

EXPERIMENTAL EVALUATION OF A FRANCIS TURBINE

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Abstract

Laboratory-Scale Francis Turbine has been used to generate experimental data for performance evaluation. The analysis presented here is based on turbine shaft load resulting in utilization of water power and includes overall efficiency, specific speed, unit quantities and critical cavitation factor. A modified critical cavitation factor relation has been obtained and verified with the existing relation.

Keywords: Hydro Power, Francis Turbine, Turbine Performance, Cavitation Factor

1. INTRODUCTION

Hydro-power means generation of mechanical power from falling water. The power, subsequently can be used for direct mechanical applications or for generating electricity.

Hydro-electricity was developed in the last century by putting massive barriers across rivers (1, 2). It created reliable power supply but gave rise to a number of environmental problems. Therefore now focus on small scale hydropower plants, without infringing the river flows. These small scale plants are "run-of-river", an ancient approach for using waterwheels.

Hydropower plants are classified as (2), Large Hydropower plants have capacity more than 25 MW capacity, Small Hydropower plants (SHPPs) have capacity between 25 MW & 2.5 MW and Micro Hydropower plants (MHPPs) have capacity below 500 KW.

Hydropower plants of all the sizes are renewable power sources and provide 19% of total power requirement world-wide (1). Conversion of water energy into mechanical energy, in these plants is through the prime mover known as hydro turbine (14).

2.1 Hydraulic Turbines

Hydropower started with the wooden waterwheel and was used for milling grains about 2000 years ago. Benoît Fournayron developed first hydraulic turbine in France in 1820s.

According to action of water on the moving blades, hydraulic turbines are classified as impulse and reaction turbines (3, 13). In impulse turbines all the water energy is converted into kinetic energy and this high speed water jet enters into turbine at atmospheric pressure, so turbine is not pressure tight. Where as in a reaction turbine entering water jet has kinetic as well as pressure energy before entering turbine impeller, therefore turbine is pressure tight. Pelton

turbine is impulse type, whereas Francis, Kaplan and Propeller turbines are reaction type.

Francis Turbine is a mixed flow reaction turbine was developed in 1848 and is named after J.B. Francis an American engineer. These turbines are in use in India in hydro plants located at Bhakra, Siva Samudaram, Ganghi Sagar, Hirakud and Rihand (4).

2.2 Basics of a Francis turbine (1)

The power available from an effective head (H) is given by (3);

$P = WH$ where W is the weight of water flowing through the system per second.

Power output is the shaft power measured with the help of a dynamometer and is given by

$$SP = \frac{2\pi NT}{60}$$

Where N is the shaft revolution per minute and T is the torque applied on shaft as load.

$T = \text{load} \times \text{drum radius.}$

$$\text{Overall Efficiency, } \eta_o = \frac{SP}{P} \times 100$$

Specific speed is a criteria for selection of type of turbine and is given by

$$N_s = \frac{N \cdot P^{\frac{1}{2}}}{H^{\frac{5}{4}}}$$

Unit quantities (Power, Discharge and Speed) are useful for predicting off-design performance of a turbine and following are their expressions.

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

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

$$\text{Unit Power, } P_u = \frac{P}{\sqrt{H^3}}$$

2.3 Cavitation Performance

Cavitation flow is associated with drop in local pressure, below vapour pressure and results in drop in efficiency, vibration and damage to various parts of the turbine (1). Based on operating conditions, cavitation flow can occur at different locations. Accordingly it is classified as given in the following table (5).

Table: Types of cavitation flow

S. No.	Type of cavitation	Location
1.	Leading edge cavitation	Suction side of runner
2.	Draft tube swirl cavitation	Outlet of runner
3.	Inter-blade Vortex cavitation	Between the blade
4.	Travelling bubble	Runner blade
5.	Trailing edge cavitation	Trailing edge of the blade

Critical cavitation factor (3) is related to the specific speed of Francis turbine by the following relation

$$S_c = 341.(N_s)^2.10^{-8}$$

Thoma's cavitation factor is based on the layout of turbine and ambient conditions and it is given by

$$S = (H_{atm} - H_v - H_s) / H$$

Where,

H_{atm} is Atmospheric pressure head

H_v is Vapour pressure head

H_s is the suction pressure head

H is the net head on the turbine

If $S > S_c$ then chances of cavitation are not there.

3. LITERATURE REVIEW

Turbines are generally operated over a wide range of operating conditions due to fluctuating power demand. That is they are operated far away from the best efficiency point (6, 12). There are three approaches viz practical, modeling and simulation. Modeling of hydraulic plants have been done (7) for linear and non-linear systems by using transfer function approach. Simulation has been done by using (8, 11) CFD on commercial packages such as ANSYS/ CFX. These

approaches require validation using practical or experimental data. Mathematical modeling of the type such as hydraulic transmission and actuation system (9, 10) enables to simulate performance by varying various hydraulic parameters such as length, diameter and geometry, which is not possible in the context of a prime mover.

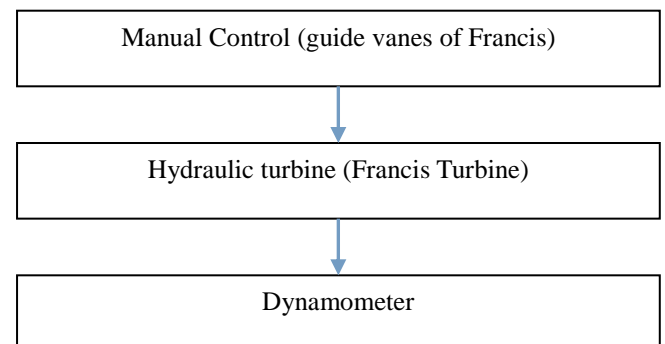
4. PRESENT WORK

In the present work, Francis turbine model has been used and laboratory experimental data has been analysed. Based on water power utilised against the shaft power demand and variation of performance and critical cavitation factor have been analysed.

4.1 Experimental Set Up and Data

Water head is created by running the Centrifugal pump. Flow rate was measured by differential pressure across an orifice. Pressure head is measured by using a pressure gauge at inlet. Speed was measured by a Tachometer. Brake power was computed by using simple dynamometer using pulley, rope, weight and spring balance. Manual governing was done.

4.2 Schematic of a Francis Turbine in a Block Diagram



4.2 Turbine Design Details

Francis Turbine has rated supply head 15 M, discharge: 1500 lpm, speed: 1500, power output: 3.75 KW, Runner inner/ outer diameter: 127/ 160 mm, number of vanes: 8, guide vanes: 10.

4.3 Methodology

Following methodology has been used for performance assessment of the turbine.

Centrifugal pump is started to generate pressure head. Then speed of turbine is set by manually guide vanes. Then resisting torque is applied through pulley of Dynamometer. Then speed of turbine gets reduced due to load. Again water power is increased by manual adjustment by bringing back to same speed of turbine.

DISCUSSIONS OF ANALYSIS

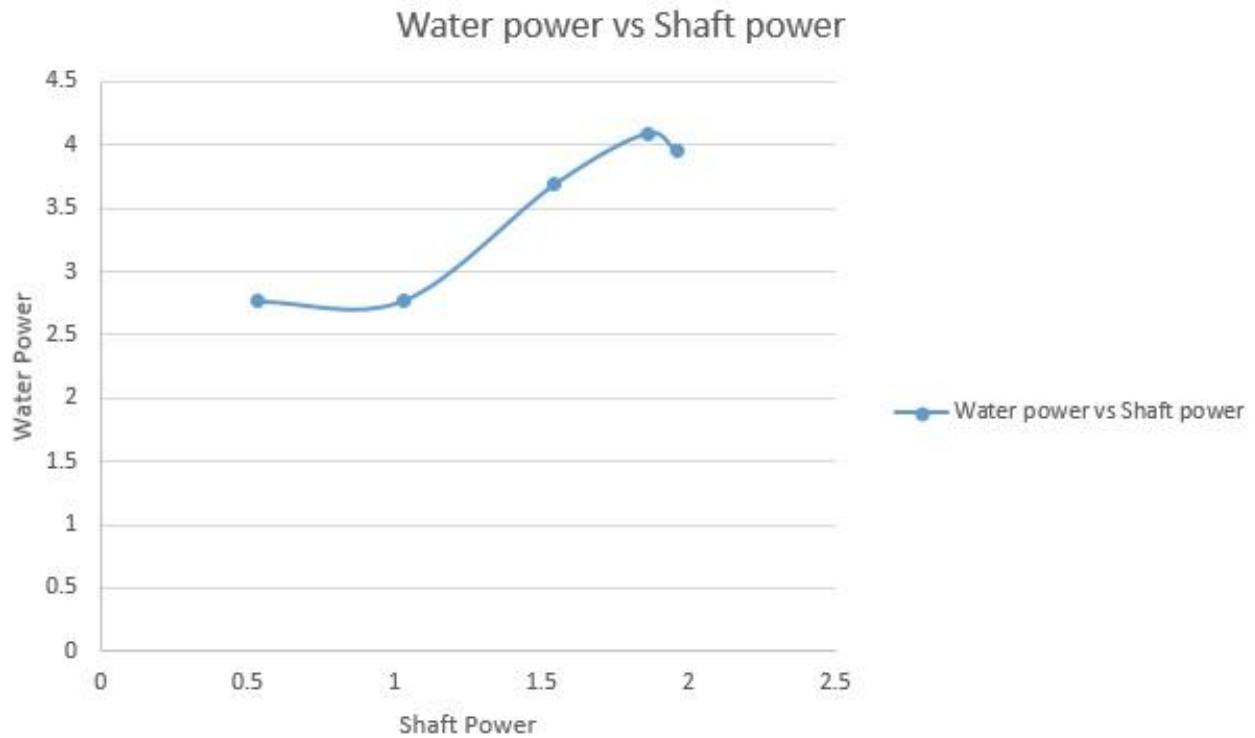


Figure 1 Water power vs Shaft power

Figure 1 shows the variation of shaft power demanded as ratio of rated capacity (3.75 Kw) vs water power utilized also as ratio of rated capacity. Initially up to shaft power demand of 0.5, water power utilized is 2.7 and there is no appreciable increase up to shaft power requirement of 1.

Afterwards there is a continuous increase up to a shaft power requirement of +2 and then there is slight reduction in utilization of water power.

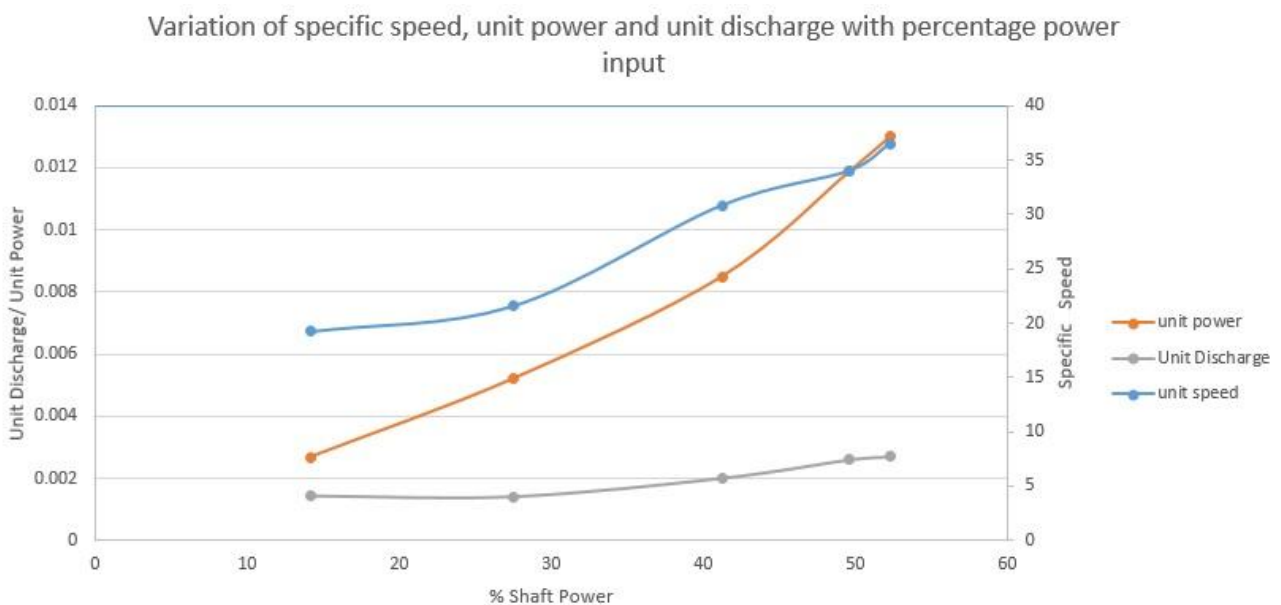


Figure 2. Unit quantities vs Shaft power

Figure 2 is the variation of unit quantities with % requirement of shaft power.

All the unit quantities increase with increase in shaft power requirement. Unit power has steep increase.

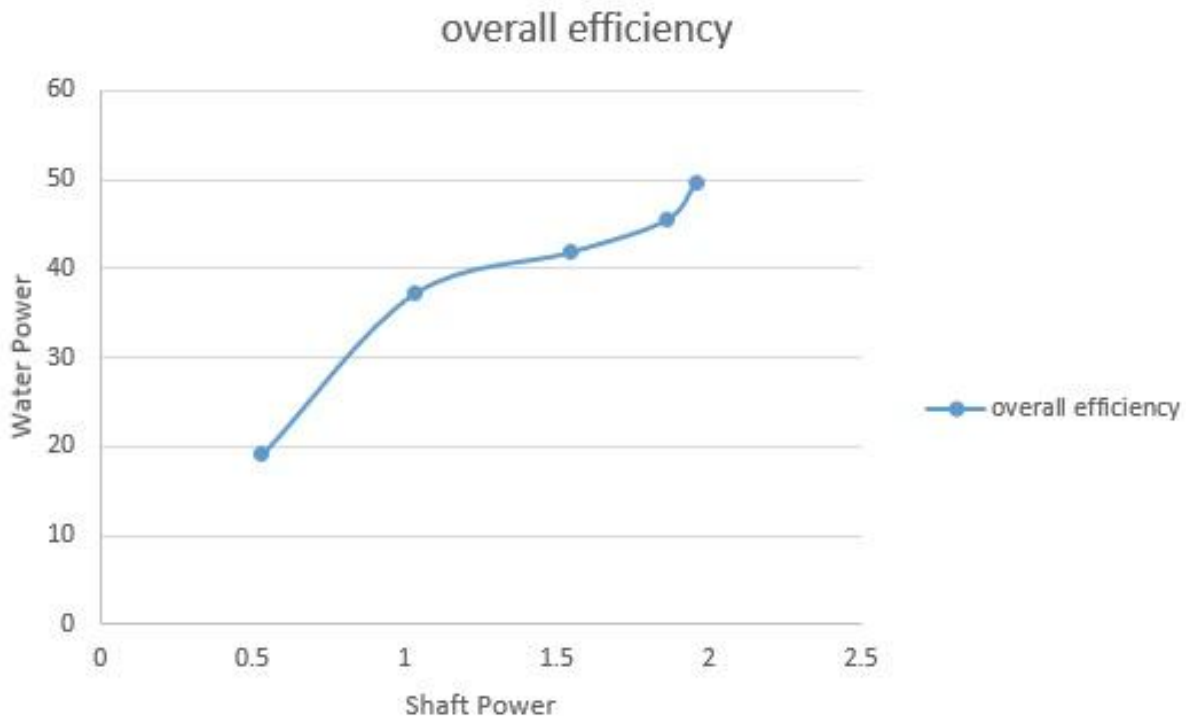


Figure 3. Over all efficiency vs Shaft power

Figure 3 shows increase in over all efficiency with increase in shaft power requirement.

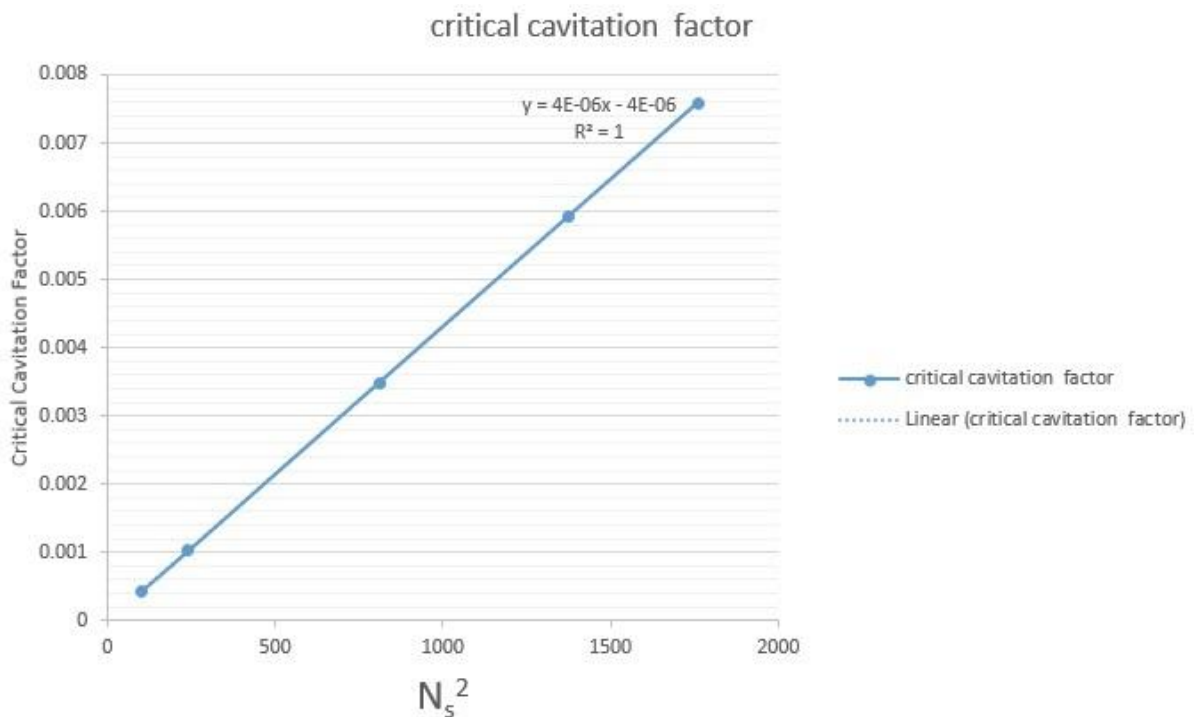


Figure 4. Critical cavitation factor vs N_s²

Figure 4 shows the variation of critical cavitation factor with square of specific speed. It's a straight line. The equation of line of best fit is

Or

$$S_{cm} = 4E-06 \cdot N_s^2 - 4E-06$$

$$Y = 4E-06x - 4E-06$$

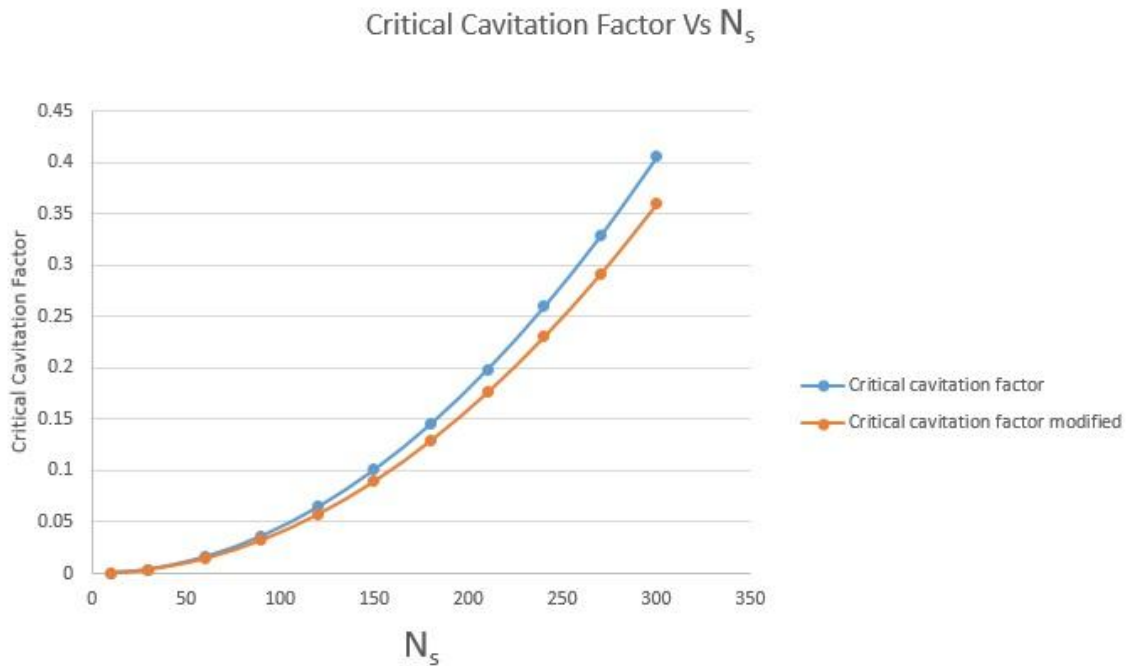


Figure 5. Critical Cavitation Factor vs Specific Speed

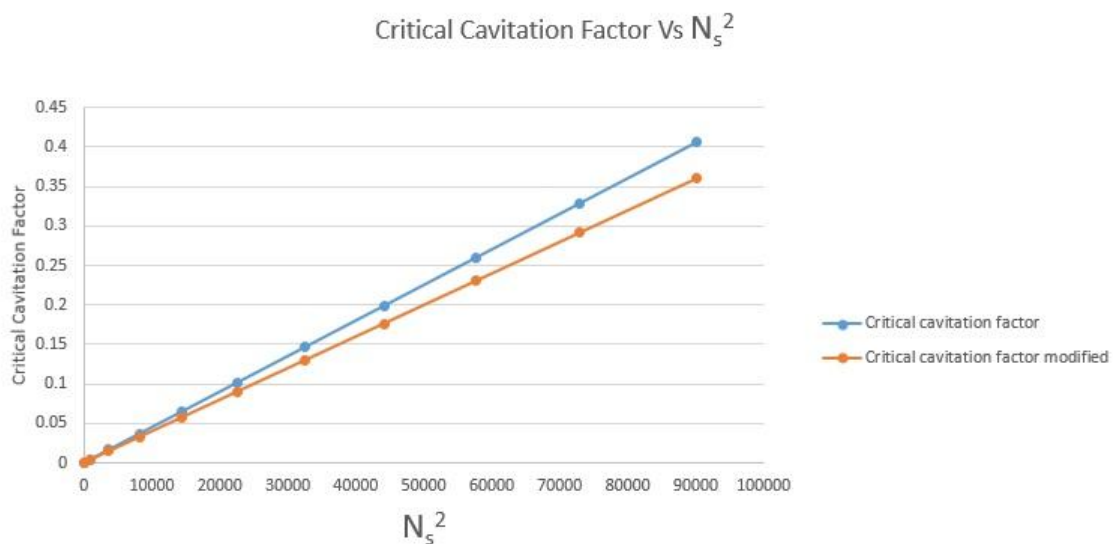


Figure 6. Critical cavitation factor vs N_s^2

Figures 5 & 6 show the variation of critical cavitation factor from original equation and modified equation with specific speed and squared specific speed. The specific speed range of Francis turbine is 30 to 300 (4). Values of critical cavitation factor obtained from modified equation are comparatively lower and therefore modified equation is more conservative.

CONCLUSIONS

1. This paper has given an overview of Hydro power and development of hydro turbines.
2. The assorted data collected from laboratory-scale Francis turbine has been used. The analysis based on shaft power demand and utilization of water power. Performance parameters include over all efficiency, specific speed,

unit quantities and critical cavitation factor.

3. From this a modified equation of critical cavitation factor is obtained, which is comparatively more conservative. This work can be further extended with more data and use of computer simulations.

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