MEASUREMENT OF TURBINE EFFICIENCY BY THERMODYNAMIC METHOD FOR FIELD ACCEPTANCE TEST OF HYDRO TURBINE AND COMPARISON WITH MODEL TEST RESULT

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INTRODUCTION

The thermodynamic method results from the application of the principle of conservation of energy (first law of thermodynamics) to a transfer of energy between water and the runner/impeller through which it is flowing. This requires very accurate measurement of temperature as the temperature difference at the inlet and the outlet of turbine is of very small magnitude. The specific mechanical energy at the runner/impeller is determined by measurement of the performance variables (pressure, temperature, velocity and level) and from the thermodynamic properties of water. To establish the efficiency, the need to measure the discharge is eliminated by using the specific mechanical energy together with the specific hydraulic energy. IEC 60041 –1991 gives two methods namely- Direct operating procedure and Partial expansion operating procedure and some basic measuring system requirements. This needed further refinement and development for practical application keeping in mind latest sophisticated instrumentation and user-friendly computer programming technique.

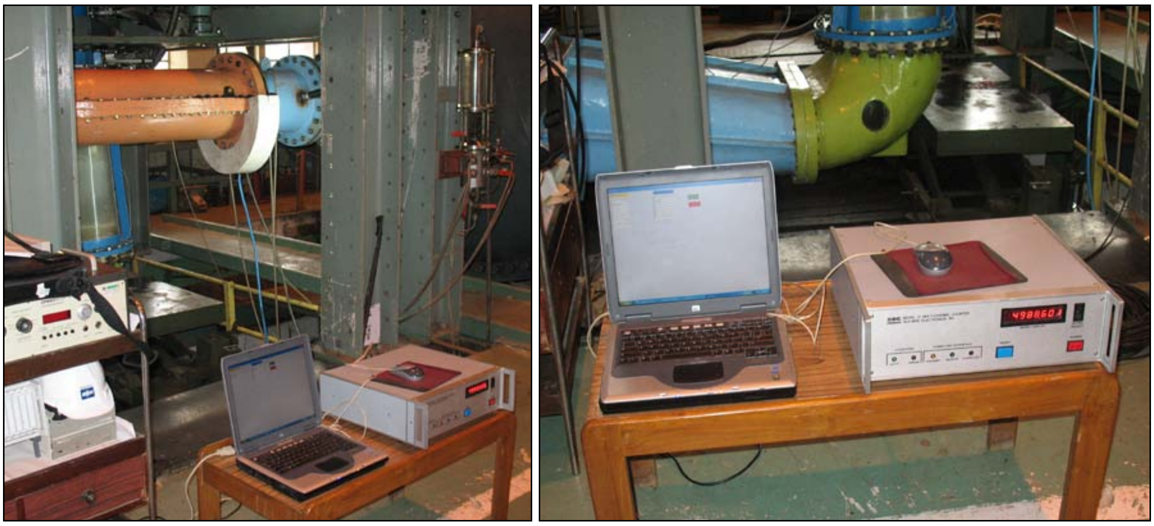
In India hydro power is being used from early 20th century and turbine model testing is being carried out since 1970`s whereas Field efficiency measurement is relatively a new trend/requirement.

For development and validation of required system of Direct operating procedure; Laboratory experimentation was done with modification in hydro turbine testing laboratory of Bharat Heavy Electricals Limited Bhopal, India.

BHEL had supplied generating set for Pykara USHEP Power House (3*50MW Pelton Turbine) TNEB, India. The turbines are used for rated head of 1026.17 m which is the highest head power house in India. Thermodynamic method was applied for efficiency acceptance test along with IMPSA Argentina. The efficiencies matched quite well with the predicted prototype efficiencies from model test and all guarantees were met successfully.

LABORATORY VALIDATION-

An arrangement was made at Hydro Laboratory BHEL Bhopal, India for the limited validation of Thermodynamic method. Thermometers SBE 3S, of Sea Birds Electronics make were used to validate temperature measurement. The output of SBE 3S thermometer was connected to the SBE model 31-multi channel counter, which in turn was connected to notebook using RS 232 to USB converter. These were installed at the inlet of hydro turbine model. Photographs of set up (fig-1) are enclosed on the following page. The test rig was set up for model testing of Francis turbine. The software developed by BHEL was used to acquire and process the reading in engineering units of temperature.



Laboratory Validation set up (Fig-1)

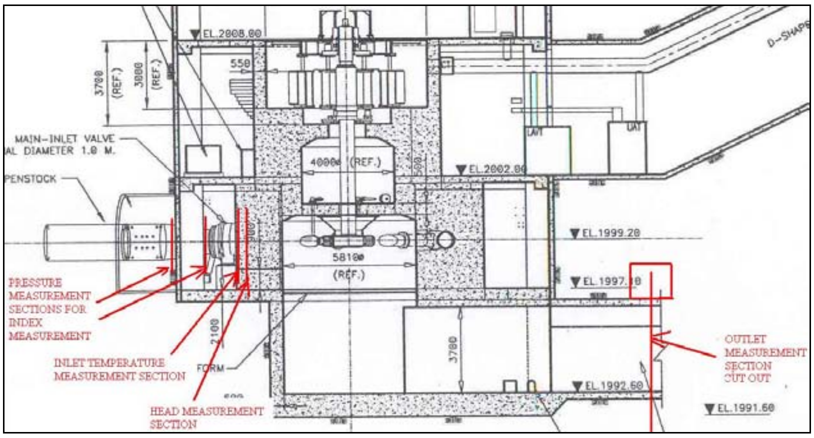
MEASUREMENT OF EFFICIENCY BY THERMODYNAMIC METHOD AT POWER HOUSE

During March 2006, Efficiency Acceptance Test on the Pykara USHEP Power House (3*50 MW Pelton Turbine) TNEB, India was carried out by Thermodynamic method on unit number three.
As per IEC 60041-1991 clause 14, the efficiency by Thermodynamic method is calculated as per clause section 14.2:

$$\eta_h = P_m / P_h = E_m / (E +/- \Delta P_h/P_m \, . \, E_m)$$

Where E_m is the specific mechanical energy, E is the specific hydraulic energy, P_h is the hydraulic power, P_m is the mechanical power and ΔP_h is the hydraulic power correction.

MEASUREMENT PROCEDURE-



Fig(2)

TEMPERATURE MEASUREMENTS AT INLET AND OUTLET

At each load, inlet temperature was measured at two points just before to inlet to distributor along with the temperature at the outlet was measured at 5 different levels, achieved by lifting/lowering the measurement frame (see photograph below). At each level two readings were taken. The temperature was logged for 3 minutes. In the calculation of the efficiency the average of all five measurements are used.

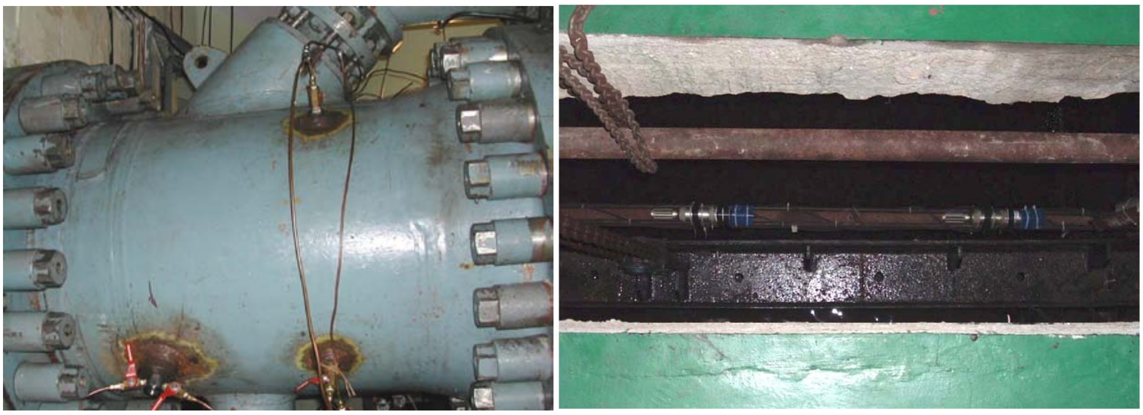
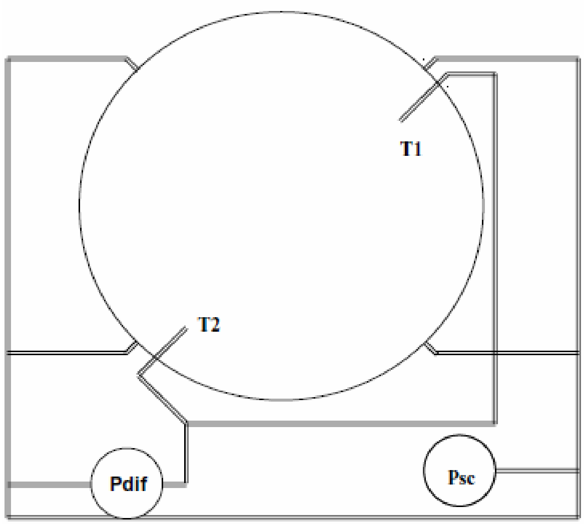


Fig. (3)

PRESSURE MEASUREMENTS-

Differential pressure transducer Psc (Yokogawa make) was connected to the inlet section after the valve. Four static pressure taps were connected in a circular manifold which was connected to the high pressure side of the differential pressure transducer. The pressure transducer was calibrated before the test. Another Differential pressure transducers Pdif (Yokogawa make) at high pressure side connected to the dynamic pressure taps (water extraction probes, marked T1 and T2 see figure below) and at low pressure side was connected to the manifold of static pressure taps. The differential pressure transducer was calibrated by a water column manometer.



Pressure & Temperature measurement at inlet to Turbine Fig. (4)

POWER MEASUREMENTS

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

AUXILIARY MEASUREMENTS

In addition to above following were also measured.

Water levels at tailrace exit
Water levels at the intake.
Injectors needle opening.

ANALYSIS OF TEMPERATURE READINGS FOR CALCULATION OF EFFICIENCY

It is extremely important to analyze the temperature readings as in all probability the temperature readings at inlet would vary with each other and this variation is likely to be more at the outlet measuring section both in horizontal (same elevation) and in vertical different elevation. After proper analysis a methodology has to be finalized for calculation of efficiency. A typical set of reading is given in Table(1) with analysis and methodology to calculate the efficiency. Efficiency value in this paper are normalized values (not absolute efficiency value) which have been calculated by formula:

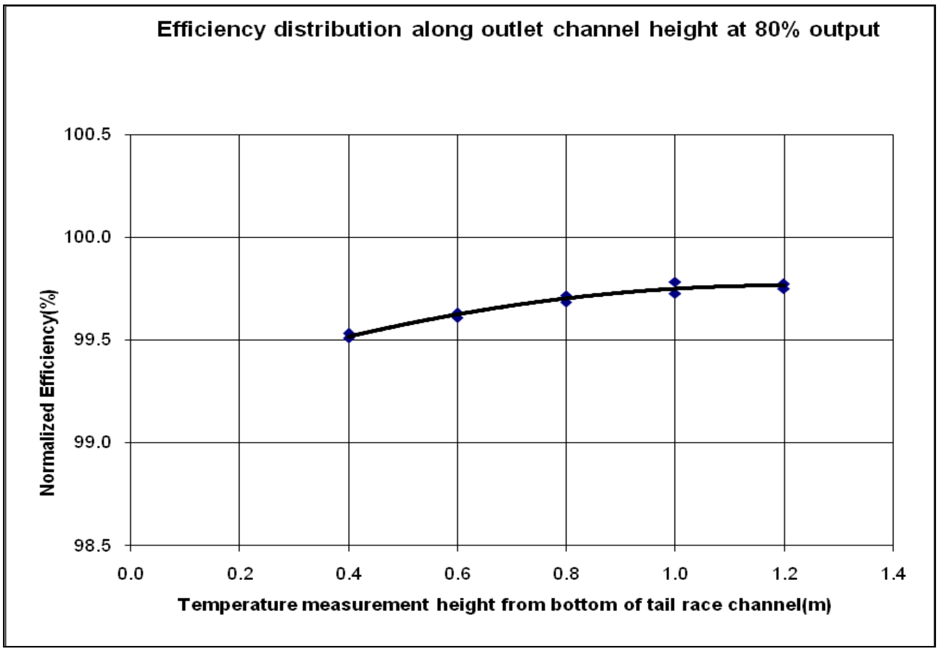
Normalized efficiency = (absolute efficiency / Maximum efficiency) x 100

Table (1)

Point No	Normalized Efficiency	TWL	Structure Level from bottom	Thermometer Level	Inlet outlet Temperature difference*
	%	m	m	m	°C
1	99.53	929.285	0.4	928.36	0.0789
2	99.51	929.285	0.4	928.36	0.0793
3	99.61	929.285	0.6	928.56	0.0769
4	99.63	929.285	0.6	928.56	0.0765
5	99.72	929.285	0.8	928.76	0.0746
6	99.68	929.285	0.8	928.76	0.0753
7	99.73	929.285	1.0	928.96	0.0743
8	99.78	929.285	1.0	928.96	0.0732
9	99.77	929.285	1.2	929.16	0.0734
10	99.75	929.285	1.2	929.16	0.0739
Average	**99.67**				

* Temperature difference between outlet and inlet sections is calculated from average temperature of two thermometers at inlet and average temperature of three thermometers at outlet at a particular elevation.

From the table (1) it can be seen maximum efficiency variation of 0.27% was calculated due to variation in temperature difference of 0.0061°C. The difference in temperature was plotted at various elevation and given in Fig(5).

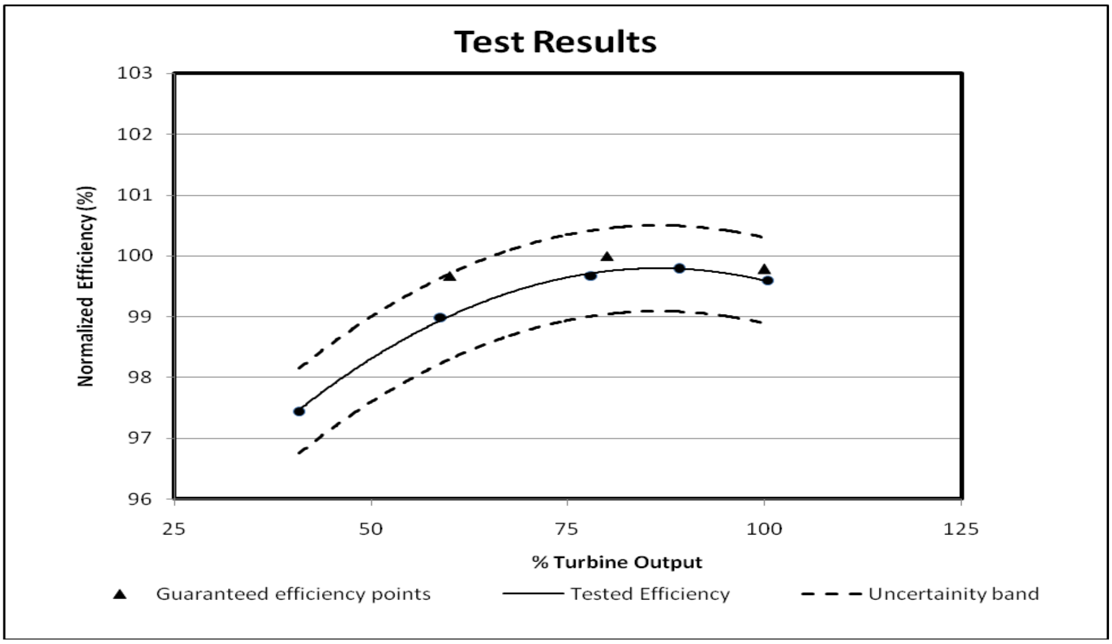


Fig(5)

As per readings temperature gradually increased from bottom to top of tail race for tested 40%, 60%, 80%, 90% &100% load points. It confirmed the temperature gradient and ruled out any discrepancy in temperature measurement. Average value of efficiency calculated was found to be matching closely with temperature at the midpoint of the water height in the channel.

COMPARISON OF TESTED EFFICIENCY WITH GUARANTEED EFFICIENCY

Test results are plotted between Turbine output and normalized efficiency and is given at Fig(6). It is evident that guaranteed efficiencies have been achieved as the guaranteed efficiencies and the tested efficiency lye within the uncertainty band. Uncertainty band is to be calculated as per IEC 60041, it is calculated by adding and subtracting uncertainty in efficiency to tested efficiency.



Fig(6)

Guaranteed efficiencies are model tested efficiencies with no scale up being a Pelton turbine.

CONCLUSION

BHEL carried out Field efficiency acceptance test of Pelton Turbine at Pykara USHEP Power House (3*50MW Pelton Turbine) TNEB, India. The efficiency measured by Thermodynamic method matches quite well with model tested efficiency if measuring sections are selected as per recommendation of IEC 60041 conditions and proper instrumentation & system is deployed. The calculation procedure should be as per IEC 60041.The description of the field acceptance tests using the Thermodynamic method gives the idea that it is a simple measuring technique. Whereas, many problems may affect the measurement accuracy and wide experience & deep knowledge of the phenomena in the real measurement of efficiency is must which allows a proper detection and solution to all problems that may be faced. Finally, it is the experience that gives the reasonable certainty to obtain good results along with proper instrumentation and proven system.

REFERENCE:

[1] International Standard CEI/IEC 60041, Field Acceptance Tests to Determine the Hydraulic Performance of Hydraulic Turbines, storage Pumps and Pump-Turbines, 1991

[2] ASME. (1992). Performance Test Code for Hydraulic Turbines. Standard PTC-18, American Society for Mechanical Engineers, NY.