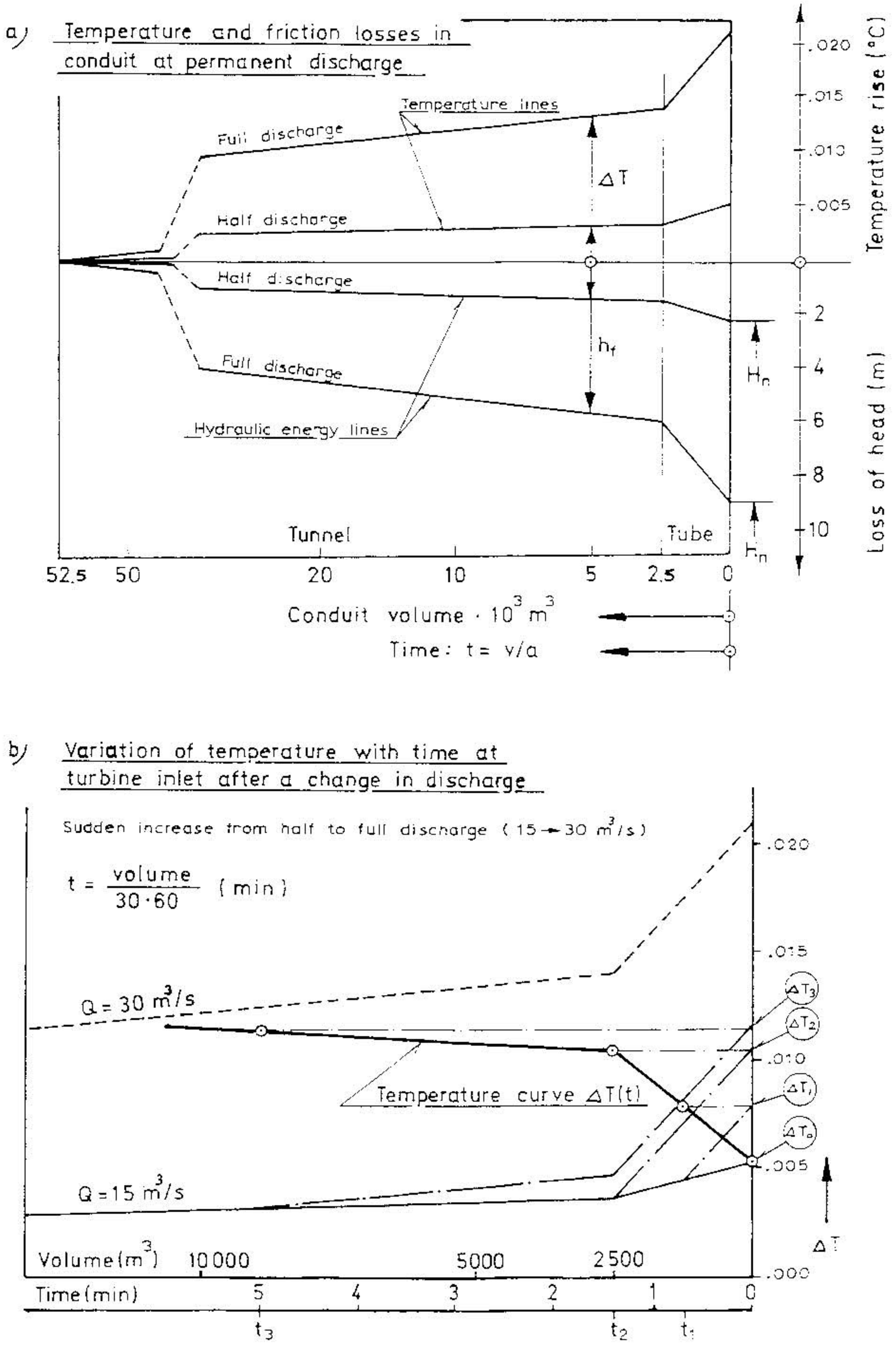



**FIG.4 Variation of energy in supply conduit**

| | | | |
|---|---|---|---|
| Oppdragsgiver: HELGELAND KRAFTLAG A/L | O.nr.: | Arkiv nr.: | Side: |
| Oppdrag: GRYTÅGA POWER PLANT | Dato: | Sign.: | |
| Sak: TEST ARRANGEMENT | FIG. 5 | | |
| | | | |

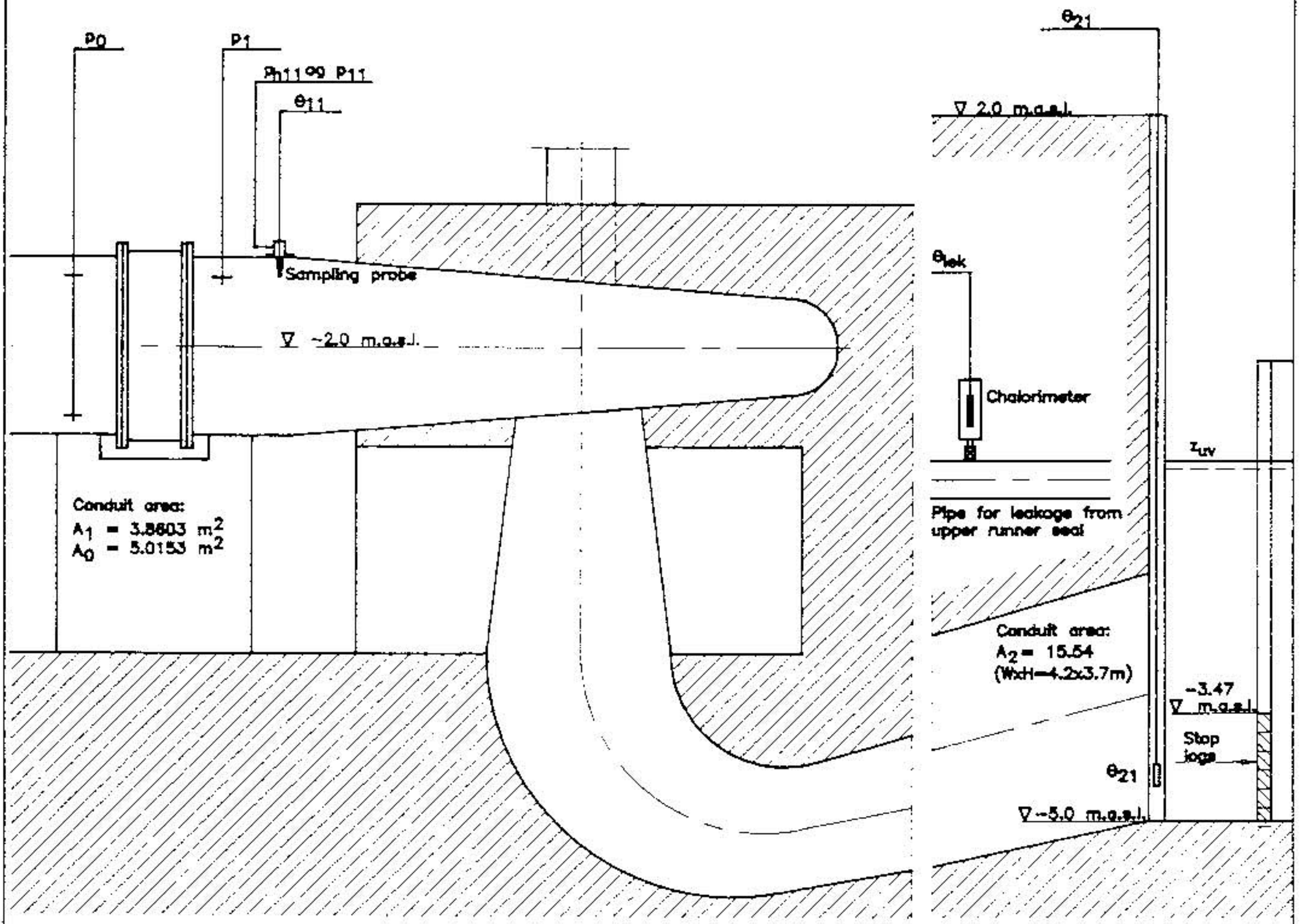



FIG.5 Test arrangement (location of measuring equipment incl. outlet stop logs)

| | | | | |
|---|---|---|---|---|
| Oppdragsgiver: | HELGELAND KRAFTLAG A/L | O.nr.: | Arkiv nr.: | Side: |
| Oppdrag: | GRYTÅGA POWER PLANT | Dato: | Sign.: | |
| Sak: | OUTLET SAMPLING ARRANGEMENT | | | FIG. 6 |
| | | | | |

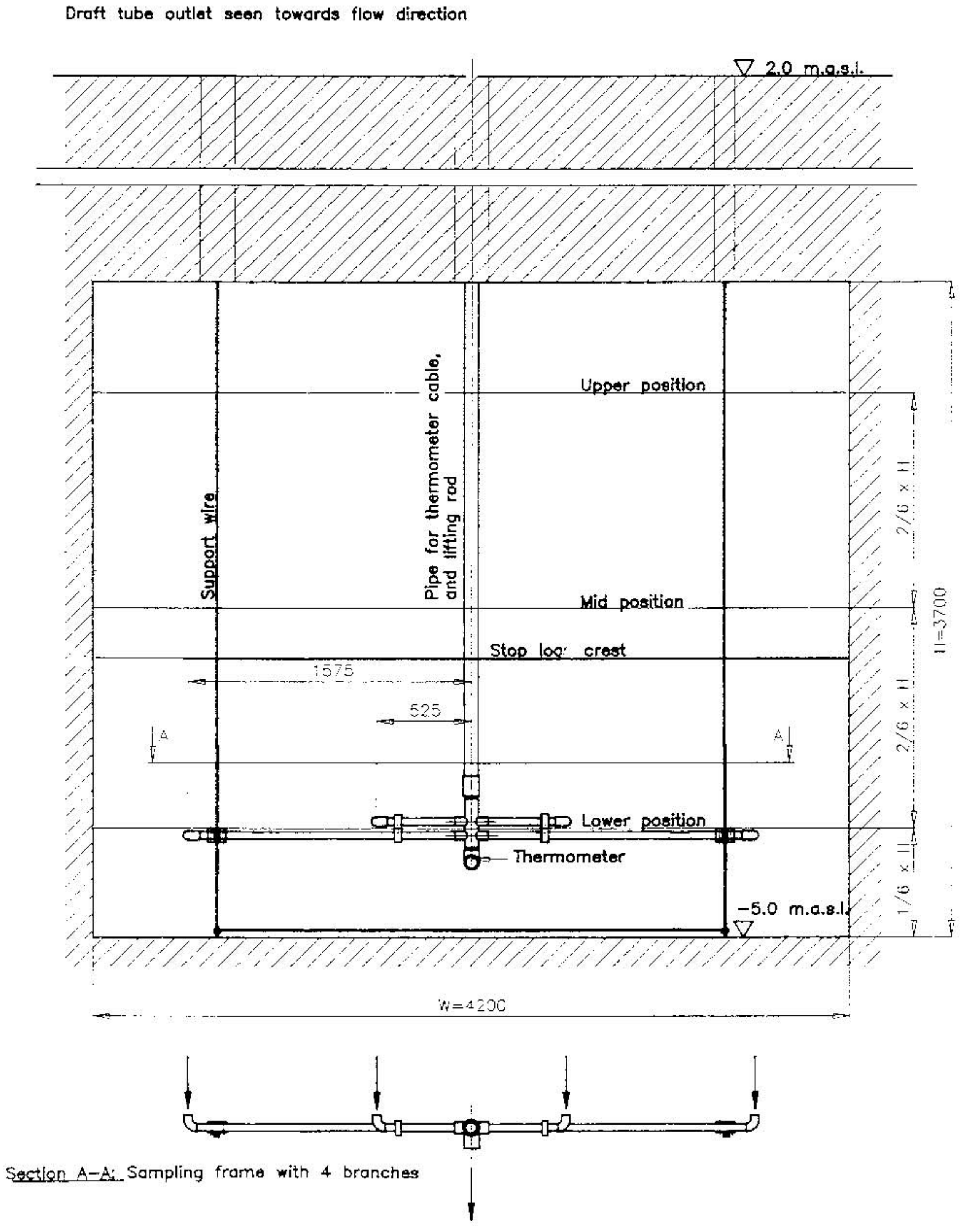
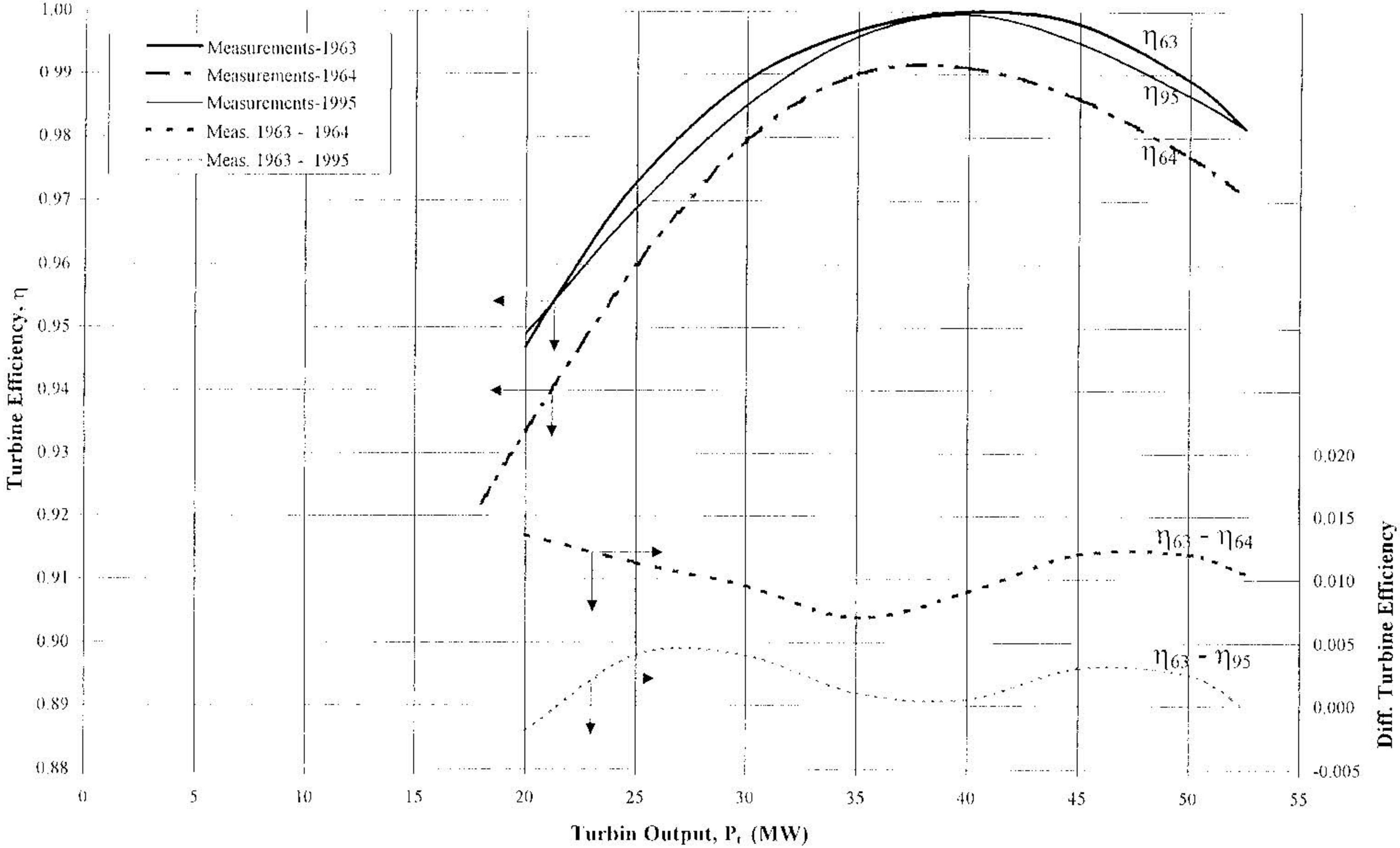



**FIG.6 Outlet sampling arrangement**

## FIG.7 Measurement results Grytåga Power Plant

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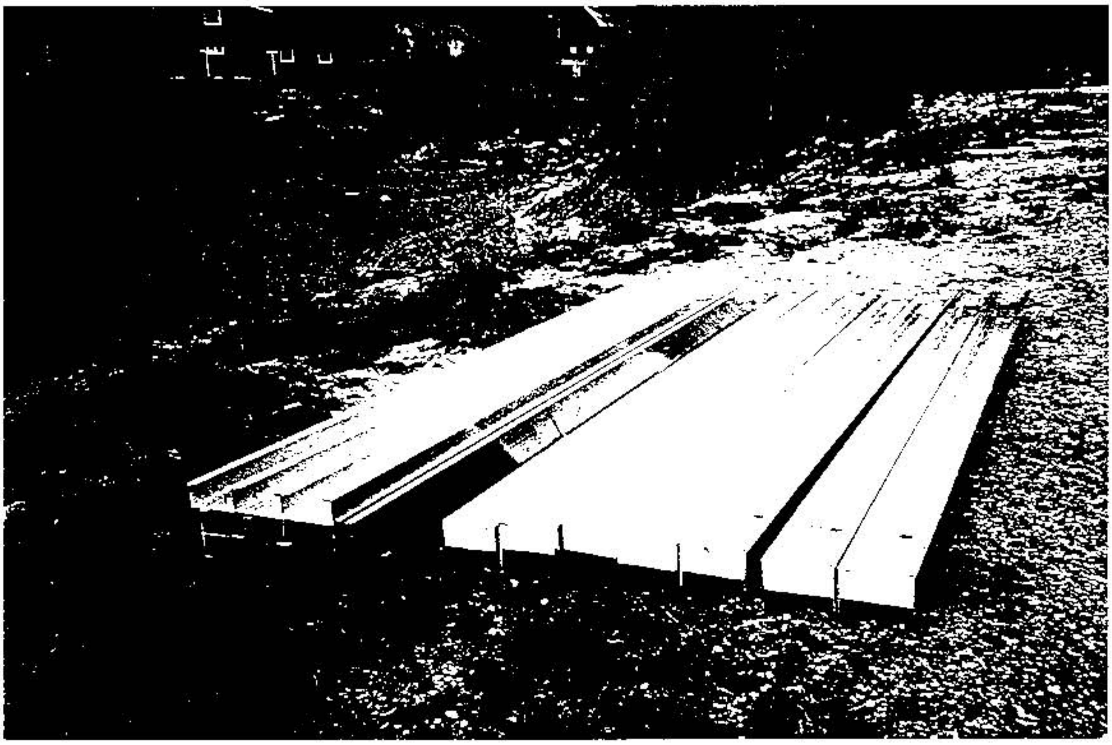

Photo 1 Extruded aluminium stoplogs

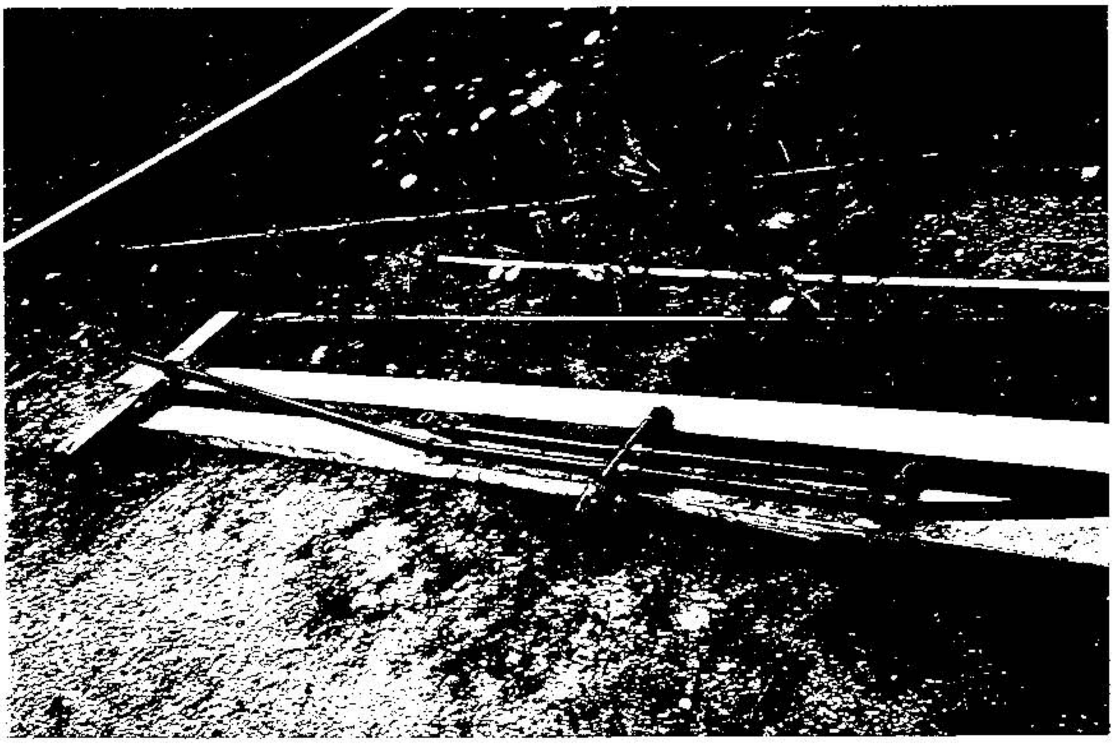

Photo 2 Outlet pitots with measuring chamber (slightly bent after measurements)

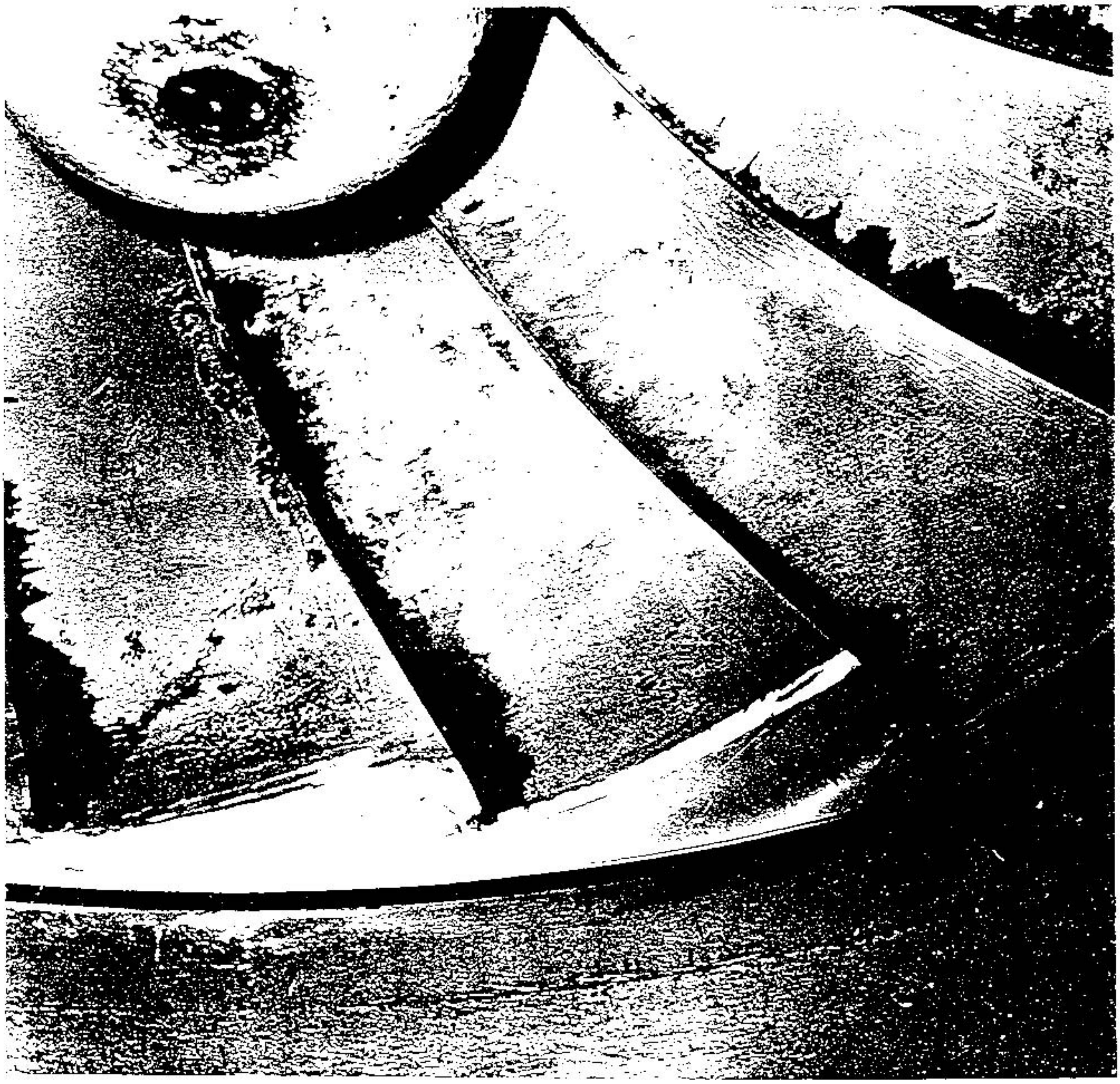

Photo 3 Outlet of turbine runner after efficiency tests in 1963