

Micro Hydro Turbine Test Facility at the NERDC

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ABSTRACT

Many off-grid micro hydropower development programs have been carried-out in recent years in Sri Lanka. Micro hydro turbines are now manufactured locally and need to be improve the geometrical parameters to achieve higher efficiencies.

To improve the manufacturing quality, and hence to achieve better performances, it made as a requirement to check performance of micro hydro turbines for the Renewable Energy for Rural Economic Development Project in Sri Lanka.

To cater the above requirement, a Turbine Test Rig Facility have been developed and established by the NERD Centre of Sri Lanka. This facility is in compliance with IEC 60193/99. It has two test loops to test high and low head turbines, of up to 10 kW capacities.

The facility include under ground sump, pump system, water supply line, base for mounting of turbine, brake-dynamometer, measuring equipments and electrical control system.

The parameters that can be measured include; speed, inlet flow, torque and inlet head. These parameters can be used to evaluate hydraulic power and efficiency values for different loading conditions of the turbine. By varying the inlet pressure and flow, the maximum hydraulic power and optimum efficiency of the turbine could be evaluated. The trial operations of the test rig have been carried-out and already been tested few turbines at the NERD Centre.

Key words: *turbine test rig facility, maximum hydraulic power, and optimum efficiency*

1 INTRODUCTION

This project was initiated as an UNDP Renewable Energy and Energy Capacity Building Project, and funded by them. The turbine test rig was designed for performance testing of micro hydro turbines of proto type up to 10 kW capacity. In place of carrying-out the test in the field, model test can be used for capacities above 10 kW, as a basis for the acceptance of hydraulic turbine. The conditions at the site may do not allow carry-out to test to its full extent in accordance with general requirement of the International Field Test Code for Hydraulic Turbines. For this reason, it might be agreed between the manufacturer and user to substitute for the field test of a prototype turbine, a model test of a homologous model to determine the performance of the prototype.

The turbine test facility could be supplied with a water head and flow and it is included a break dynamometer. Water head, flow rate, rotational speed of turbine and delivered torque can be measured by standard measuring equipments.

2 OBJECTIVE

Main objective of this turbine test rig is to find out the performance of hydro turbines. Test rig facility can simulate the site condition and these results will be very important for taking prediction about real situation in the site. Presently this test rig facility undertakes performance testing of hydraulic machinery and to support local enterprises of any tasks directed towards the design and manufacturing of small hydro power plants.

A hydro turbine test rig facility was established in the NERD Centre and testing started in year 2006. Performance testing of a hydro turbine was made in compliance with the Standard IEC 60193. According to the standards turbine efficiency could be tested with accuracy of $\pm 2\%$

The following curves should be found out for the performance test.

- [1] Efficiency Vs speed or RPM
- [2] Efficiency Vs flow rate
- [3] Flow rate Vs guide vane angle
- [4] Power Vs guide vane angle or efficiency
- [5] Power Vs flow rate

The turbine test rig facility consists with two testing loops, to undertake testing of high head and low head turbines.

3 SPECIFICATIONS OF TURBINE TEST RIG FACILITY

3.1 Equipments

- Break dynamometer:- Maximum speed: 4000 RPM, Maximum torque: 157 Nm, Accuracy of torque measurements: ± 0.15 Nm, Accuracy of speed measurements: ± 4 RPM
- Orifice meter: – High head system: (100 PSI), Orifice plate: diameter 56.85 mm in ID 104.6 mm pipe (Accuracy $dQ = \pm 0.81$ liters/sec)
Low head system: (30 PSI), Orifice plate: diameter 187.7 mm in ID 314.3 mm pipe (Accuracy $dQ = \pm 1.2$ liters/sec)
- Pumps: - Hydro turbine test rig with 2 Nos. of high head pumps (70 m head, Flow rate: 22 l/s) and 2 No of low head high flow pumps (30 m head, flow rate 300 l/s)

3.2 Brake Dynamometer

The brake dynamometer consists of four major parts namely, compound wound DC motor mounted in a cradle, 4 quadrant digital DC drive, load cell and amplifier with control equipment.

The purpose of the dynamometer is to provide an accurately speed controlled motor or brake with the ability to measure the torque developed in the case of brake and the torque supplied in the case of a motor. To achieve this purpose, the DC motor is suspended in a free to rotate cradle, and a load cell is used to prevent the cradle from rotating. The DC motor is supplied from a digital DC drive which controls its speed. The load cell is calibrated in Nm, and the speed display in rpm, so the total power either delivered or absorbed can be calculated.

The 4-quadrant drive allows the motor to operate in either direction of rotation. When the system is operating as a motor, energy is transferred from the supply to the motor shaft. When the system is operating as a brake, energy transferred from the motor shaft to the supply mains.

A tacho-generator is fitted to the motor shaft to measure the motor speed to ensure it remains constant. The design of the DC machine used for the dynamometer is such that it can be used as either a motor or a generator. It is referred to as a motor only because it is more convenient. The quadrant drive decides on the basis of the applied torque to the motor shaft whether it is operating as a motor as a generator.

| | |
|---------------------------------|----------------------------------------------|
| Input AC supply: | 415V +/- 10 %, 3 phase +earth, 50 Hz, 4 wire |
| Maximum AC supply current: | 65 amps per phase continuous |
| Maximum armature current: | 71.4 amps continuous |
| Maximum motor speed: | 4000 rpm |
| Minimum motor speed | 0 rpm |
| Maximum measurable torque: | 157 Nm |
| Maximum ambient temperature: | 45 ⁰ C |
| Accuracy of torque measurement: | +/- 0.15 Nm |
| Accuracy of speed measurement: | +/- 4 rpm |
| Termination tightening torque: | for 110 A unit |

3.3 Orifice Meter

An orifice meter is a device which measures the rate of fluid flow. It uses the same principle as a Venturi nozzle, namely Bernoulli's principle which says that there is a relationship between the pressure of the fluid and the velocity of the fluid. When the velocity increases, the pressure decreases and vice versa.

An orifice plate is basically a thin plate with a hole in the middle. It is usually placed in a pipe in which fluid flows. As fluid flows through the pipe, it has a certain velocity and a certain pressure.

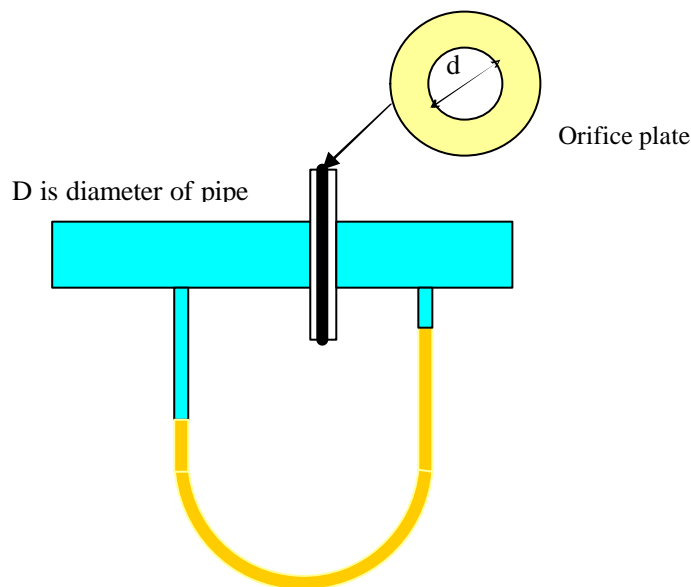


Fig 1: Configuration of Orifice meter

Flow rate calculation

$$Q = 0.01252 \frac{CZ_d^2}{\sqrt{1 - (d/D)^4}} \sqrt{\frac{h}{r}} \quad (1)$$

$$Q = \frac{CZ_d^2}{2563.645 \sqrt{1 - (d/D)^4}} \sqrt{h} \quad (2)$$

Where;

D Upstream pipe internal diameter (mm)

- d Orifice diameter (mm)
- h Pressure difference measured in mm H₂O (Water over mercury)
- ρ Density of water (kg/m³)

Table 1: Geometrical parameters of orifice meters

| Test loop | D (mm) | d (mm) | d/D |
|-----------|--------|--------|--------|
| Low head | 314.3 | 187.7 | 0.5971 |
| High head | 104.6 | 56.85 | 0.5435 |

C and Z_d are fixed constants for a particular orifice plate geometry. Z=Z_RZ_d depends weakly on the flow rate via Z_R. For accurate calculations Z_R should be determined from relevant Reynolds number.

Z_R = 1.005, then Z=1.00701

Table 2: Fixed constant of test loops

| Test loop | C | Z _d |
|-----------|--------|----------------|
| Low head | 0.6083 | 1.000 |
| High head | 0.6076 | 1.002 |

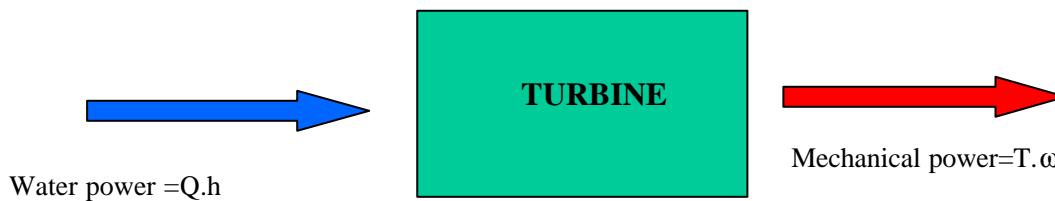
4 TESTING OF TURBINES

A small or model hydro turbine is mounted on the turbine test rig to test the performance. The water line should be connected to the inlet of turbine and turbine shaft is coupled with the brake-dynamometer. Inlet pressure is measured by using a pressure gauge and water flow rate is measured by the orifice meter. Output mechanical power of the turbine is measured by using the brake-dynamometer with the help of delivered torque by the turbine and rotational speed of Hydro turbine.

In this test, by varying the input pressure the maximum hydraulic power of the turbine is tested. For pelton turbines, tests will be conducted for each jet to measure hydraulic power of each jet.

The following parameters could be measured by using the measuring equipments in the test rig.

- Water pressure
- Water Flow rate
- Output torque
- Rotational speed of the turbine



5 TESTING OF MOTORS & GENERATORS

Break dynamometer can be used to test motors and regenerators. This system can be worked as a prime mover as well as a break dynamometer while input or output torque is being measured. Output or input power of generator or a motor was measured by using the brake-dynamometer with the help of delivered or absorbed torque by a generator or motor and rotational speed of a generator or motor.

6 ANALYSING OF TEST RESULTS

6.1 Calculation

The calculation of shaft power and efficiency of the turbine is as follows.

$$\text{Shaft power} = T \cdot \omega + \text{Bearing \& coupling loss} \quad (3)$$

T – Torque (Nm)

ω - Rotational speed (rad/s)

$$\text{Efficiency} = \frac{\text{Shaft power}}{\text{water power}} = \frac{T \cdot \omega + \text{Bearing \& coupling loss}}{P \cdot Q} \quad (4)$$

P – Water inlet pressure (N/m²)

Q - Water flow rate (m³/s)

6.2 Error calculation

The calculations of accuracies of the measuring instruments of the test facility are as follows.

$$h = \frac{\text{Shaft power}}{P \cdot Q} \quad \longrightarrow \quad \text{Efficiency of turbine} \quad (5)$$

To estimate the accuracy, [IEC60193-99] provides formula. Alternatively, the formula below can be used;

$$\frac{dh}{h} = \sqrt{\left(\frac{dT}{T}\right)^2 + \left(\frac{d\omega}{\omega}\right)^2 + \left(\frac{dP}{P}\right)^2 + \left(\frac{dQ}{Q}\right)^2} \quad (6)$$

Accuracies of the measuring instruments as follows;

- Accuracy of torque (dT) = ± 0.15 Nm
- Accuracy of speed (dω) = ± 0.41 rad./s
- Accuracy of flow (dQ) = ± 0.00081 m³/s
- Accuracy of pressure (dP) = ± 34.56 N/m²

7 TEST REPORT

The final report is prepared in draft form and submitted to the purchaser and supplier of the turbines, to obtain approval of both parties as to the details of calculation and the presentation of results. Any difference in viewpoint shall be resolved by both parties, with each having equal rights in determining the final form of the report.

8 RECOMMENDATIONS & DISCUSSION

The developed and established turbine test rig facility has two test loops namely high pressure and low pressure and ability to undertake up to 10 kW capacity of prototype or model.

Already, the existing test facility was used to test several pelton turbines and permanent magnet generators and issued to test certificated to the customers. The tested pelton turbines were made to supply electricity to rural villages which came under the Renewable Energy for Rural Economic Development Project (RERED).

Now, actions have been taken by the Centre to set up an additional test loop of 250 mm inside diameter with new high head pump of 55 kW capacity, to achieve head of 140 m and flow up to 22 litres/sec respectively. After development, the test loop, it can undertake testing of high head turbines up to 20 kW capacity.

It also expects to develop a software package, to monitor and record all measuring parameters of the test rig, in a control room.

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