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Performance Analysis For Reaction Turbine – A Case Study

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Abstract.
Performance test on a model of a Francis 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 76% and 88% of the full load. The maximum efficiency and power obtained at Nu =362, whereas maximum efficiency obtained is 74% at 95% wicket gate opening, Predicted result based on the modal study for a prototype obtained is within the specified limit.
Keywords: Hydraulic turbine, Francis 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

Modern Francis turbine is an inward mixed flow reaction turbine i.e. the water under pressure enters the runner from the guide vanes towards the center in radial direction and discharged out of the runner axially. The Francis turbine opetes under medium heads and requires medium quantity of water. It is employed in the medium head (30 to 450 m) hydel power plants [1]. Unlike the impulse turbine, the Francis turbine operates with its wheel submerged in water. The water, before entering the turbine, has pressure as well as kinetic energy. All pressure energy is not transformed into kinetic energy as in case of impulse turbine. Only 60% of the potential energy is converted into kinetic energy in the runner. The remaining 40% go as waste [12]. The water leaving the turbine has still some of the pressure as well as kinetic energy. A draft tube of an increasing cross-sectional area is normally installed at the exit of runner. It helps in converting the kinetic energy of the water at the runner exit into useful pressure energy which otherwise have gone waste as exit losses. This increases the efficiency of turbine also. The details of draft tube design have been reported in [13, 14. 15]. A casing is also essential for this turbine. Various authors and researchers investigated the performance of Francis turbine changing different geometrical parameters. 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, Francis 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	:	1250rpm.
Power output	:	3.75 kW.
Specific speed	:	05.5 rpm.
Runaway speed	:	2250 rpm.
Runner diameter	:	160 mm.
No. of guide vanes	:	10
Unit speed	:	51.5 rpm.

The test rig mainly consists of a Francis turbine, a mono-block pump set (rated head + 20m. & discharge = 2000lpm.) 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 roap – brake arrangement is treated as the load to the turbine.

The Francis turbine unit essentially consists of a spiral casing (of closed grained C.1), an outer bearing pedestal and rotor assembly with runner (of bronze), 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. A straight conical draft tube is provided at the exit of the runner for recovering the kinetic energy from the exit water. The adjoining of the grade vanes are made with the help of a hand wheel and a suitable link mechanism. The net supply head on the turbine is measured buy a pressure and vacuum gauge fitted at the inlet and exit of the runner whereas; shaft speed was recorded with a digital tachometer.
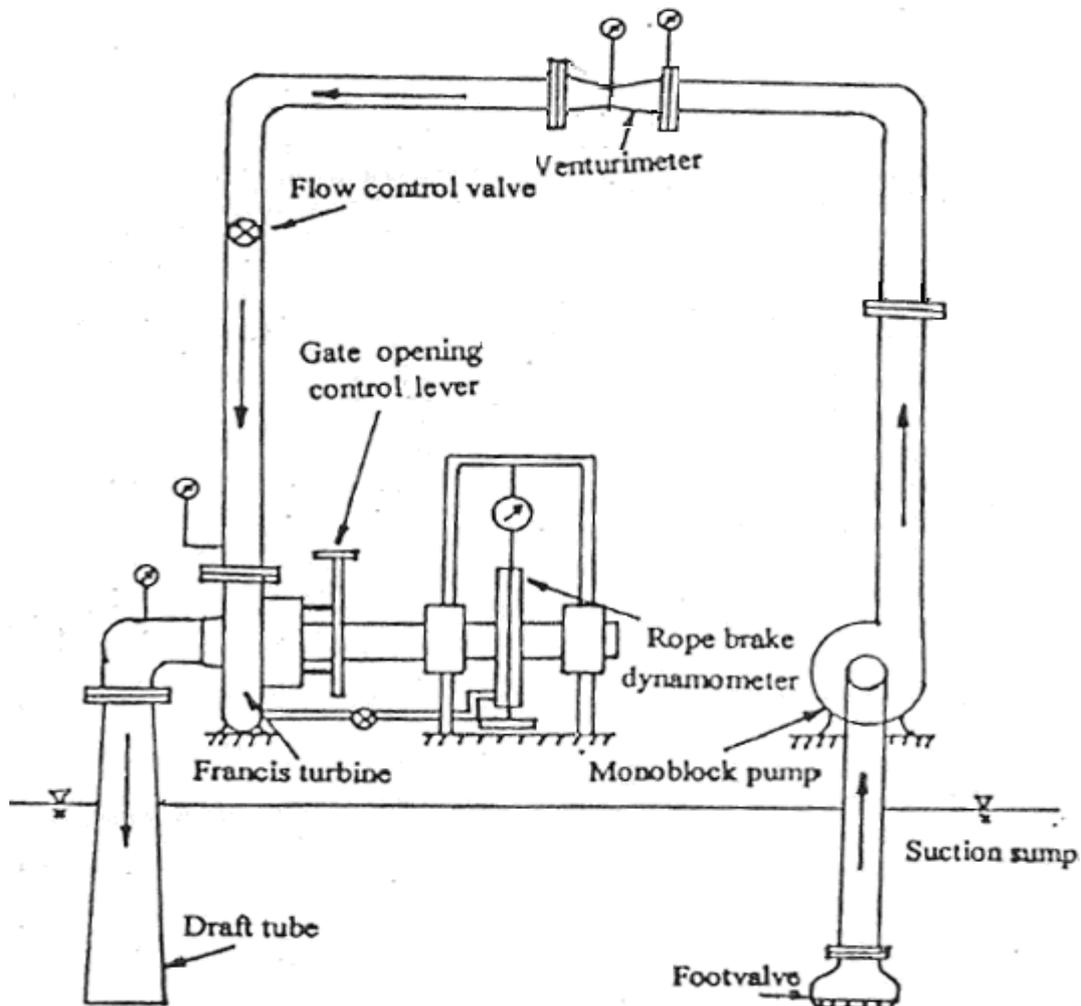

FIGURE 1. Schematic diagram of the experimental test rig of Francis turbine

III. 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, $N_u = \dfrac{N}{\sqrt{H}}$

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

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

Non-dimensional specific speed.

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

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

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

Obtaining the performance parameters as described above, an attempt was made to predict the performance of a prototype by using Dub-Moody's empirical formula [1] and others. However, the predicted performance of the prototype is not included in the presented here.

IV. Results and discussions

Experimental results obtained on five wicket gate openings of the Francis 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 and with the decrease in N_u. The phenomenon is similar as expected. However, the variation of the slope of the curves below 200 of N_u is marginal. It indicates slight variation in discharge upto N_u= 200 at a particular wicket gate opening.

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 $N_u = 362$ for all the openings of the wicket gates. Further, maximum value of Pu Has been obtained at 95% opening of the wicket gate though there is marginal change in P_u For 50% and 75% opening of the wicket gates.

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 $N_{u =} 400$ and attains maximum efficiency of about 74% for 95% opening of wicket gate. However, the maximum values lies between 58% and 73% 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 76 to 88% of the full load of the turbine.

Based on the previously discussed performance parameters, constant efficiency curves, known as Muschel curves for the present Francis turbine has been drawn and presented in Fig. 6. It indicates wide variation of iso-efficiencies for the tested model, ranging from 45% to 73%. However, to achieve the highest efficiency, the wicket gate opening should be within 50% and 95%.

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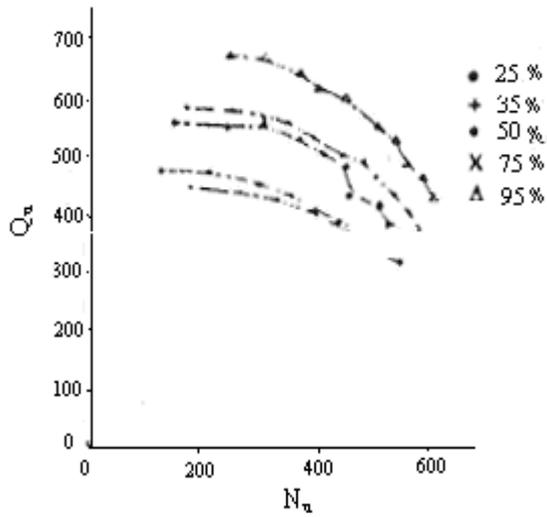
FIGURE 2. Variation of unit discharge (Q_u)
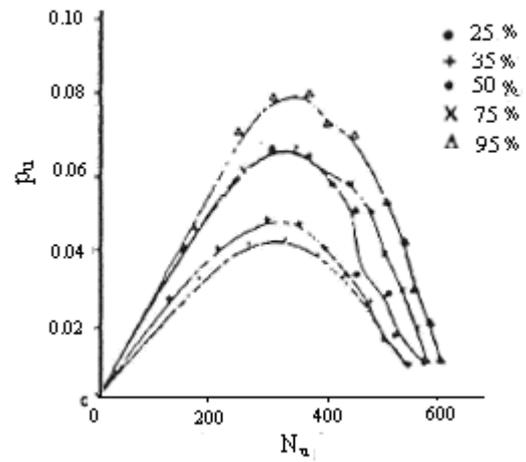with unit speed (N_u)
at various wicket gate opening

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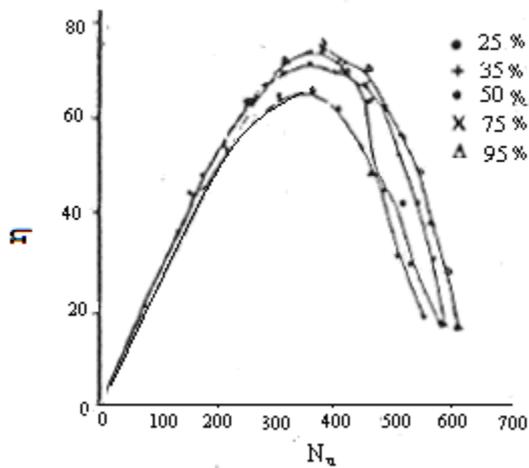with unit speed (N_u)
at various wicket gate opening

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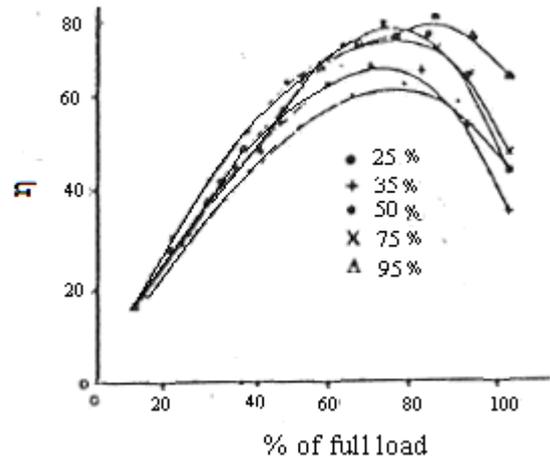at various wicket gate opening

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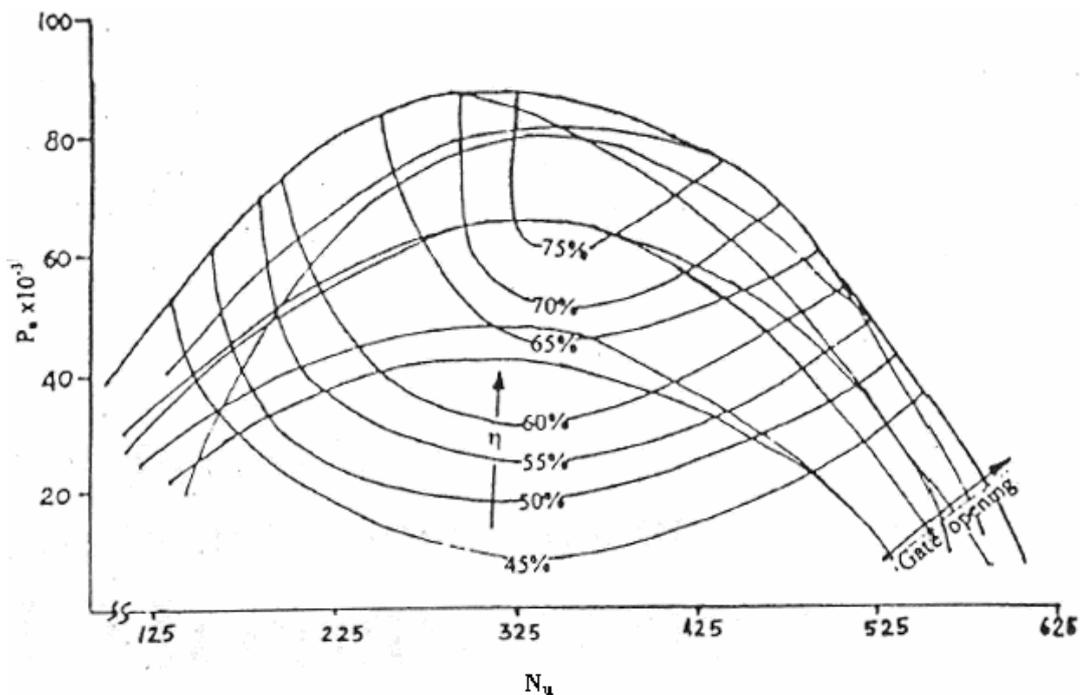at various wicket gate opening

FIGURE 6. Muschel curve

V.   Conclusion

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

1. Maximum efficiency of the present Francis turbine at various wicket gate openings lies between 76% - 88% of full load.
2. No appreciable change in unit discharge for N_u <200.
3. Maximum unit power the machine can develop at Nu = 362. For all the wicket gate openings.
4. Maximum efficiency of the machine is around 74% at 95% opening of wicket gate.

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