*International Journal of Latest Trends in Engineering and Technology*
*Vol.(20)Issue(2), pp.001-006*
*DOI: http://dx.doi.org/10.21172/1.202.01*
*e-ISSN:2278-621X*

# PERFORMANCE ANALYSIS OF FRANCIS TURBINE TEST RIG

Aunshuman Chatterjee[1]

Abstract- **Water is the main driving force behind turbo machines and positive displacement pumps. To maximise the derived energy out of it, it is necessary to determine and analyse the input conditions such as head, gate opening and load in the existing environment. The strategy adopted during experiments on Francis turbine test rig is that the head is kept constant and the load is varied from 2Kg to 6Kg at 100%, 75%, 50% and 25% gate openings. The discharge varies with negative gradient for Francis turbine with respect to speed and the power varies sinusoidally. Centrifugal effects of the casing lead to lower discharge at higher speeds.**

**Keywords –Turbo machine, Discharge, Power, Load, Gate opening, Francis turbine**

## I. INTRODUCTION

Hydraulic turbine is one of the major source of power generation in modern era. The inception of turbines dates back to early nineteenth century with the advent of water wheels which is a machine for converting the energy of flowing or falling water into useful forms of power. Some of the key developments in hydropower technology happened in the first half of the ninteenth century. In 1849, British–American engineer James Francis developed the first modern water turbine the Francis turbine which remains the most widely-used water turbine in the world today[1]. In the 1870s, American inventor Lester Allan Pelton developed the Pelton wheel, an impulse water turbine, which he patented in 1880. Into the 20th century, Austrian professor Viktor Kaplan developed the Kaplan turbine in 1913 – a propeller-type turbine with adjustable blades[1]. These machines are widely categorized as the '**power generating turbomachines**'. These machines produce power by expanding fluid from high pressure to low pressure i.e by using energy of the incoming fluid (mainly water) to drive the rotating element which in turn drives the power generator.

Certain parameters such as pressure head, discharge of water, speed and output power influences the performance of the turbines. Model turbines are tested under different conditions of these parameters. Results are plotted in the form of curves and are known as '**performance characteristics curves**'. These curves depict the behaviour of their prototypes and the input parameters for their maximum efficiency can be gauged. The purpose of the performance characteristics or curves is to delineate useful information regarding performance of the turbine operating under different conditions [2].

In the current work, emphasis is given to the performance of a Francis turbine test rig under different fluctuating conditions of load and gate opening. The Francis turbine being a reaction turbine is expected to provide interesting results on power and efficiency. Discharge varies with the gate opening but due to the whirling component of the inlet water velocity, some residual loss is expected in the power output and discharge. The focus is on the variation of these aspects relative to the load.

[1]*Department of Mechanical Engineering, Girijananda Chowdhury Institute of Management and Technology, Guwahati, 781017 (Assam.), INDIA*

Unit quantities play an important role in comparing the performance characteristics as the quantities can be used to compare the parameters such as head, discharge , speed and power of the prototype with test rig.

## II. LITERATURE SURVEY

The turbine is a turbo-machine which extracts energy from a fluid by virtue of a rotating system of blades. The extraction of energy can be ***impulsive*** or a combination of ***impulse and reactive force***.
In the later type water is admitted under pressure at the entire periphery of the wheel through a set of guide vanes at a predetermined angle**[3].** The water under pressure enters the set of curved vanes at the outer periphery, in a tangential direction to the vanes and exits with reduced pressure and velocity at the inner circumference of the wheel[3]**.** While doing so the change in momentum and pressure causes a reaction force which in turn causes a torque at the axis of the wheel [3].

### II A. MAIN CHARACTERISTICS

Main characteristics are those that help in understanding the behaviour of a turbine towards selection of a turbine unit to meet specific requirements. Main characteristic curves are also known as *constant head characteristics***[3]**. They are drawn by:

- Conducting experiment at constant head.
- Head and gate openings are kept constant and speed is varied by varying load on the turbine.
- For each value of speed, corresponding values of power and discharge are obtained.

Some of the works are highlighted below:

- Maintaining gate opening and had constant, speed is regulated with varying quantity of water in a Francis turbine experimental set-up. Brake Horse Power (BHP) was measured and constant head characteristics curve and constant pressure characteristics curve were drawn. The head showed that unit discharge and unit speed are rising curves where the discharge increased with the increase in speed. The overall efficiency was also calculated at percentage full load. [4]
- A prototype and a model were defined to analyse the performance characteristics to affect the changes during different conditions. The dimensional ratio between a prototype turbine and its model is 1:2000. For various hrs of operation this prototype has been fixed. Different set of readings were taken and curves were plotted according to these readings. A theoretical model was defined to Analyse various performance characteristics. [5]
- A model of a two-bucket Savonius type hydraulic turbine was constructed and tested in a water tunnel to arrive at an optimum installation condition. Effects of two installation parameters, namely a distance between a rotor and a bottom wall of the tunnel, a rotation direction of the rotor, on the power performance were studied. A flow field around the rotor was examined visually to clarify influences of installation conditions on the flow field. The flow visualization showed differences of flow pattern around the rotor by the change of these parameters. [6]
- In this work different parameters have been used to spawn water, which contains potential energy. The water injected on blades of hydraulic turbines. The water energy effecting parameters (height, quantity of water etc.) has been examined by taking combination of parameters. The outcome obtained by theoretical calculations is identical to the experimental results.[7]
- A theoretical method of predicting PAT performance is developed using theoretical analysis and empirical correlation. In the next step, computational fluid dynamics (CFD) was adopted in the direct and reverse modes performance prediction of a single stage centrifugal pump. To give a more accurate CFD result, all domains within the PAT control volume were modelled and hexahedral structured mesh was generated during CFD simulation. Complete performance curves of its pump and turbine modes were acquired. Eventually, relatively accurate theoretical and numerical PAT performance prediction methods were developed. [8]

## III. RESEARCH METHODOLOGY

The Francis Turbine as shown in fig. 1 consists of spiral casing, an outer bearing pedestal and rotor assembly with runner shaft and brake drum, all mounted on a suitable sturdy cast iron base plate. A straight conical draft tube is provided for the purpose of regaining the kinetic energy from the exit water and also facilitating easy accessibility of the turbine due to its locating at higher level than the tailrace. A transparent hollow Perspex cylinder is provided in between the draught bend and the casing for the purpose of observation of flow at exit of runner. A rope brake arrangement is provided to load the turbine. Adjusting the guide vanes for which a hand wheel and a suitable link mechanism are provided can control the output of the turbine. The net supply head on the turbine is measured by a pressure and vacuum gauge.


Fig.1 Francis turbine test rig

TABLE 1. SPECIFICATIONS OF FRANCIS TURBINE TEST RIG

| | |
|---|---|
| **Pump:** | |
| • Type | Centrifugal high speed, single suction volute |
| • Power required | A.C. 5HP/3.7 Kw 3 Phase, 440 Volts. |
| • Dial gauge | 10 Kg. |
| **Runner:** | |
| • Runner diameter | 162 mm |
| • Nos. of Guide Vanes | 10 Nos. |
| • Head | 8-22.0 meter |
| • Speed | 2870-3100 rpm |

*Head measurement in the test rig (H):*

Head is the change in water levels between the hydro intake and the hydro discharge point. It is a vertical height measured in metres. The more the head, the higher the water pressure across the hydro turbine and the more power it will generate.

$$H = 10.33 \times [P_d + \{P_v/760\}] + 1 \text{ m of water} \text{ ----------- } (1)$$

where, $P_d$= Pressure gauge reading, kg/cm$^2$;

$P_v$ = Vacuum gauge reading (mm of Hg)

*Discharge measurement in the test rig (Q)*

$$Q = \frac{C_d a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}} \ m^3/s; \text{ ----------- } (2)$$

where, $h = 10.33x\,(P_1 - P_2)$
$C_d$ = co-efficient of venturimeter = 0.98;
$a_1$, $a_2$ = cross-sectional area at the inlet and throat of venturimeter = 0.00503 $m^2$ and 0.00126$m^2$ respectively;
$P_1$ and $P_2$ = Pressure gauge reading at the inlet and throat of the venturimeter respectively in kg/$cm^2$

*Power output of the test rig (P):*

$P=\{(w_1-w_2+w_3)Re2\pi Nx746\}/4500$-----------------*(3)*

$w_1$ = dead weight (kg);
$w_2$ = dial gauge reading (kg) =0.250 kg (in every case);
$w_3$= weight of the dial and rope= 0.740kg;
Re = Effective radius = 0.109m;
N= Speed of the runner shaft (rpm).

Strategy adopted for the experiments:

- The average value of head is taken as constant for a particular gate opening
- Corresponding to that gate opening, the speed, discharge and power are noted down for a particular load
- The speed, discharge and power are converted to their unit quantities

## IV. RESULTS AND DISCUSSION

Main characteristics curve are drawn by:

i. varying the speed at constant head and gate openings by varying the load on the turbine;
ii. for each values of speed, corresponding discharge and power is obtained

Fig 2. shows the variation of unit discharge with unit speed at constant head and gate opening at different gate openings.

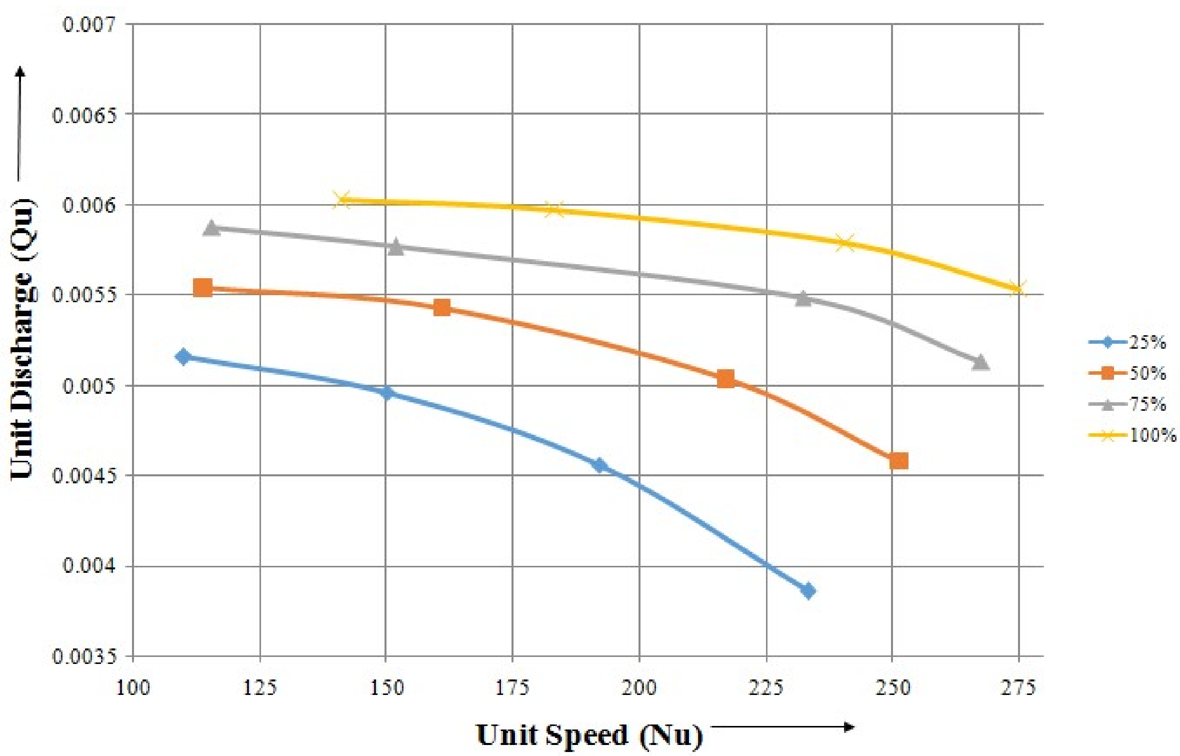


Fig. 2 Unit Speed Vs Unit discharge at constant head and gate opening

The following inferences can be drawn:

i. The lower speeds are almost equal which indicates that the energy output is equal at lower speeds irrespective of the discharge.

ii. For a particular gate opening, the discharge decreases with increase in speed. This can be attributed to the centrifugal effect of the turbine with a proportionately large volume of water adhering to the walls of the casing.

iii. With increase in gate opening, the discharge increases for a particular speed. This can be attributed to the fact that the casing of a Francis turbine being spiral in nature with the cross sectional area being reduced from inlet to outlet, the absolute of velocity of water is reduced at outlet. This causes a dip in the tangential component of velocity of water at outlet which is responsible for the rotation of the runner

Fig 3.shows the variation of unit power with unit speed at constant head and gate opening.

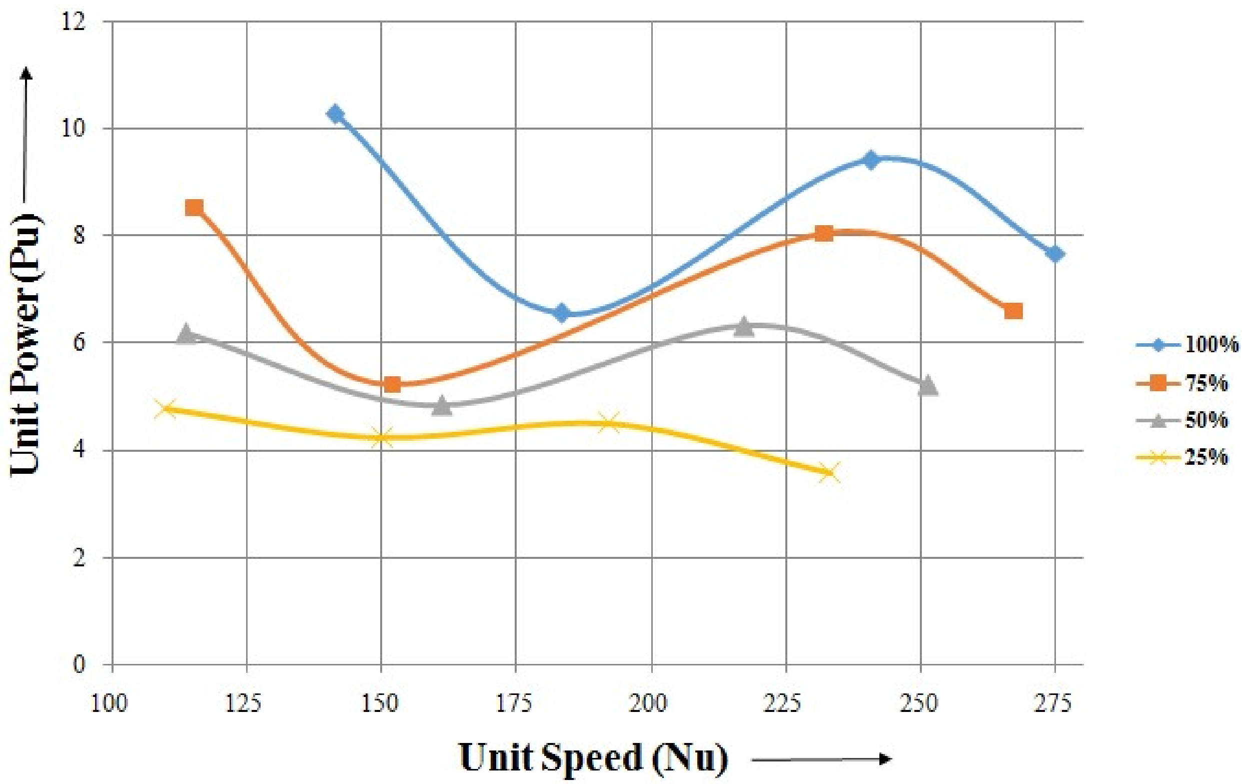


Fig. 3 Unit Speed Vs Unit power at constant head and gate opening

The following inferences can be drawn:

i. The power curves are parabolic in nature with peaks and valleys. The output power first increases with speed and then decreases. At higher speeds, the torque decreases due to inertial effect, producing lower power.

ii. The peaks and valleys attained deviates from smaller to larger gate openings towards higher speeds. Example- a peak attained between (200-225) $N_u$ at 50% gate opening appears between (225-250) $N_u$ at 75% gate opening. Thus the power curves *lags* at larger gate openings. The reason for this lag is due to the fact that at higher volumetric flow, eddy currents develop which offer resistance to the drive motion and hence the power output.

iii. The maximum power attained is higher at larger gate openings due to the fact that power is directly proportional to the product of discharge and head. With head being constant, power output increases as discharge increases.

## V. CONCLUSION

With increase in speed the discharge decreases for Francis turbine for a particular gate opening due centrifuging action and eddy losses. Larger rpm leads to lesser discharge rate of water as it has to overcome the resistance due to the external load. With increase in speed the power first increases and then decreases for Francis turbine. At maximum rpm, the turbine unit almost attains the runaway condition and thus the power becomes negligible. At high discharge, the whirl component is converted to the tangential component of velocity and thus leads to maximization of power.

## REFERENCES


[1] *International Hydropower Association*.

[2] D. K Mandal et al. "*Fluid Mechanics and Hydraulic Machines*",Vikash Publishing House 1995.

[3] K. Subramanya "Hydraulic Machines", McGrawHill Publication Núñez-Mata, O.; Palma-Behnke, R.; Valencia, F.; Jiménez-Estévez, P.M.G. Adaptive Protection System for Microgrids Based on a Robust Optimization Strategy. Energies 2018, 11, 308. [CrossRef]

[4] T. Teresa et.al "Experimental Analysis on Francis Turbine at Full Load to Determine the Performance Characteristics Curves", *International Journal of Mechanical Engineering and Technology (IJMET). Volume 9, Issue 2, February 2018,* pp. 663–669.

[5] Harikrishnan R et.al "Resolution for Parametric Discrepancies in The Flow of Francis Turbine". *International Journal of Mechanical Engineering and Technology*, *7(6), 2016,* pp. 31–40.

[6] Mitoshi Nakajima et.al "Performance of Savonius Rotor for Environmentally Friendly Hydraulic Turbine", *Journal of Fluid Science and Technology. Volume 3, No. 3, 2008*.

[7] R. K. Tyagi et.al "Hydraulic Turbines and Effect of Different Parameters on output Power", *European Journal of Applied Engineering and Scientific Research, 2012, 1 (4):179-184.*

[8] Sun-Sheng Yang et.al "Theoretical, numerical and experimental prediction of pump as turbine performance"/ *Renewable Energy 48 (2012)* pp. 507-513.