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Experimental Investigation of Small Scale Pelton Turbine Characteristics

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Abstract – Electricity is typically generated at hydroelectric power facilities using hydraulic turbines. Hydraulic turbines use the potential energy of the water to convert it into mechanical energy, which is subsequently transformed into electrical energy by means of a generator. The hydraulic turbines are separated into two main parts namely action and reaction turbines. The Francis, Kaplan, Uskur, and other reaction turbines are utilized at lower heads and flow rates, whereas the action turbines, such as Pelton, Turgo, and so forth, are employed at high heads and low flow rates. The power, efficiency, and specific speed of hydraulic turbines under different operating situations must be determined in order to determine their operational limits, sustainability, economy, and maintenance duration. While it is feasible to identify by numerical approaches at a lesser cost, experimental research of the characteristics of hydraulic turbines is a more practical approach. However, due to the size of the hydraulic turbines, experimental research is very expensive and challenging. Hence, small scale models are used in the experimental investigation for the reduction of the test cost. Using a particular experimental setup, an experimental examination was carried out in this study to determine the small scale Pelton turbine characteristics at various working conditions. The results of the study show that the power produced by the Pelton turbine increases with the increase of net head while the efficiency of the Pelton turbine reaches the maximum level at a specific flow rate and then decreases. On the other hand, power and efficiency of the Pelton turbine increase at a specific load depending on the valve opening position while turbine specific speed decreases with rising load and valve opening position.

Keywords: Renewable Energy, Hydraulic Turbines, Pelton Turbine, Turbine Characteristics, Efficiency

I. INTRODUCTION

Hydraulic machines are devices that transfer energy from hydraulic to mechanical, or vice versa. Turbines are hydraulic devices that transform hydraulic energy into mechanical energy, and pumps are hydraulic devices that transform mechanical energy into hydraulic energy [1, 2]. Type of energy at the intake, flow direction through the vanes, head available at the inlet, discharge through the vanes, and specific speed are all factors that can be used to categorize hydraulic turbines. Regarding how energy is used, hydraulic turbines can be divided into the impulse (or action) and the reaction turbines. The reaction turbines are mainly Francis and Kaplan turbines which work under low–medium head and medium–high discharge with using the both pressure and kinetic energy of water while the impulse turbines are mainly Pelton and Turgo turbines which works under high head and low discharge by using only the kinetic energy of water [3, 4]. The impulse turbine known as the Pelton wheel, named for a renowned engineer, has a tangential flow and only kinetic energy is accessible at the turbine entrance. Additionally, it works best at very high head and modest discharges at low specific speeds. There is atmospheric pressure present at the intake and out of the Peton turbine. Hence, Pelton turbines does not negatively affect cavitation due to it occurs at negative ambient pressure [5, 6].

II. EXPERIMENTAL SETUP

The experimental setup consist of water tank, flow meter manometer, turbine, generator, measurement devices and control panel as seen in Fig. 1. The flow rate is measured by means of flow meter; net head at turbine inlet is measured by using a manometer, turbine speed is measured via a digital tachometer, current and voltage are also measured by using ammeter and voltmeter during experiments. The measured values during tests are given in Table 1.

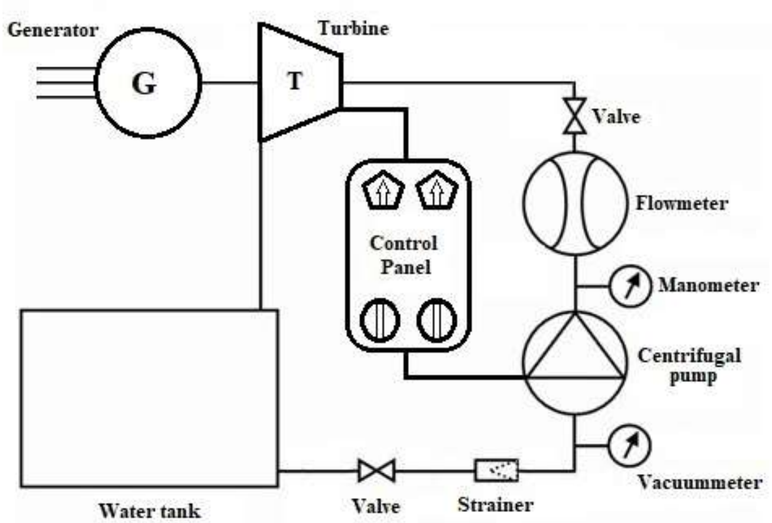

Fig. 1. Schematic layout of test setup

Table 1. Measured values during tests

Ambient conditions		p_{amb}	0.982 bar																		
		T_{amb}	20 °C																		
Valve opening position (%)		25					50					75					100				
Load (%)		20	40	60	80	100	20	40	60	80	100	20	40	60	80	100	20	40	60	80	100
Measured values	p_{ind} [bar]	1.9	1.9	1.9	1.9	1.9	2	2	2	2	2	2.5	2.5	2.5	2.5	2.5	2.7	2.7	2.7	2.7	2.7
	Q [m^3/h]	16	16	16	16	16	17	17	17	17	17	18	18	18	18	18	19	19	19	19	19
	n [d/dk]	2750	2640	2260	1930	1875	2615	2510	2150	1835	1780	2480	2383	2040	1742	1692	2358	2265	1938	1655	1608
	I [ampere]	0.69	1.36	2.02	2.27	2.18	0.62	1.17	2.03	2.58	2.65	0.6	1.05	1.54	2.64	2.71	0.62	1.06	1.58	2.08	2.85
	V [voltage]	166	132	88	78	75	235	192	127	88	66	322	294	253	212	132	340	311	240	208	150

III. CALCULATION OF PELTON TURBINE CHARACTERISTICS

Pelton turbine characteristics were calculated by using the measured values as follow [7–11]. Turbine net head is calculated using measured manometer pressure and ambient pressure as follows.

$$H = \frac{p_{ind} + p_{amb}}{\gamma} \text{ [m]} \tag{1}$$

Hydraulic power at the turbine inlet is calculated using the net head and flow rate as follows.

$$P_h = \rho . g . Q . H = \gamma . Q . H \text{ [W]} \tag{2}$$

Turbine mechanical power is calculated using torque and angular velocity as follows.

$$P_m = \tau . \omega \text{ [W]} \tag{3}$$

$$\omega = \frac{2\pi n}{60} \text{ [rad/s]} \quad (4)$$

Turbine efficiency is calculated using hydraulic power and mechanical power as follows.

$$\eta_t = \frac{P_m}{P_h} x100 \text{ [\%]} \quad (4)$$

Electrical power produced by generator is calculated by using current and voltage values as follows.

$$P_e = I.\,V \text{ [W]} \quad (5)$$

Generator efficiency is calculated by using mechanical power and electrical power as follows.

$$\eta_g = \frac{P_e}{P_m} x100 \text{ [\%]} \quad (6)$$

Turbine specific speed is calculated using flow rate, net head and turbine speed as follows.

$$n_s = n\frac{\sqrt{Q}}{H^{3/4}} = n\frac{\sqrt{P}}{H^{5/4}} \text{ [–]} \quad (7)$$

IV. RESULTS AND DISCUSSON

Fig. 2 shows that the variation of flow rate and net head at different valve opening position. The capacity or flow rate is described as the quantity of fluid that is passing through a cross-section in a specific period of time. The effective head or net head is the head available at the turbine inlet for power production. Turbine flow rate and net head increase with rising valve opening position as seen in Fig. 2. This means that energy input namely hydraulic power enhances at the turbine inlet with increase of valve opening position as seen in Fig. 3.

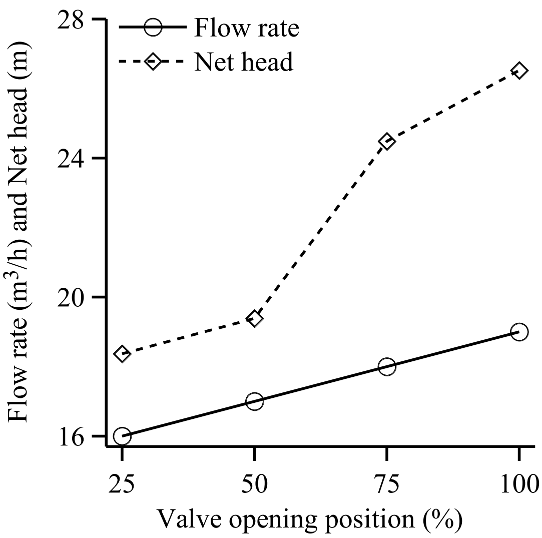

Fig. 2. Variation of flow rate and net head at different valve opening position

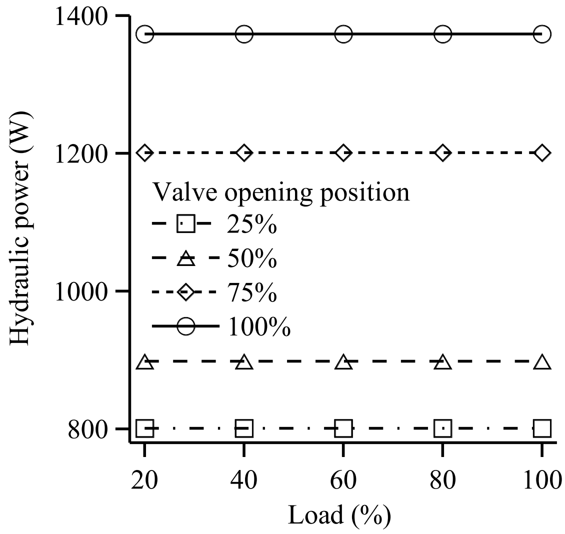

Fig. 3. Variation of hydraulic power with load at different valve opening position

Fig. 4 indicates that the variation of turbine mechanical power with load at different valve opening position. Pelton turbines convert kinetic energy namely hydraulic power of water into mechanical power. As seen in Fig. 4, turbine mechanical power enhances with rising of valve opening position due to increasing hydraulic power. Turbine mechanical power reaches its maximum value at a specific load for each valve opening position and then decreases as seen in the figure. Additionally, the maximum value of turbine power is occurred at higher load value with increase of valve opening position because of the rising of hydraulic power at turbine inlet.

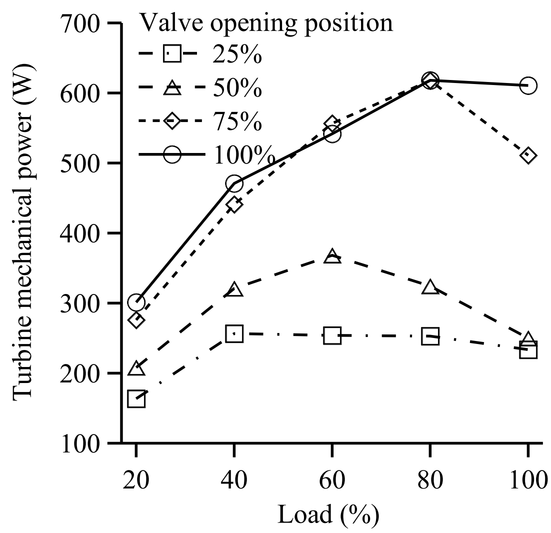

Fig. 4. Variation of turbine mechanical power with load at different valve opening position

Fig. 5 demonstrates that the variation of turbine efficiency with load at different valve opening position. Turbine efficiency is defined as the ratio of net work output of the turbine to the net input energy supplied to the turbine. Turbine efficiency increases up to a certain valve opening position and load and then decreases as seen in Fig. 5. The maximum turbine efficiency values generally is obtained at 75% valve opening position while the maximum turbine efficiency point depending on load varies with valve opening position.

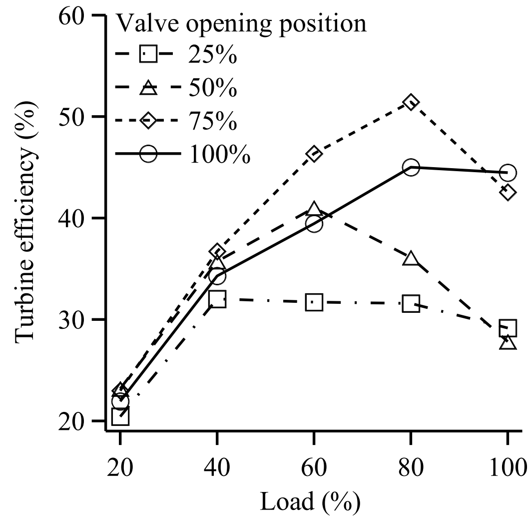

Fig. 5. Variation of turbine efficiency with load at different valve opening position

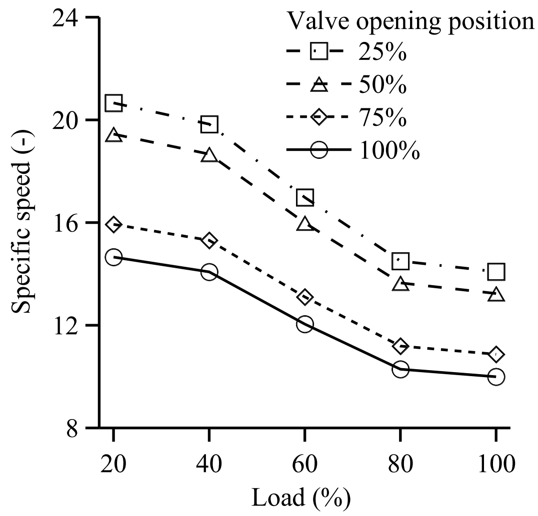

Fig. 6. Variation of specific speed with load at different valve opening position

Fig. 6 exhibits that the variation of specific speed with load at different valve opening position. The specific speed of a turbine is described as the speed of a geometrically similar turbine which would produce unit power in kilowatt under unit head (one meter). Turbine specific speed decreased with rising load while it increases with decrease of valve opening position as seen in Fig. 6. This means that as the hydraulic power at the turbine inlet increases, the turbine must rotate less to produce the same power.

V. CONCLUSIONS

In this study, an experimental examination was performed to determine the small scale Pelton turbine characteristics at various working conditions via a particular experimental setup. Following conclusions can be summarized from the results of the study.

- Mechanical power produced by the Pelton turbine increases with the increase of net head and flow rate due to rising hydraulic power into the turbine inlet.
- The mechanical power and efficiency of the Pelton turbine increase at a specific load depending on the valve opening position and then decreases due to increasing mechanical losses
- Turbine specific speed decreases with rising load and valve opening position due to the turbine needs to rotate less to produce the same power when the hydraulic power turbine inlet increases.

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