

CHAPTER -8

TURBINE AND GOVERNOR TESTING (Reviewed by Dr. R. P. Saini, AHEC)

TURBINE TESTING

8.1 Shop Assembly and Tests

All components/sub-assemblies should be properly match-marked to ensure correct re-assembly and alignment in the field.

The following shop assembly and testing requirements in Supplier's works should essentially be included in quality assurance plan (Reaction Turbine):

- Stay ring with spiral casing – for matching segments and alignment
- Draft Tube Liner – for matching segments
- Wicket gate Mechanism – to be assembled on its stay ring and following parameters should be checked:
 - ◇ Clearances between end faces of wicket gates and inner/outer distributing cone,
 - ◇ Clearances between consecutive wicket gates in fully closed position at three places along their length,
 - ◇ Opening between consecutive wicket gates in 50%, 75% and 100% open positions at three places along their length,
 - ◇ Minimum force required at regulating ring to move the wicket gate mechanism freely.
- G.V. Servomotor – hydraulic testing, stroke checking and oil leakage past piston and piston rod
- Turbine Runner – for free movement of blades, stroke, blade angles, oil leakage through piston & blade seals and static balancing.
- Guide bearing – for proper fitting
- Oil Pumping Unit – for operational check
- Pressure Vessels – soundness of weld joints and hydrostatic test
- Governor – complete performance testing as per relevant IEC code
- Oil Head Distributor – hydraulic testing and leakage of oil
- Inlet valve for free movement
- Inlet valve servomotor - hydraulic testing, stroke checking and oil leakage past piston and piston rod
- All bought out items as per quality plan submitted and agreed at sub-supplier's works

8.2 Tests on Sub Assemblies

Tests on sub-assemblies should be carried out to verify their accuracy and proper functioning. Radiographic, magnetic particle, dye penetration, ultrasonic inspections and hydrostatic testing should be performed to ensure soundness as per agreed quality plan and applicable National/International Standards.

8.2.1 Material Tests

Material tests for important components such as runner hub, runner blades, levers, wicket gates, turbine shaft, guide & thrust bearing pads / bushes, piston rods and other important components should be carried out as per agreed quality plan. Purchaser's Engineer should review the test certificates during inspection.

8.2.2 Defects and Corrections

Any leakage, distortion, or other defects developed during or after the tests should be corrected and the item shall be retested.

8.2.3 Tests on Bought out Components

All motors/pumps/compressors, etc. should be tested as per relevant Indian or other Standards.

8.3 Pre-Commissioning Field Tests

Following measurements/tests in addition to tests recommended by Contractor should be included in quality plan for pre-commissioning tests:

- Wicket Gates clearances in fully closed condition – vane to vane and at mating surfaces with outer & inner distributor cones
- Engagement of servomotor lock in wicket gate closed condition
- Characteristic - Servomotor stroke Vs wicket Gate opening
- Characteristic - Wicket gate openings Vs runner blade angles
- Wicket gates and runner blades opening and closing times and servomotor cushioning time
- Radial clearances between throat ring and runner blades
- Diametrical clearances of guide bearings
- Dielectric and Insulation Resistance Tests on all electrical motors as per relevant standards
- Operational tests on oil pressure system to verify :
 - Safety and unloader valve settings
 - Setting of pressure relays for automatic control of pumps
 - Setting of pressure relay for emergency low pressure
 - Setting of emergency low oil level in pressure tank
 - Air replenishment in oil pressure tank in auto/manual mode
 - Test to verify pumps capacity
 - Low and high oil level in sump - alarm signals
 - Tests to verify number of close/open operations with oil pump
 - Pump operating regime i.e. pumping time Vs idling time with wicket gate & runner servomotors at 90% open position
- The governor should be adjusted and tested in the field for optimum performance in simulated operating conditions. Specifically the following tests/checks should be performed :
 - Verify logic control scheme from local/remote including start/stop, load control, emergency shutdown, controlled action shutdown, locking and other feature
 - Verify stability and response of governor during:
10% to 20% step change load acceptance and rejection, or a combination of these.
 - Verify parallel operation of unit as per droop settings selected.
 - Verify setting range of permanent droop, on/off-line temporary speed droop, derivative time constants, frequency dead band, speed setting limits, gate setting limits, no load gate limit, speed relays etc.

- Verify servomotor response time
- Other test to verify performance as per applicable IEC code 308(1970) for testing of speed governing systems for hydraulic turbines.
- Operation of level controllers in OPU for automatic operation of pumps and signal for high oil level alarm.
- Calibration of instruments, switches and level controllers.

8.4 Commissioning Tests

Following commissioning tests should invariably be included in tests recommended by Contractor before putting the machine on 72 hours continuous run for handing over:

Checking and stabilize the performance of the governor for:

- Logic control scheme from local/remote including start/stop, load control, emergency shutdown, controlled action shutdown, locking and other feature
- Stability and response of governor during 10% to 20% step change and load
- Load Acceptance and rejection, or a combination of these.
- Verify parallel operation of unit as per droop settings selected.
- Automatic starting, stopping, synchronizing and emergency shut down by simulating emergency conditions
- Checking the setting of over speed trip device by over speeding the machine
- Checking setting of various speed relays in governor
- Checking operation of machine without cooling water in guide bearing for half an hour.
- Checking speed rise and pressure rise at 75% and 100% sudden load rejection of individual generating unit and simultaneous 100% sudden load rejection from both units. .
- Checking shaft vibrations with contact less probe and bracket vibrations at bearing housings, throat ring and manhole of draft tube at various operating conditions.
- Tests for meeting performance guarantee.
- Operation of inlet valve and engagement of seal,
- Opening / closing time of inlet valve,
- Operation of level controllers in OLU for automatic operation of Pumps and signal for high oil level alarm,
- Calibration of instruments, switches and level controllers.

8.5 Tests to Meet Turbine Performance Guarantee

Turbine output and efficiency are guaranteed under penalty (Para 7.5). Turbine performance and efficiency testing is included in the turbines contract specification. Performance testing typically involves the measurement of head, power, and flows. Objective of three tests are as follows:

- a) Verify guarantees
- b) Obtain gate opening/head relationship
- c) Gate opening/blade tilt/head relationship for a Kaplan turbine
- d) Establish base link performance against which later tests be performed

Turbine output is determined from generator using high accuracy sub-standard instruments and instrument transformer for measuring losses in the field.

For small units field tests for losses are not generally made and factory measurements are considered adequate.

Field efficiency test requires measurement of net head, output, speed and water quantity with high accuracy. This requires expertise and requisite test instrumentation.

Bharat Heavy Electricals India Limited has facilities and expertise to carry out, these tests for all type of turbines. Head is measured using precision pressure transducers generator output using high accuracy power analyzer. Many methods suitable for different types of powerhouses have been used for flow measurement and requirement for acceptance results are detailed in IEC – 41 for turbines.

For small hydro up to 25 MW (SHP) Alternate Hydro Energy Centre (AHEC) of Indian Institute of Technology (IIT) Roorkee is equipped with requisite instrumentation and expertise for carrying out performance evaluation of SHP. Practice in India as regards efficiency tests SHP is as follows:

8.5.1 Flow Measurement

IEC-60041 recommends the following methods for measuring the discharge rate through the turbine under test:

- i) Pressure - time method (Gibson Method)
- ii) Propeller current meters
- iii) Acoustic method (ultrasonic method)
- iv) Tracer method
- v) Pilot tubes
- vi) Weirs
- vii) Standardized differential pressure devices
- viii) Volumetric gauging method

The method best suited to the given situation is selected for the measurement. As recommended by IEC-60041 and as far as possible, two methods are simultaneously used for cross verification and to have redundancy.

Pressure Time Method (Gibson Method): Pressure time method is based on the relationship between the force due to the change of pressure difference between two sections and the acceleration or deceleration of the mass of water between the sections due to closure of gate. A pressure-time graphical recording of pressure wave passage is obtained by gradually closing the gate in continuous movement and the change of pressure between two measuring cross-sections is integrated along time scale. Intermediate free surface is not allowed to exit between measurement sections. This was used for Bhakra Left Bank 90 MW Turbines testing in 1960.

Current Meter Method: Velocity area method uses a number of current meters placed at specific points in a suitable cross section of a penstock/flow channel. Suitable integration of velocity distribution over the area gives discharge.

This method was adopted for Bhakra Right Bank Turbines in 1967. Current meters were installed in a section of the penstock pipe.

Ultrasonic method: Based on the principle that propagation velocity of an ultrasonic wave and the flow velocity is summed vectorially. By measuring the times of transverse of pulses in two directions – upstream & downstream, the average velocity of fluid is determined.

Tracer Method: Tracer method of discharge measurement is based on dilution principle with constant rate of injection of a traceable dye into the flowing water and determination of the resultant concentration of the tracer at a point far enough downstream to ensure thorough mixing, relative to its initial concentration. HMDS uses fluorescent Rhodamine dye and a high precision Fluorometer for this method.

Thermodynamic Method: Based on principle on conservation of energy (first law of thermodynamics) the specific mechanical energy at the runner/impeller is determined by measurement of performance variables

(pressure, temperature, velocity & level). This method is suitable for specific hydraulic energy greater than 1000 j/kg (head>100m).

Index Testing: Index testing is carried out to ascertain the shape of efficiency curve of prototype by measurement of relative discharge by winter-kenedy index method. Discharge is indexed for one particular point and discharge at other point is calculated relative to this indexed point. These tests can be useful for determining correct relationship between runner/impeller blade angle and guide vane opening for the most efficient point of operation of double regulated machines thus reducing time required for acceptance tests and to provide additional tests data during field efficiency testing. Also it can provide change in efficiency due to onset of cavitation and also extend the information on performance outside the guaranteed range.

8.5.2 Field Efficiency test for SHP (Small Hydro up to 25 MW)

For SHP in India current meter and Acoustic methods are being used. Recently, horizontal beam and vertical beam acoustic Doppler current profiles (ADCPs) have also been used. This method is based on a very recent technology and not mentioned in IEC-60041. Index testing is used for relative efficiency measurements.

8.5.2.1 Acoustic Method

The ultrasonic transient time flow meter (UTTF) responds to average velocity of the fluid along the path of the ultrasonic beam, and works more satisfactorily in the absence of suspended particles and bubbles. Gradually, UTT flow meters are becoming popular and more acceptable under international standards for measuring water flow rate (or discharge) for turbine efficiency measurement. IEC-60041 does not accept UTTF as a primary method of discharge measurement for Turbine Efficiency Measurement (TEM), but allows its use subject to an agreement between the parties concerned. A new standard IEC-62006, which is the counterpart of IEC-60041 for small turbines (but still in draft stage) accepts this method as a primary method because of good experience with it world over and the technological improvements in the technique and instruments that have taken place.

8.5.2.2 Ultrasonic Doppler Flow Meter

This is also a new method being used in India though not recognized in IEC 60041. In this flow meter an ultrasonic wave is transmitted into the flowing liquid by a transducer acting as the transmitter. A part of the wave is reflected by bubbles or suspended particles in the liquid and is returned to the transducer. Thus the transducer acts as the receiver as well as transmitter. Since the reflecting particles/bubbles are traveling at the fluid velocity, the frequency of the reflected wave is shifted according to the Doppler principle. So the velocity of the reflector (which is also the point velocity of the fluid at that location), v is given by following equation:

$$v = \frac{\Delta f v}{2 f_0 \cos \theta}$$

Where,

Δf = difference between transmitted and received frequencies at the transducer

v = velocity

f_0 = frequency of sound in still liquid

θ = angle of transmitter/receiver crystal with respect to the direction of flow

Thus the point velocity is directly proportional to the frequency shift. The ultrasonic Doppler flow meter has a very special advantage over the UTTF that its repeatability is of the order of 0.01%. However, it should be noted that the principle can be and is used either for measuring the water velocity at a certain point in the water channel or conduit, or for determining the velocity profile, rather than the average velocity as is the case with UTTF. Point velocity meter is useful in laboratory research work only. Velocity profiles, on the other hand, are immensely useful in measuring discharge in the field by determining

velocity profile in the measuring section of open channels. Depending on the orientation of the acoustic beam, the velocity or current profilers are of two types:

- a) Horizontal-beam acoustic Doppler current profiler (ADCP)
- b) Vertical-beam acoustic Doppler current profiler (ADCP)

8.6 SHP Performance Test Case Study

Performance tests carried on a 1500 kW 2 jet Pelton turbine driven generating unit in India by Alternate Hydro energy Centre IIT Roorkee is summarized as follows:

Following performance tests were carried out

- i) Maximum power output test
- ii) Unit efficiency
- iii) Index test

Particulars of the unit

Generator rating	:	1500 kW, 0.8 pf, 50 Hz, 3.3 kV, Y
Cont. overload capacity	:	20% (1800 kW)
Rated speed of generator	:	750 rpm
Runaway speed	:	1410 rpm
Turbine particulars	:	Pelton, horizontal shaft, two jets
Rated head	:	290.4 m
Rated discharge	:	0.630 m ³ /s per unit
Altitude of station	:	1850 m
Latitude	:	32 ^o North

8.6.1 Maximum Power Output Test

8.6.1.1 Particulars of the Test

The objective of the test is to check if the machines are capable of delivering the maximum power specified by the manufacturer at rated speed and rated head. The machine under test is run continuously until the temperatures of its windings stabilize and there is no abnormal temperature rise. Prior to this test, the digital multi-function (DMF) meters on the panels had been checked against a reference meter and found to be accurate enough for measuring power. So power outputs of generators were read on these DMF meters.

8.6.1.2 Test Results

Generation of both the machines was adjusted to little above 1800 kW (actual readings were 1805 kW and 1809 kW, respectively). They were continued for long enough until temperature rise of windings of each machine was well within normal limits. It was therefore concluded that both the machines are capable of delivering power output of 120% of the rated value, i.e., 1800 kW.

8.6.2 Unit efficiency test

8.6.2.1 Particulars of the test

The objective of the test is determine the efficiency of the machine at rated speed and, as far as possible, at rated head at different loads. The two machines being identical and test provisions being available only on machine-1, the test was carried out only on this machine. The test was conducted on four loads, namely 60%, 80%, 100% and 110% of the rated value, (1500 kW). During the test on each load the needle positions of its two jets were maintained equal as far as possible. The parameters measured and measurement methods/instruments used were as under:

Electrical power output	:	Portable digital precision wattmeter
Discharge rate	:	Ultra Sonic Transient Time Meter (UTTTF) with clamp-on transducers
Location of UTTTF	:	Common penstock (straight section)
Machine speed	:	Digital speed indicator on panel
Water temperature	:	Thermocouple type thermometer

The efficiency at each load was calculated from the observations taken at regular intervals during each test run. Average values of observations were used in the calculations.

Electrical Power, P_e	=	Wattmeter reading x CT ratio x VT ratio	
	=	Wattmeter reading x 13500	
Altitude of station	=	1850 m	
Latitude of station	=	32° N	
	Hence, g	= 9.789 m/s^2	
Temp. of water	=	7° C	
Water head	=	3 MPa (approx.)	
	Hence, ρ	= 1001.3 kg/m^3	
Net Head, H	=	$p \times 1000/\rho + z + V^2/2g$	(1)
Height of PG above mean level of points of contact of water jets z	} =	0.253 m	
Pipe diameter	=	350 mm	
Velocity, V	=	$Q/\text{area of cross section}$	
$V^2/2g$	=	$5.52 Q^2$	
	Hence, H	= $9.987 p + 0.253 + 5.52 Q^2$	
Hydraulic Power, P_h	=	$\rho g H Q$	(2)
Unit efficiency	=	p_e/p_h	(3)

Test Results

The average observed values and results of calculations are tabulated below:

Sl. No.	Parameter	Unit	Load on Machine			
			60%	80%	100%	110%
1.	Machine speed	RPM	750	744	738	735
2.	Wattmeter reading	W	68.51	90.46	111.53	123.11
3.	Electrical output of Generator (P_e)	kW	924.89	1221.21	1505.66	1661.99
4.	UTTTF reading (Q)	m^3/s	0.38549	0.50641	0.62892	0.70095
5.	Pressure gauge reading	kg/cm^2	29.845	29.717	29.5557	29.456
6.	Net head (H) from equation (1)	M	299.136	298.453	297.622	297.144
7.	Hydraulic input to turbine (P_h) from equation (2)	kW	1130.28	1481.43	1834.69	2041.54
8.	Unit efficiency from equation (3)	%	81.83	82.43	82.07	81.41

8.6.2.2 Load Efficiency Curve

The load-efficiency curve for the machine as plotted from the above results is given in figure 8.1

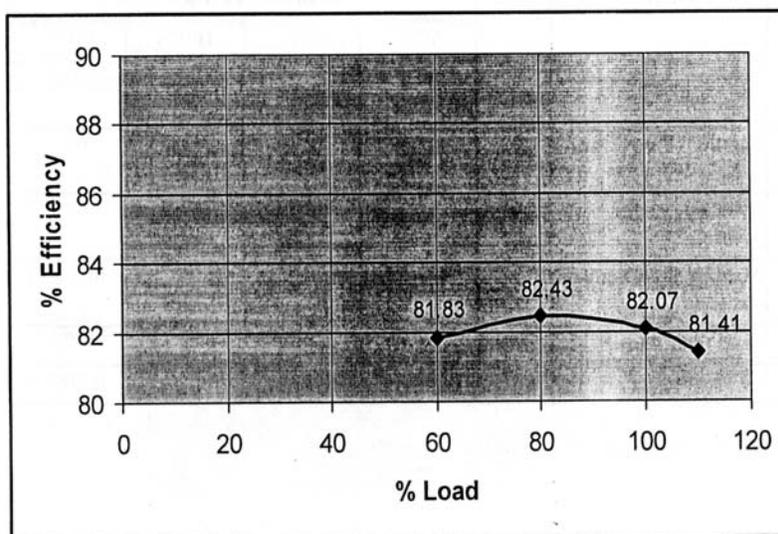


Figure 8.1
(Source: Alternate Hydro Energy Centre)

8.6.3 Index Test

8.6.3.1 Particulars

Following were the objectives of the index test:

- Relationship between average needle position and discharge rate through the turbine.
- Relationship between the head over thin-plate weir constructed in the tailrace channel and the discharge rate through it.

The test was conducted simultaneously with the unit efficiency test. Needle positions were read on the **needle position indicators** on the panel. The head over weir was measured with an **ultrasonic level sensor**.

8.6.3.2 Test Results

The test results are given in the table below:

Sl. No.	Parameter	Unit	Load on Machine – 1			
			60%	80%	100%	110%
1.	Needle 1 position	%	28.1	39.0	51.9	60.1
2.	Needle 2 position	%	28.7	39.7	52.8	61.1
3.	Average needle position	W	28.4	39.35	52.35	60.6
4.	Average level sensor reading	%	78.1590	79.1753	80.1518	80.5653
5.	Head over weir*	mm	264.0	312.3	358.7	378.5
6.	UTTTF reading	m ³ /s	0.38549	0.50641	0.62892	0.70095

*Calculations are shown in the following table.

Sl. No.	Load on machine (%)	Average reading of ULS (%)	Rise in level ⁽¹⁾ (%)	Head Over Weir ⁽²⁾ (mm)	Discharge rate measured by UTTTF (m ³ /s)
1.	60%	78.1590	5.5590	264.0	0.38549
2.	80%	79.1753	6.5753	312.3	0.50641
3.	100%	80.1518	7.5518	358.7	0.62892
4.	110%	80.5693	7.9693	378.5	0.70095

8.6.3.3 Curves

The two curves, discharge versus average needle position and discharge versus head over weir, plotted from the above test results are given in figure 8.2 & figure 8.3. These can be used by the O&M engineers for calculating discharge from either the average needle position or the head over weir.

8.7 Governor Testing

8.7.1 Performance and testing should be as per IEC 60308 – 2005 – Hydraulic turbine testing of control system.

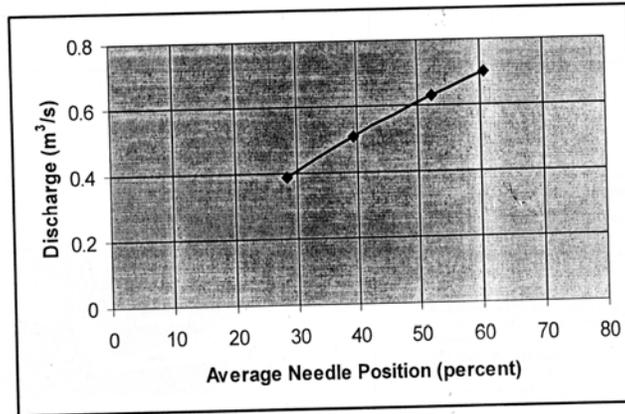


Figure 8.2
(Source: Alternate Hydro Energy Centre Report)

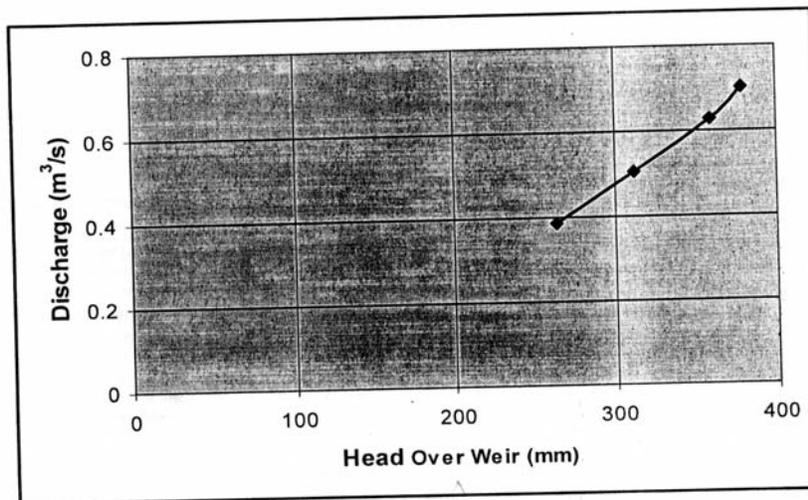


Figure 8.3
(Source: Alternate Hydro Energy Centre Report)

Following tests and inspection reports after tests should be provided by manufacturers of governor in accordance with IEC/IEEE standards.

- Factory acceptance tests
- Commissioning test
- Site acceptance test

8.7.2 Factory acceptance Tests (Performance)

Tests in accordance with IEC 60308 (1313) should be performed at governor manufacturers factory to demonstrate that governor performance meets the specified requirements e.g.

- i) Speed and blade dead band test
- ii) Dead time test

- iii) Speed droop test
- iv) Damping verification test (range of adjustment)
- v) Start/stop sequence test

Equipment Tests

- i) Transient immunity tests
Digital governor system should be tested for surge withstands capacity in accordance with IEC 60255
- ii) Electromagnetic interference
- iii) Radio interference
- iv) Seismic tests as specified

Field Acceptance Tests

- i) Control actuator timing
- v) Governor speed control damping test
- vi) Dead time test
- vii) Load rejection tests at 25%, 50%, 75% and 100% of rated generation.
- viii) IEEE std. 125 – 2007 specifies steady state stability tests to be performed as per stability criteria specified.

Control tests

- i) Speed reference range test
- ii) Gate limit control test
- iii) Manual control test
- Online set point response test
- On line simulated speed test
- Communication test

References

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2. IEC 41 : 1991, Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump-turbines.
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4. IEC 193A: 1972, First supplement to IEC 193 (1965).
5. IEC 308: 1970, International code for commissioning, operation and maintenance of hydraulic turbines.
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8. IEC 60994: 1991, Guide for field measurement of vibrations and pulsations in hydraulic machines (turbines, storage pumps and pump turbines).
9. Alternate Hydro Energy Centre IIT Roorkee Test – Lab Report
10. IEEE std. 125-2007 – IEEE recommended practice for preparation of equipment specification of hydraulic turbines intended to drive electric generators.
11. IEC 60308 – 2005 – Hydraulic turbine testing of control system.