

Efficiency Analysis of Different Types of Turbine

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ABSTRACT: A water turbine is a rotary machine that converts kinetic energy and potential energy of water into mechanical work. This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine. Generally there are three main types of turbine i.e, Pelton wheel turbine, Kaplan turbine and Francis turbine as per the flowing condition and energy available at inlet of turbine. Efficiency of turbine is the ratio of the actual work output of the turbine to the work output of the turbine if the turbine undergoes an isentropic process between the same inlet and exit pressures. The work deals of the paper are the comparison between the efficiencies of different type of turbines with the change of spear location and loading condition. The paper divulges that the efficiency of Pelton and Kaplan turbine are more as compared to francis turbine.

KEYWORDS: Hydraulic, Pelton, Kaplan, Francis, Efficiency, Reveals.

I. INTRODUCTION

Hydraulic machine are defined as those machine which convert hydraulic energy into mechanical energy or mechanical energy into hydraulic energy. Turbine is defined as the hydraulic machine which converts hydraulic energy into mechanical energy. This mechanical energy is used in running an electric generator which is directly coupled to the shaft of the turbine. Thus the mechanical energy is converted into electrical energy. The electric power which is obtained from the hydraulic energy is known as hydroelectric power. Early turbine examples are windmills and waterwheels.

Following are the types of turbine according to energy available at inlet:

Reaction Turbine - A reaction turbine is a type of turbine that develops torque by reacting to the pressure or weight of a fluid; the operation of reaction turbines is described by Newton's third law of motion (action and reaction are equal and opposite). The pressure of the fluid changes as it passes through the rotor blades. If at the inlet of the turbine, the water possesses kinetic energy as well as pressure energy, the turbine is known as reaction turbine.

Impulse Turbine- In the impulse turbine first all pressure energy of water convert into the kinetic energy through a nozzle and generate a high speed jet of water. This water jet strikes the blade of turbine and rotates it. In the reaction turbine there is pressure change of water when it passes through the rotor of turbine. If at the inlet of turbine, the energy available is only kinetic energy, the turbine is known as impulse turbine.

Pelton Wheel Turbine: The Pelton wheel is an impulse type water turbine. It was invented by Lester Allan Pelton in the 1870s. The Pelton wheel extracts energy from the impulse of moving water, as opposed to water's dead weight like the traditional overshot water wheel. Many variations of impulse turbines existed prior to Pelton's design, but they were less efficient than Pelton's design. Water leaving those wheels typically still had high speed, carrying away much of the

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dynamic energy brought to the wheels. Pelton's paddle geometry was designed so that when the rim ran at half the speed of the water jet, the water left the wheel with very little speed; thus his design extracted almost all of the water's impulse energy—which allowed for a very efficient turbine.

Francis Turbine- Francis turbines are the most common water turbine in use today. They operate in a water head from 40 to 600 m (130 to 2,000 ft) and are primarily used for electrical power production. The electric generators that most often use this type of turbine have a power output that generally ranges from just a few kilowatts up to 800 MW, though mini-hydro installations may be lower. Penstock (input pipes) diameters are between 3 and 33 ft (0.91 and 10 m). The speed range of the turbine is from 75 to 1000 rpm. A wicket gate around the outside of the turbine's rotating runner controls the rate of water flow through the turbine for different power production rates. Francis turbines are almost always mounted with the shaft vertical to isolate water from the generator. This also facilitates installation and maintenance.

Kaplan turbine- The Kaplan turbine is a propeller-type water turbine which has adjustable blades. It was developed in 1913 by Austrian professor Viktor Kaplan, who combined automatically adjusted propeller blades with automatically adjusted wicket gates to achieve efficiency over a wide range of flow and water level.

The Kaplan turbine was an evolution of the Francis turbine. Its invention allowed efficient power production in low-head applications that was not possible with Francis turbines. The head ranges from 10–70 metres and the output from 5 to 200 MW. Runner diameters are between 2 and 11 metres. Turbines rotate at a constant rate, which varies from facility to facility. That rate ranges from as low as 69.2 rpm (Bonneville North Powerhouse, Washington U.S.) to 429 rpm.

II. WORKING OF TURBINE

Pelton wheel turbine- The water from the reservoir flows through the penstocks at the outlet of which a nozzle is fitted. The nozzle increases the kinetic energy of the water flowing through the penstock by converting pressure energy into kinetic energy. At the outlet of the nozzle, the water comes out in the form of a Jet and strikes on the splitter, which splits up the jet into two parts. These parts of the Jet, glides over the inner surfaces and comes out at the outer edge. The buckets are shaped in such a way that buckets rotates, runner of the turbine rotates and thus hydraulic energy of water gets converted into mechanical energy on the runner of turbine which is further converted into electrical energy in a generator/alternator.



Fig:1 Apparatus of Pelton Wheel Turbine



Fig: 2 Francis Turbine Apparatus



Fig: 3 Kaplan Turbine Apparatus

Francis Turbine- The governing mechanism changes the position of guide blades to affect a variation in the water flow rate in the wake of changing load condition of the turbine. When the load changes, the governing

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mechanism rotates all guide blades about their axis through the same angle so that the water flow rate to the runner and its direction essentially remain the same at the all passages between any two consecutive guide vans. The penstock pipe feeding the turbine is often fitted with a relief valve, also known as the pressure regulator. When guide vanes are suddenly closed, the relief valve opens and diverts the water direct to tail race. The simultaneous operation of guide vanes and relief valve is termed as double regulation.

Kaplan Turbine- Due to the low water heads it allows the water flow at larger in the Kaplan turbine. With help of the guide vane the water enters. So the guide vanes are aligned to give the flow a suitable degree of swirl. The swirl is determined according to the rotor of the turbine. The water flow from the guide vanes are passes through the curved structure which forces the radial flow to direction of axial. The swirl is imparted by the inlet guide vanes and they are not in the form of free vortex. With a component of the swirl in the form of axial flow are applies forces on the blades of the rotor. Due to the force it loses both angular and linear momentum.

III. OBSERVATION AND CALCULATION

1. Pelton Wheel Turbine

(A) Observation:

Diameter of main pipe = 6.5 cm

Area of main pipe = 0.003 sq. M

Diameter of orifice pipe= 3.9

Area of orifice pipe=0.001 Sq. M.

$C_d = 0.62$

(B) Observation table:

The observation of the Pelton wheel turbine at first spear position is described below in the table.

Table: 1 Pelton wheel turbine for spear position at 5

S.N o.	Load (Kg)	Nozzle reading(Kg/Sq cm)	Speed	P1(Kg/Sq cm)	P2 (Kg/Sq cm)	Hea d (h)	Spring Balance	Discharge Q (m ³ /s)	Torque(N-mm)	H _t	B.H.P (KN)	I.H.P.(KN)
1	2	1.65	745.5	2.1	1.9	16.5	0.5	0.01	2.20	2	0.17	0.19
2	4	1.55	738	2.4	1.8	15.5	0.6	0.011	5.03	6	0.4	0.58

The observation of the Pelton wheel turbine at Second spear position is described below in the table.

Table: 2 Pelton wheel turbine for spear position at10

S.No.	Head (h)	Load (Kg)	Speed	P1(Kg/Sq cm)	P2 (Kg/Sq cm)	Spring Balanc e	Discharge Q (m ³ /s)	Torque(N-mm)	H _t	B.H.P (KN)	I.H.P.(K N)
1	14	2	770	1.95	1.6	0.3	0.01	2.5	3.5	0.2	0.34
2	16	4	708.5	2.4	1.9	0.6	0.01	5.3	5	0.39	0.49

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(C) Calculation

$$H_1 = 10 \times P$$

$$H_1 = 10 \times 1.65 = 16.5$$

$$Q = C_d \times a_1 \times a_2 (2 \times g \times H_1)^{1/2} / (a_0 - a_1)^{1/2}$$

$$Q = 0.62 \times 0.003 \times 0.001 (2 \times 9.81 \times 16.5)^{1/2} / ((0.003)^2 - (0.001)^2)^{1/2}$$

$$Q = 0.01$$

$$T = 9.81 \times W \times 0.150$$

$$T = 9.81 \times 1.5 \times 0.150$$

$$T = 2.20$$

$$BP = 2 \pi n t / 60 \times 10^3$$

$$BP = 2 \times \pi \times 745.5 \times 2.20 / 60 \times 10^3$$

$$BP = 0.17$$

$$H_t = (p_1 - p_2) \times 10$$

$$H_t = (2.1 - 1.9) \times 10$$

$$H_t = 2$$

$$IP = \rho \times g \times Q \times H_t / 1000$$

$$IP = 1000 \times 9.81 \times 0.01 \times 2 / 1000$$

$$IP = 0.19$$

$$\eta = BP / IP \times 100$$

$$\eta = 0.17 / 0.19$$

$$\eta = 89.47\%$$

2. Francis Turbine

(A) Observation

Diameter of main pipe = 0.1 m
Area of main pipe = 0.007 sq. M
Diameter of orifice pipe = 0.06 m
Area of orifice pipe = 0.002 Sq. M.
 $C_d = 0.62$

(B) Observation table

The observation of the Francis turbine at first spear position is described below in the table.

Table: 3 Francis Turbine for spear position at 5

S.No.	Head (h)	Load (Kg)	Speed	P1(Kg/Sq cm)	P2 (Kg/Sq cm)	Spring Balance	Discharge Q (m ³ /s)	Torque(N-mm)	H _t	B.H.P (KN)	I.H.P.(KN)
1	12.5	2	1706	1.3	0.75	0.3	0.02	2.5	5.54	0.446	1.07
2	10.5	4	1545	1.6	0.9	0.5	0.018	5.1	7	0.833	1.23

The observation of the Francis turbine at Second spear position is described below in the table.

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Table: 4 Francis Turbine for spear position at 10

S.No.	Head (h)	Load (Kg)	Speed	P1(Kg/S q cm)	P2 (Kg/Sq cm)	Spring Balance	Discharge Q (m ³ /s)	Torque (N-mm)	H _t	B.H.P (KN)	I.H.P. (KN)
1	6	2	1420	1.17	0.3	0.4	0.014	2.35	8.7	0.349	1.19
2	5	4	1340	1.15	0.15	0.5	0.012	5.15	10	0.722	1.17

(C) Calculation

$$H_1 = 10 \times 1.25 = 12.5$$

$$Q = C_d \times a_1 \times a_2 (2Xg \times H_1)^{1/2} / (a_0 - a_1)^{1/2}$$

$$Q = 0.62 \times 0.007 \times 0.002 (2 \times 9.81 \times 12.5)^{1/2} / ((0.007)^2 - (0.002)^2)^{1/2}$$

$$Q = 0.02$$

$$T = 9.81 \times W \times 0.150$$

$$T = 9.81 \times 1.7 \times 0.150$$

$$T = 2.50$$

$$BP = 2\pi n t / 60 \times 10^3$$

$$BP = 2 \times \pi \times 1706 \times 2.50 / 60 \times 10^3$$

$$BP = 0.446$$

$$H_t = (p_1 - p_2) \times 10$$

$$H_t = (1.55 - 1) \times 10$$

$$H_t = 5.5$$

$$IP = \rho \times g \times Q \times H_t / 1000$$

$$IP = 1000 \times 9.81 \times 0.02 \times 5.5 / 1000$$

$$IP = 1.07$$

$$\eta = BP / IP \times 100$$

$$\eta = 0.446 / 1.07 \times 100$$

$$\eta = 41.68\%$$

3. Kaplan Turbine

(A) Observation

Diameter of main pipe = 0.15 m

Area of main pipe = 0.017 sq. M

Diameter of orifice pipe = 0.09 m

Area of orifice pipe = 0.006 Sq. M.

C_d = 0.62

(B) Observation Table:

The observation of the Kaplan turbine at first spear position is described below in the table.

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Table: 5 Kaplan Turbine at spear position 5

S.No	Head (h)	Load (Kg)	Speed	P1(Kg/Sq cm)	P2 (Kg/Sq cm)	Spring Balance	Discharge Q (m ³ /s)	Torque (N-mm)	H _t	B.H.P (KN)	I.H.P.(KN)
1	15.2	2	1875	1.66	1.51	0.2	0.1	2.64	1.5	0.518	1.47
2	16	4	1673	1.75	1.61	0.3	0.071	5.44	1.4	0.95	0.97

The observation of the Kaplan turbine at Second spear position is described below in the table.

Table: 6 Kaplan Turbine at spear position 10

S.No.	Head (h)	Load (Kg)	Speed	P1(Kg/Sq cm)	P2 (Kg/Sq cm)	Spring Balance	Discharge Q (m ³ /s)	Torque(N-mm)	H _t	B.H.P (KN)	I.H.P.(KN)
1	8	2	1423	1.46	1.41	0.1	0.21	2.79	0.5	0.41	1.03
2	9	4	1218	0.91	0.75	0.3	0.043	5.15	1.6	0.65	0.67

(C) Calculation

$$H_1 = 10 \times P$$

$$H_1 = 10 \times 1.52 = 15.2$$

$$Q = C_d \times a_1 \times a_2 (2 \times g \times H_1)^{1/2} / (a_1^2 - a_2^2)^{1/2}$$

$$Q = 0.62 \times 0.017 \times 0.006 (2 \times 9.81 \times 15.2)^{1/2} / ((0.017)^2 - (0.006)^2)^{1/2}$$

$$Q = 0.1$$

$$T = 9.81 \times W \times 0.150$$

$$T = 9.81 \times 1.8 \times 0.150$$

$$T = 2.64$$

$$BP = 2 \pi n t / 60 \times 10^3$$

$$BP = 2 \times \pi \times 1875 \times 2.64 / 60 \times 10^3$$

$$BP = 0.518$$

$$H_t = (p_1 - p_2) \times 10$$

$$H_t = (1.66 - 1.51) \times 10$$

$$H_t = 1.5$$

$$IP = \rho \times g \times Q \times H_t / 1000$$

$$IP = 1000 \times 9.81 \times 0.1 \times 1.5 / 1000$$

$$IP = 1.47$$

$$\eta = BP / IP \times 100$$

$$\eta = 0.518 / 1.47 \times 100$$

$$\eta = 35.23\%$$

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IV. EXPERIMENTAL RESULTS

1. Pelton Wheel Turbine

Figure is showing the actual representation of the observation which was taken from the Pelton wheel turbine.

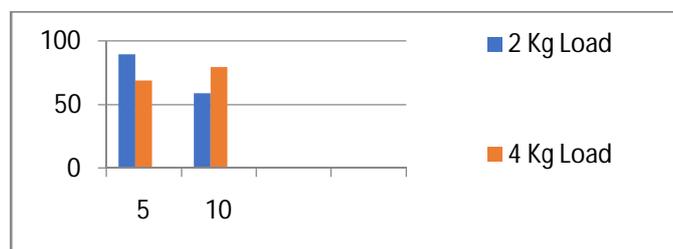


Fig: 4 Efficiency Comparison Graph of Pelton Wheel Turbine

2. Francis Turbine

Figure is showing the actual representation of the observation which was taken from the Francis turbine.

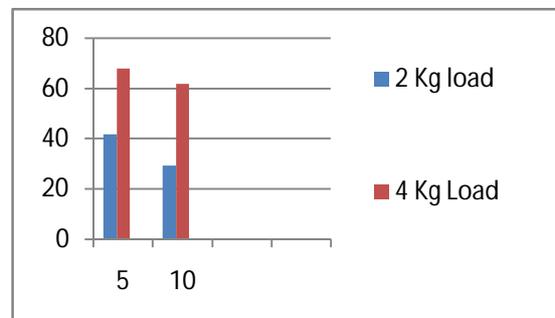


Fig: 5 Efficiency Comparison Graph of Francis Turbine

3. Kaplan Turbine

Figure is showing the actual representation of the observation which was taken from the Kaplan turbine.

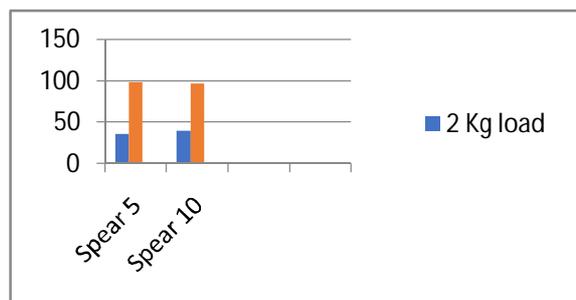


Fig: 6 Efficiency Comparison Graph of Francis Turbine

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Table: 7 Efficiency Comparisons

Following Table is the final comparison of different types of turbine in different loading condition and spear position.

S.No.	Spear	Load	Pelton Wheel Turbine	Francis Turbine	Kaplan Turbine	Most Efficient Turbine
1	5	2	89.47%	41.68%	35.23%	Pelton Wheel Turbine
2	5	4	68.96%	67.72%	97.93%	Kaplan
3	10	2	58.82%	29.32%	39.80%	Pelton
4	10	4	79.59%	61.79%	97.00%	Kaplan

V. CONCLUSION

- Table 7 Shows that Kaplan turbine and Pelton Wheel turbine are most efficient turbine.
- Figure 2 Shows that the efficiency of Francis turbine increase as the increment in the load at spear position of 5
- Figure 3 Shows that the efficiency of Kaplan turbine increase as the increment in the load at spear position of 5.
- Figure 2 Shows that the efficiency of Francis turbine increase as the increment in the load at spear position of 10
- Figure 2 Shows that the efficiency of Francis turbine increase as the increment in the load at spear position of 10

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