A PROPSAL FOR IMPROVING THE THERMO DYNAMIC METHOD.

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Introduction.

The paper presents the Thermodynamic Efficiency Measurement at 2 power plants in Norway where both temperature and velocity have been measured proving that it is possible to weigh the energy in a correct way by this method.
In addition the measurement of a vertical Small Hydro Pelton turbine is presented where the measuring condition made a systematic error when using perforated pipes for collection the water at the turbine outlet. A discussion on the possible reason for the error is given.

Examples are given of measurement by using weighted energy from the measuring points by measurement of both velocity and temperature in each point.

Measurement at Bratsberg Power plant.

The technical data for the turbine at Bratsberg yields**: P = 60 MW, Hn=130 m, n = 300 RPM**.
In general it will not be correct to measure the temperature in 3*3 = 9 positions and use the average temperature for the energy calculation of the energy at the outlet from the turbine.
At Bratsberg a measurement was made by using a collector as illustrated in fig.1 for a test to include the influence from the stagnation pressure of the water to obtain the right amount of water from each point in 6 locations across the draft tube outlet.

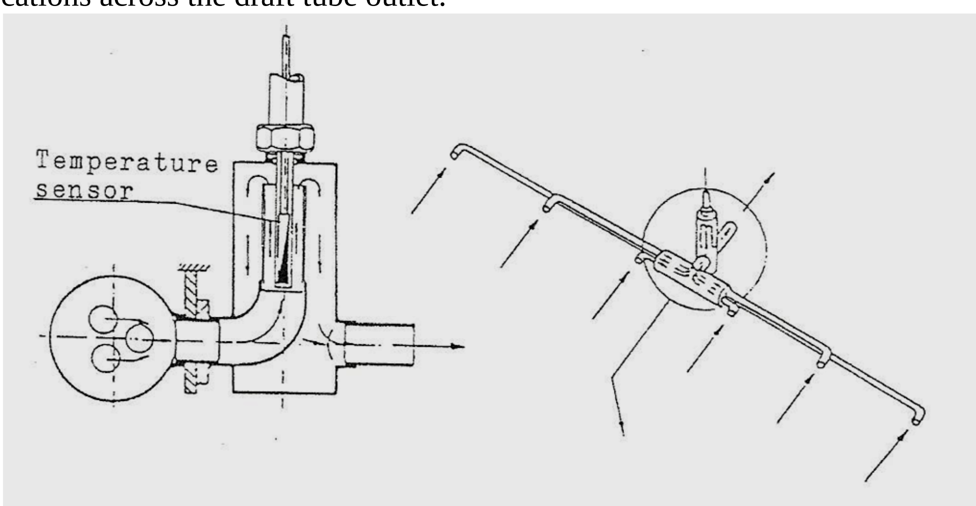

Fig.1 The flow collector used for the temperature measurement at Bratsberg. /Ref. 1/

However, even if the stagnation pressure into each inlet was representative for each point a certain overpressure occurred in the collector where the pipes were jointed and thus this measurement did not get an inflow proportional to the speed of the water at each point./Ref.1/

A new measurement was made at Bratsberg in 1995 with separate measurement of both velocity and temperature in 6 points on a traversing frame covering 6x6 measuring points.
The result is shown in fig. 2 and fig 3.

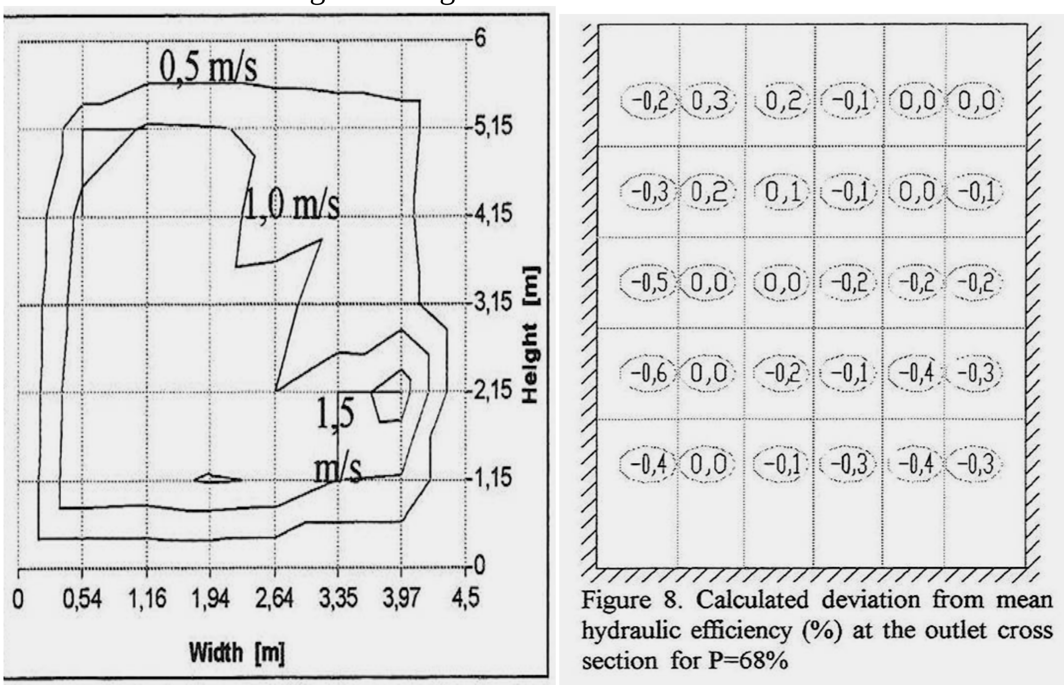

Figure 8. Calculated deviation from mean hydraulic efficiency (%) at the outlet cross section for P=68%

Fig. 2 Measuing result from BratsbergPower plant at 68% load with measurement of both flow velocity and temperature proving that the point of highest velocity had an efficiency 0.4% below the mean velocity. /Ref. 2/.

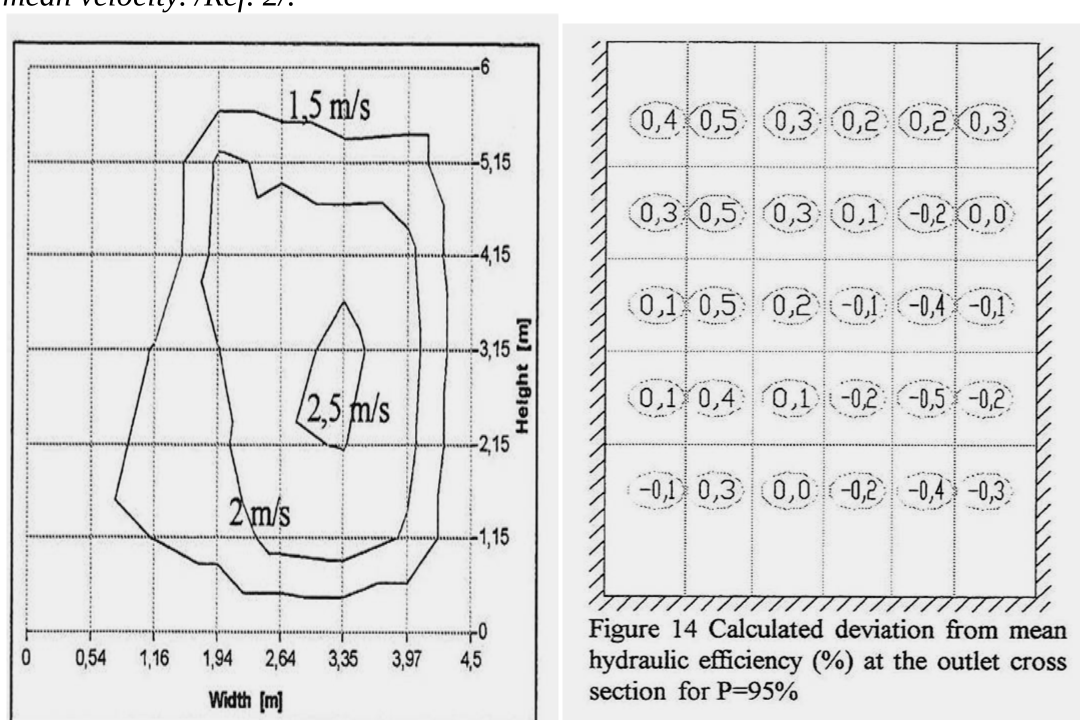

Figure 14 Calculated deviation from mean hydraulic efficiency (%) at the outlet cross section for P=95%

Fig. 3 Measured velocities and deviations from mean efficiency at different locations in the draft tube outlet gate at 95% load at Bratsberg /Ref. 2/ Highest velocity was found near the point of average efficiency in this case.

Measurement at Driva power plant

Another measurement was made at Driva Power Plant on a high head Francis turbine where both velocity and temperature where measured at the draft tube gate.
The technical data for the turbine which were measured are: **P=71.5 MW, Hn=540 m, n=600 Rpm**.
This measurement was made by M.Sc. Erik Nielsen in his Ph.D work in 1992.
By measuring both velocity and temperature it was proven that we would have no inflowing water from the lowest points in the draft tube if a collecting system of any kind had been used.
By using flowmeters and measuring temperature and velocity separately the outlet energy could be calculated correctly. The measuring frame which was traversed from bottom to top on 3 levels according to IEC rules is shown in fig 4.
The results of the measurement at 45 MW illustrated in fig. 5 is taken from this measurement.

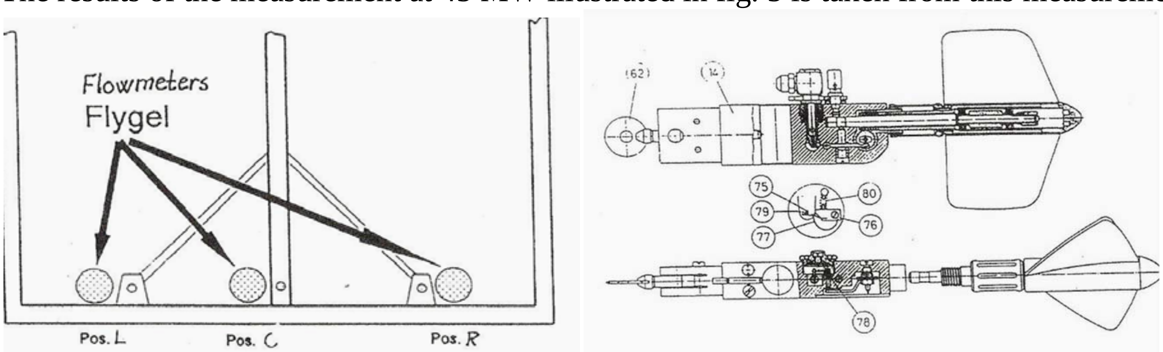

Fig. 4 Measuring arrangement for the high head turbine for Driva Power plant. Left. The measuring frame moved up and down in the draft tube gate frame. Right the flowmeters.

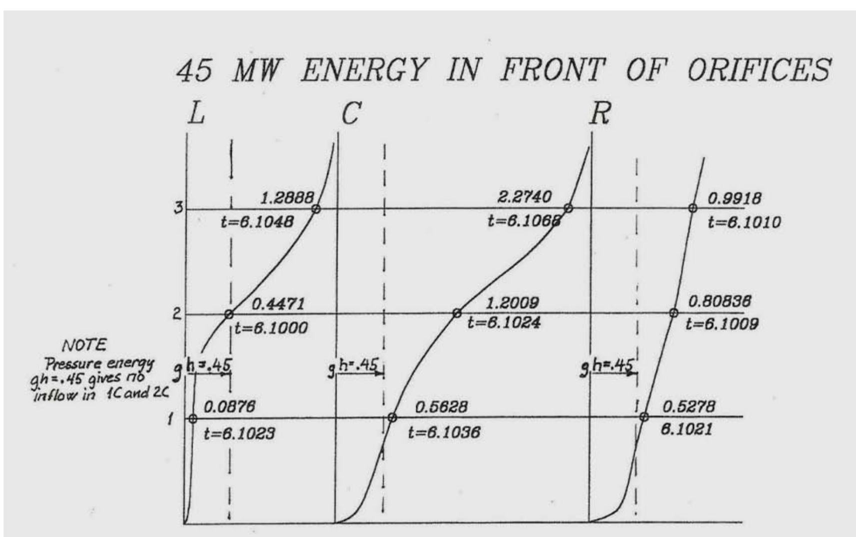

Fig. 3. Energy distribution (Joule) and temperature distribution °C at 45 MW output

Fig 5 Measuring result from Driva at 45 MW. /Ref. 3/

Meassurement at Sværen power plant

Sværen power plant is a small hydro power plant where one Pelton turbine is installed with following technical data: P = 2 946 kW, Hn=220 m and n = 600 RPM.
It is well known that it is difficult to get god measuring condition when measuring efficiency by the Thermodynamic method in a Pelton turbine.
The reason is that some water is sucked back up to the runner in the centre and then this water will hit the back of the buckets when streaming outwards driven by the centripetal force. When hitting the buckets foam is created by a mixture of water and air. This water have a much higher temperature than the average water and is floating in top in the outlet channel close to the turbine until it is mixed with the main flow of water some distance downstream of the turbine.
This phenomena is well known and then the measuring point of temperature by the thermodynamic must take place a certain distance from the turbine where the foam has disappeared from the surface. Using perforated pipes will give a false temperature because water from the high velocity field i.e. at the surface will dominate the inflow.
At Sværen power plant this problem was extremely difficult because the measuring point was planned to be located upstream of a weir. This weir was located approximately one turbine casing diameter downstream of the turbine outlet i.e. very close to the turbine.
In fig. 6 left the arrangement of the perforated pipes is shown and to the right is shown the foam on top of the high velocity water streaming towards the weir, bypassing the perforated pipes.

Fig.6 Left. Arrangement of the perforated pipes upstream of wear the weir. Right. The foam bypassing the perforated pipes.

In the case of Sværen a measurement with a combination of flowmeters and temperature probes, would have proven a strong variation in both flow velocity and temperature between bottom and top. However, by knowing both temperatures and velocities the total energy could be calculated like the example shown for Driva power plant. Still the measurement should have been further downstream from the turbine to avoid the low density foam which might give uncertainty in the velocity measurement.
Especially in front of a weir both velocity and temperature must be measured separately to get a correct result because of the strong variation in velocity.
Perforated pipes should never be used because water from the high velocity field will be dominating the temperature in the water inside the pipe and thus a false result will be the case.
As illustrated in fig 7 the velocity field upstream of a weir will have a very low velocity at the bottom and the temperature in a perforated pipe will be dominated by surface water.

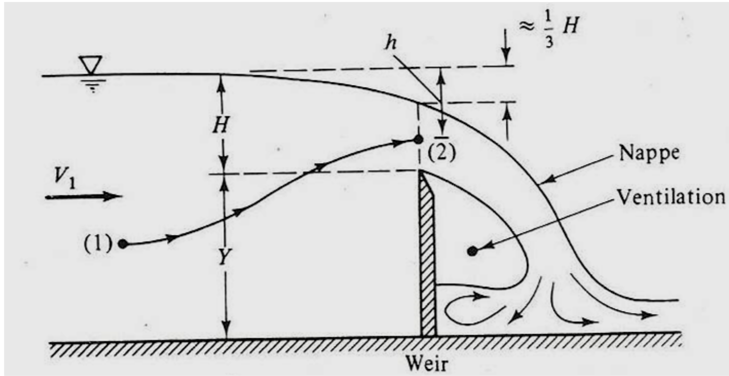

Fig. 7 Schematic illustration of the flow crossing a weir.

The result from the efficiency measurement at Sværen gives a clear indication of the dominating inflow of the water closest to surface especially because the efficiency dropped when the surface became lower at lower load both at reduced needle opening and at reduced number of jets in operation.
In fig 8 is shown the result from the efficiency test.

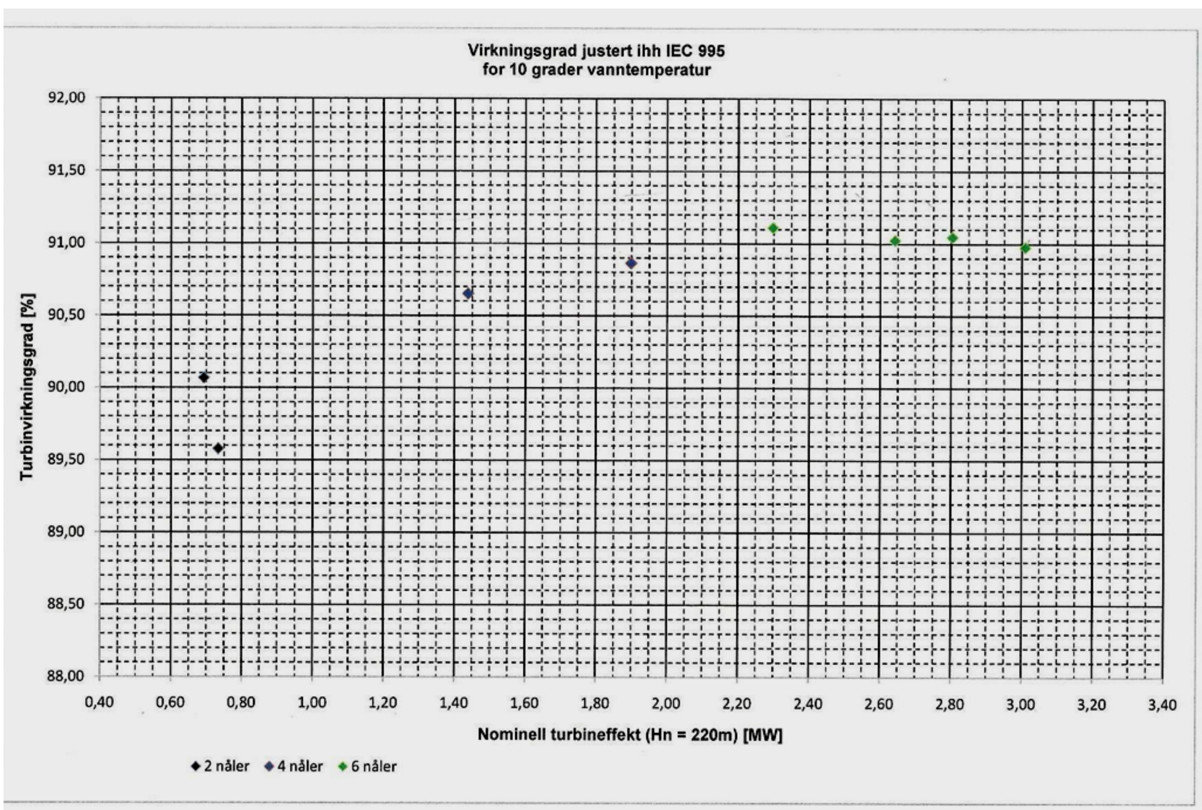

Fig. 8 Result from efficiency test with 2 jets 4 jets and 6 jets at Sværen. Note the drop in efficiency at decreased flow and height of the surface in front of the weir.

For a comparison the measured efficiency from a small hydro turbine and model turbines adjusted to the efficiency at full load at power plant Sværen, is shown in fig. 9.

It should be remarked that the efficiency at 6 jets and 4 jets and often 2 jets normally have the same maximum efficiency as for 6 jets. Then we obviously have a systematic error in the measurement at SVÆREN caused by using perforated pipes.
This error could be prevented by measuring both velocity and temperature and move the measuring point further downstream from the turbine. (For Sværen this would be difficult because the weir was built as a part of the cooling water system for the generator.)

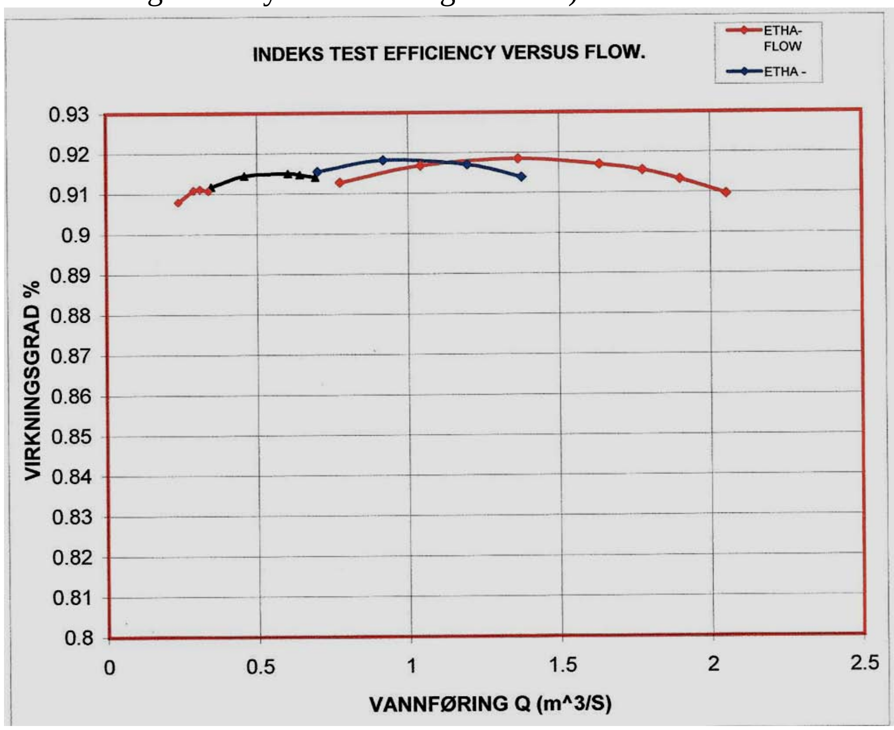

Fig. 9 Index test based on similar efficiency measurements in a similar 6 jet small turbine and various model tests.

CONCLUDING REMARKS

At present time it should be no problem to arrange for measuring both velocity and temperature across the outlet of a turbine. Then a weighted efficiency from different measuring point should be used.
It should however be emphasized on the fact that it is very difficult to make a reliable measurement too close to the Pelton turbines because of the "hot water" in the foam.
Finally, perforated pipes may give false results and should be substituted by measurement of both velocity and temperature separately. This is in order to be able to weigh the energy as a function of both the velocity and temperature. In modern time it should be easy to get such equipment. The time collecting data and calculate the efficiency should be short with computerized equipment.

REFERENCES:

Ref. 1: H.Brekke   Measuring Uncertainties of Specific Energy in Draft Tube Outlet. GPMT 16.th Meeting in Salzbourg Oct. 05-08. 1992

Ref. 2: O.B.Dahlhaug A Study of Swirl Flow in Draft Tubes. PhD Work Norwegian University of Science and Technology 1997.