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Performance Analysis for an Impulse Turbine – A Case Study

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ABSTRACT
Performance test on a model of a Pelton turbine has been carried out in the laboratory for various gate opening of the turbine. The parameters have been expressed in the term of unit quantities. The result show that the peak efficiency lies between 70% and 90% of the full load. The maximum efficiency and power obtained at Nu =135, whereas maximum efficiency obtained is 66% at 90% wicket gate opening, Predicted result based on the modal study for a prototype obtained is within the specified limit.
Keywords*: Hydraulic turbine, Pelton Turbine, Model, Unit Quantities, Muschel curve.*

Nomenclature

H	Head of the turbine Area ratio	N	Rotational speed of the turbine
Q	Discharge of the turbine	N_s	Non-dimensional specific speed of the turbine
P	Power of the turbine	N_{sp}	Specific speed of the turbine
u	Unit quantities		

I. INTRODUCTION

Pelton Wheel Turbine is an impulse or a constant pressure water turbine. In this case water head is very high. The Pelton turbine operates under very high heads and requires low flow rate. It is employed in the high head (above 300m) under low discharge (1000 m^3/s) in hydel power plants [1]. Pelton wheel consists of a wheel called rotor. The rotor of the turbine consists of a circular disc with a number of double spoon shaped buckets evenly distributed over the periphery. The water is the supplied from the reservoir. In such type of Turbine available hydraulic energy of the water is converted into the kinetic energy at atmospheric pressure by means of the nozzle. Each nozzle directs the jet along a tangent to the circle through the centers of the buckets. Each bucket consists of a splitter which divides the incoming jet in to two equal portions and after flowing round the smooth inner surface of the bucket the water leaves with a relative velocity almost opposite in direction to the original jet. The change in momentum of the water jet in passing over the buckets exerts tangential force on the wheel causing it to rotate. Thus, converts the hydraulic energy into the mechanical energy by means of the shaft rotation. Pelton wheels are made in all sizes. There exist multi-ton Pelton wheels mounted on vertical oil pad bearings in hydroelectric plants. The largest units can be up to 200 megawatts. The smallest Pelton wheels are only a few inches across, and can be used to tap power from mountain streams having flows of a few gallons per minute. Some of these systems utilize household plumbing fixtures for water delivery. These small units are recommended for use with thirty meters or more of head, in order to generate significant power levels. Depending on water flow and design, Pelton wheels operate best with heads from 15 meters to 1,800 meters, although there is no theoretical limit.[2]. Typically overall efficiencies for these turbines can vary from 50 to 70 % with higher overall efficiencies occurring in high head systems[3]. Various authors and researchers investigated the performance of Pelton turbine changing different geometrical parameters like development of auxiliary Pelton wheel where pressure energy can be transmitted to kinetic energy of Pelton wheel [4].

Modal studies have been also reported in literature [2-9, 11]. However, during recent times, no such work was carried out with models as well as prototypes. Further, prediction of the performance of the prototype based on the results of model studies is also not available in current literature. Hence, the motivation of the present study. In the present study, Pelton turbine, capable of delivering 3.75 kW of power output at rated condition has been studied at various running conditions and based on the data collected, a number of characteristic & performance curves of such a turbine have been plotted. Moreover, an attempt was made to premier the performance of a larger turbine, which is geometrically, kinematically and dynamically similar to the said model.

II. MATERIALS AND METHODS

The schematic diagram of the experimental set up used for the present study is shown in Fig. 1. The test has been carried out at Fluid Mechanics & Machinery lab. in Department of Mechanical Engineering, Durgapur Institute of Advanced Technology and Management, Durgapur. The test rig has been developed and supplied by M/s. Technical Teaching (D) Equipment, Bangolore, India. The specifications of the said turbine [10] are given below:

Rated supply head	: 15.0 m.
Discharge	: 2000 1pm.
Normal speed	: 1000 rpm.
Power output	: 3.75 kW.
Specific speed	: 5.5 rpm.
Runaway speed	: 2000 rpm.
Runner diameter	: 160 mm.
No. of bucket	: 18
No. of Jet	: 1
Unit speed	: 51.5

The test rig mainly consists of a Pelton turbine, a mono-block pump set (rated head + 20m. & discharge = 2000 lpm.) to supply water to turbine, a calibrated venturimeter (area ratio = 0.45, throat diameter + 66 mm, inlet cone angle + 200, diverging cone angle =100) to measure the discharge of the pump, pressure gauges, piping system and a suction sump. The head developed by the pump is used as the operating head of the turbine whereas, the measured load supplied to the rope brake arrangement is treated as the load to the turbine.

The Pelton turbine unit essentially consists of an outer bearing pedestal and rotor assembly with wheel with buckets and a nozzle, a shaft (of stainless steel) and brake drum (of polished C.1) with cooling arrangements, all mounted on a suitable sturdy C.1 base plate. The adjoining of the spear arrangement is made with the help of a hand wheel and a suitable mechanism. The net supply head on the turbine is measured buy a pressure gauge fitted at the inlet of the runner whereas; shaft speed was recorded with a digital tachometer.

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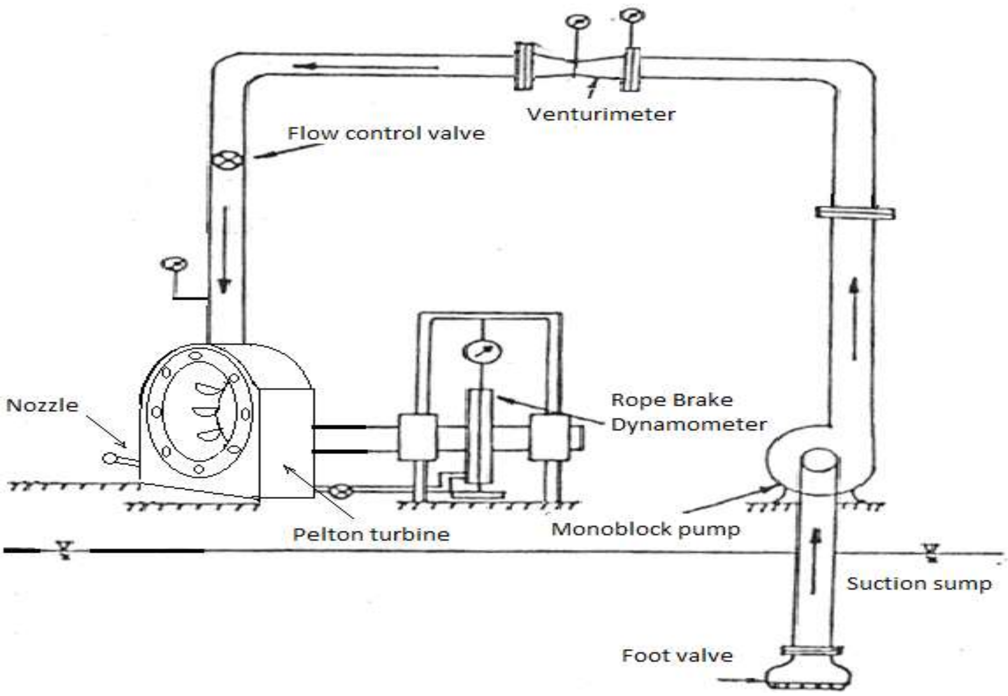

FIGURE 1. Schematic diagram of the experimental test rig of Pelton turbine

Important Formulae Used

Knowing the discharge (from venturimeter reading) and head applied to the turbine, the input power to the turbine is calculated whereas, the output is obtained knowing the rotational speed of the turbine shaft and torque produced.

The performance / characteristic curves of the turbine at various wicket gate openings have been plotted in terms of unit quantities. The unit quantities, according to the definition are as follows:-

Unit speed, $N_u = \frac{N}{\sqrt{H}}$

Unit discharge, $Q_u = \frac{Q}{\sqrt{H}}$

Unit Power, $P_u = \frac{P}{H^{3/2}}$

Non-dimensional specific speed.

$$Ns = \frac{N\sqrt{P}}{\sqrt{p}(gH)^{5/4}}$$

And specific speed, $N_{sp} = \frac{N\sqrt{P}}{H^{5/4}}$

Further, according to Sayers [4], $N_{sp} = N_s X 187$

III. RESULTS AND DISCUSSIONS

Experimental results obtained on five wicket gate openings of the Pelton turbine are discussed in the following paragraphs: Fig.2 shows the variation of unit discharge (Q_u) with N_u. The figure depicts that the discharge increases with the gate opening. The phenomenon is similar as expected. However, there is no variation of the slope of the curves with N_u. Variation of unit power with N_u has been plotted in Fig. 3. The figure indicates that the unique maximum value of P_u exists at N_u = 135 for all the openings of the wicket gates. Further, maximum value of Pu has been obtained at 50% opening of the wicket gate.

Efficiency variation with N_u for the tested model at various wicket gate openings is produced in Fig. 4. The figure illustrates that the maximum efficiency for all the wicket gate openings exists at $N_{u\,=}$ 155 and attains maximum efficiency of about 66% for 90% opening of wicket gate. However, the maximum values lies between 56% and 65% for various openings of wicket gates.

Variation of efficiency with % of full load is shown in Fig. 5. It depicts that the peak efficiency shifts a little towards the right side as the wicket gate opening increases. It is obvious that the output power developed by the machine increases with the increased amount of discharge and hence the wicket gate opening. However, the peak efficiency point lies between 62 to 78% of the full load of the turbine. Based on the previously discussed performance parameters, constant efficiency curves, known as Muschel curves for the present Pelton turbine has been drawn and presented in Fig. 6. It indicates wide variation of iso-efficiencies for the tested model, ranging from 45% to 75%. However, to achieve the highest efficiency, the wicket gate opening should be within 50% and 90%. Further based on the result obtained, the performance of a prototype of larger size has been attempted to predict (efficiency, output power, etc.) using various empirical formulae but the figures are not presented here due to limited space.

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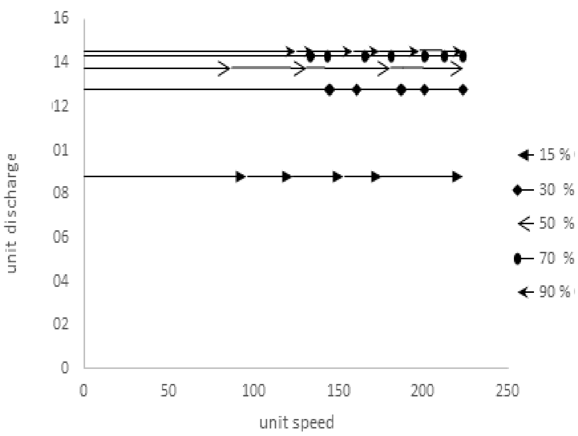

FIGURE 2. Variation of unit discharge (Q_u) with unit speed (N_u) at various wicket gate opening

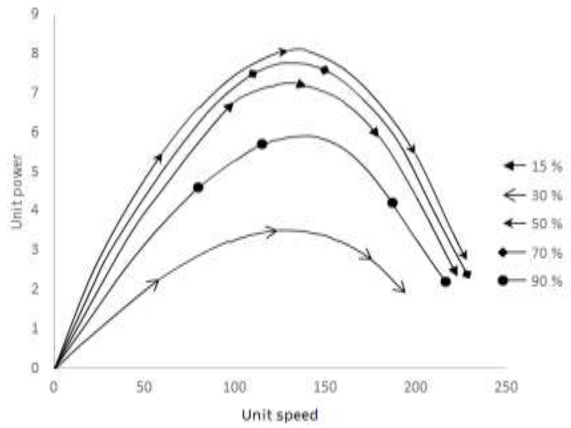

FIGURE 3. Variation of unit power (P_u) with unit speed (N_u) at various wicket gate opening

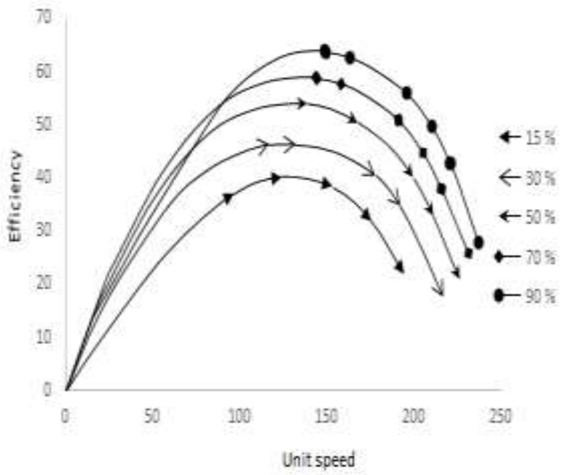

FIGURE 4. Variation of efficiency (η) with unit speed (N_u) at various wicket gate opening

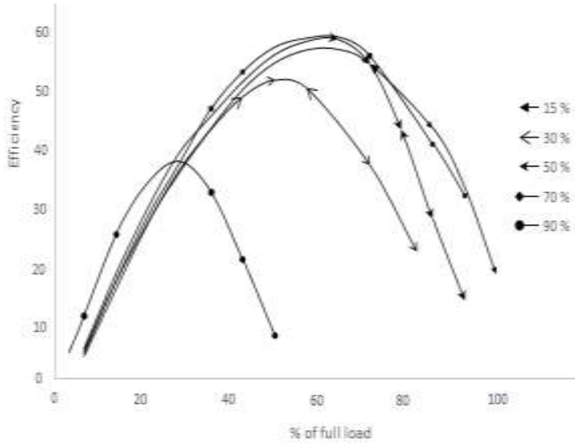

FIGURE 5. Variation of efficiency (η) with % of full load at various wicket gate opening

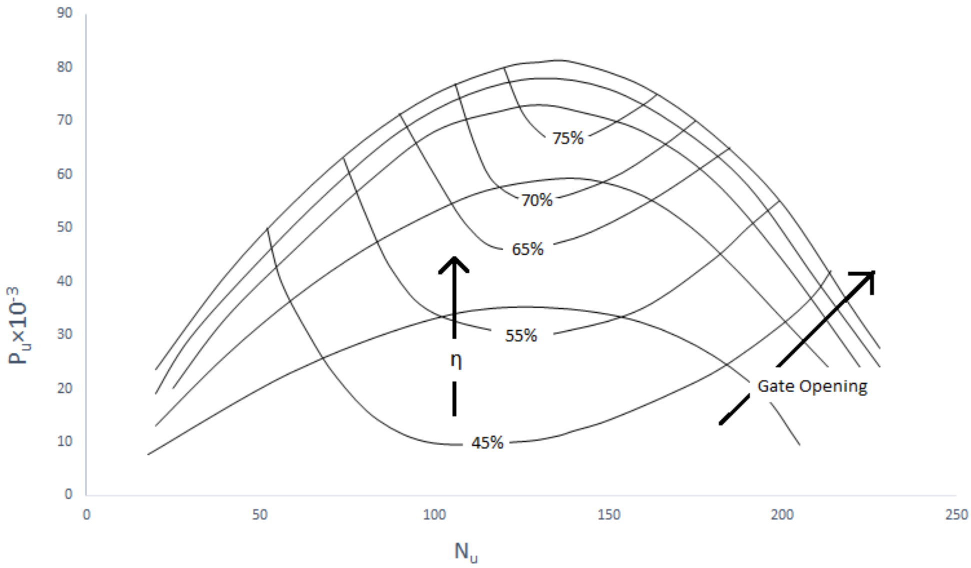

FIGURE 6. Muschel curve

IV. CONCLUSION

Based on the present investigation the following conclusions are made:-

1. Maximum efficiency of the present Pelton turbine at various wicket gate openings lies between 70% - 90% of full load.
2. No appreciable change in unit discharge for N_u .
3. Maximum unit power the machine can develop at Nu = 135. For all the wicket gate openings.
4. Maximum efficiency of the machine is around 66% at 90% opening of wicket gate.

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