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Design, Construction and Performance Testing of 1 kW Pelton Turbine for Pico Hydro Power Plant

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Abstract: The generation of electricity from water is the most effective and the cheapest way to get energy. The pico scale renewable energy is to bring electricity to remote villages that are not near transmission lines. In hydropower plant water turbine is one of the most important parts to generate electricity. The main purpose of this project is to develop the living standard in rural areas and to reduce the use of non-renewable energy. In this research paper, 1 kW pelton turbine design is based on head and flow rate of Department of Research and Innovation. The available head and flow rate are 10 m and 0.02 m^3/sec. The pelton turbine is a tangential flow impulse turbine. There are two main components of this turbine namely, runner and nozzle. A 1 kW medium head hydro concrete turbine is constructed in Taung Da Gone Industrial 3 at Yangon. The pelton turbine project was tested at Department of Research and Innovation.

Keywords: Renewable Energy, Pico Hydro, Pelton turbine, Runner, nozzle

1. INTRODUCTION

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. In hydro power plants the kinetic energy of falling water is captured to generate electricity. A turbine and a generator convert the energy from the water to mechanical and then electrical energy. There are several classifications related to the dimension of hydropower plants. An actually useful classification is the following.

(i) Large hydropower > 100 MW
(ii) Medium hydropower 15 -100 MW
(iii) Small hydropower 1 MW-10 MW
(iv) Mini hydropower 100 kW-1MW
(v) Micro hydropower 5-100 kW
(vi) Pico hydropower up to 5kW

Typical hydroelectric plant is shown in Figure 1. Micro hydro systems are particularly suitable as remote area power supplies for rural and isolated communities, as an economic alternative to extending the electricity grid. The systems provide a source of cheap, independent and continuous power, without degrading the environment.

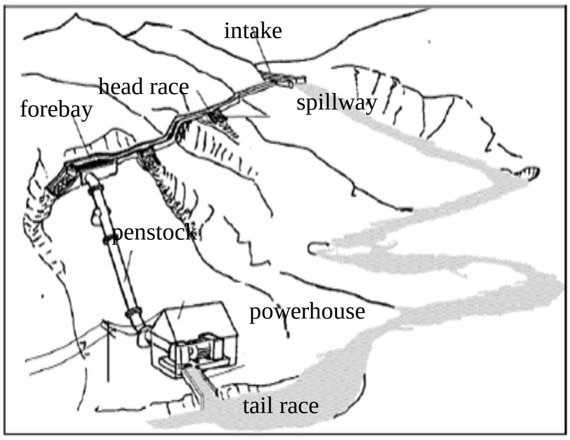

Figure 1. Typical Hydroelectric plant

2. TYPES OF HYDRAULIC TURBINE

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be used for generating electrical power when combined with a generator. Turbines are also divided by their principle of operation and can be divided into impulse and reactions turbine. The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. Reaction turbines are pressure type turbines that rely on the pressure difference between both sides of the turbine blades. For micro-hydro applications, Pelton turbines can be used effectively at head down to about 20m. Draft tubes are not required for impulse turbine since the runner must be located above the maximum tail water to permit operation at atmospheric pressure. Impulse turbines are usually cheaper than reaction turbines because there is no need for a special pressure casing or for relatively high heads.

2.1. Pelton Turbine

A Pelton turbine is a hydraulic turbine where the runner is rotating from the impulse of water jet on its buckets. The Pelton wheel is a special type of axial flow impulse turbine and is used for very high heads. In large scale hydro installation, Pelton turbines are normally only considered for heads above 100m. A Pelton turbine consists of a set of specially shaped buckets mounted on a periphery of a circular disc as shown in Figure 2. The runner consists of a circular disc with a number of buckets evenly spaced round its periphery. The rim of the runner disc are fastened bucket-shaped blade which are for a better discharge of the water divided by a ridge or splitter into two symmetrical parts. The water jet is deflected by the bucket and thus transfers its energy to the wheel. In order to achieve the most efficient position of the bucket for the impinging water, a notch is made into the edge of the bucket at the largest radius. This notch is carefully sharpened to ensure, as far as possible, a loss-free entrance of the bucket into the jet. The pelton bucket is designed to deflect the jet through 165 degrees which is the maximum angle possible without the return jet interfering with the following bucket for the oncoming jet.

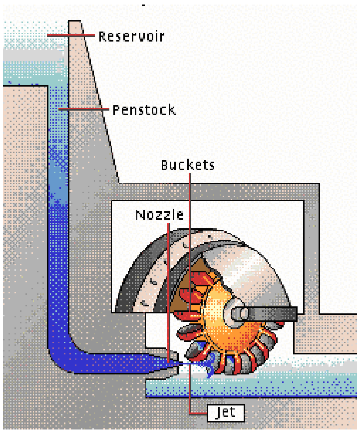

Figure 2. Components of Pelton turbine

3. SELECTION OF TURBINE

The choice of water turbine depends on the site conditions, notably on the head of water H and the flow rate Q. Figure 3 indicates which turbine is most suitable for any particular combination of head and flow rate. Reaction turbines suited for low head and high flow rate. Pelton turbine is suitable for high head and low flow rate.

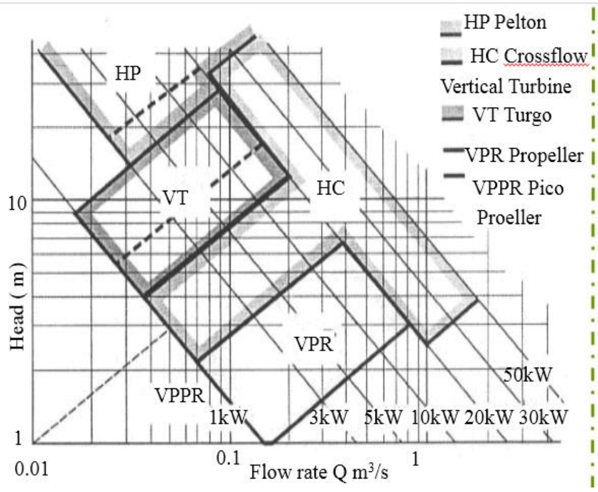

Figure 3. Choice of Turbine in Terms of Head and Flow rate

4. DESIGN CONSIDERATION OF PELTON TURBINE

The effective head and power available of this Pelton turbine is considered at 10 m and 1 kW. The power developed by a turbine is given by the following equation.

$$P = \eta_o \rho g Q H \tag{1}$$

The required shaft power is 1.47 kW.

The specific speed can be calculated from the following equation.

$$N_s = \frac{N\sqrt{P}}{(H)^{5/4}} \tag{2}$$

The speed of the turbine can be calculated from the following equation.

$$N = 147.7\sqrt{H} \tag{3}$$

4.1. Design aspects of Pelton Turbine

The following points should be considered while designing a Pelton turbine. The absolute velocity of water at inlet can be obtained by using this equation

$$V_1 = C_v\sqrt{2gH} \tag{4}$$

The tangential velocity of wheel is determined the following factors.

$$k_u = \frac{u}{V_1} \tag{5}$$

The mean diameter or the pitch circle diameter of the Pelton turbine is known from this equation.

$$u = \frac{\pi D N}{60} \tag{6}$$

Number of nozzle is single jet. Thus the jet diameter of 1000 kW Pelton turbine can be calculated from this equation.

$$d_0 = 0.545\sqrt{\frac{Q}{z_0\sqrt{H}}} \tag{7}$$

Jet ratio is a size parameter for the turbine. This value can be obtained by using this equation.

$$m = \frac{D}{d} \tag{8}$$

The number of buckets required for the efficient operation of the Pelton turbine is calculated from this equation.

$$z = 15 + 0.5m \tag{9}$$

Table 1, which presents a variation of number of buckets with jet ratio.

Table 1. Approximate Number of Buckets for a Pelton turbine

Jet ratio	6	8	10	15	20	25
No: of bucket	17-21	18-22	19-24	22-27	24-30	26-33

The blade pitch p_1p_2 on the pitch circle can be obtained by using this equation.

$$p_1p_2 = \frac{2\pi R}{z} \tag{10}$$

The relative velocity with the direction of motion of the vane at outlet is 15˚ Velocity triangle from Figure 4.

$\phi = 15^\circ$

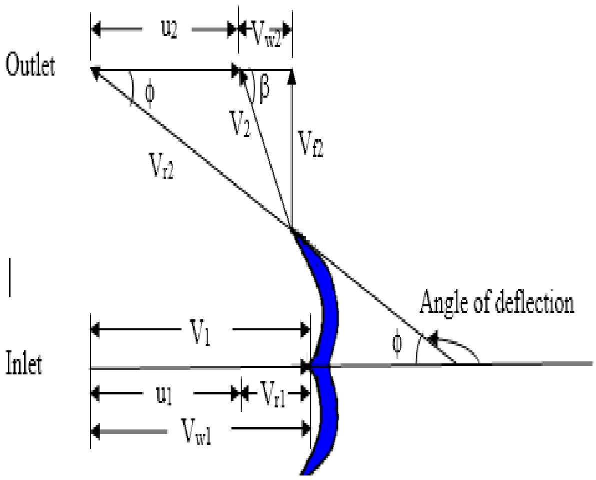

Figure 4. Inlet and outlet velocity diagram of pelton Turbine

(i) Relative velocity of water at inlet

$$V_{r1} = V_1 - u_1 \quad (11)$$

(ii) Whirl velocity of water at inlet and outlet

$$V_{w1} = V_1$$

$$V_{w2} = V_{r2} \cos\phi - u_2 \quad (12)$$

(iii)Flow velocity of water at outlet

$$\sin\phi = \frac{V_{f2}}{V_{r2}} \quad (13)$$

(iv) Angle at exit runner

$$\tan\beta = \frac{V_{f2}}{V_{w2}} \quad (14)$$

The force exerted by the jet of water to the direction of motion is given as

Jet force on the runner $F = \rho a V_1 (V_{w1}+V_{w2})$ (15)

4.2 Bucket weight

Jet force on the bucket can be obtained by using this equation

$$P_0 = \rho a V_1 \frac{(V_1 - u)^2}{V_1}(1-\cos\alpha) \quad (16)$$

The centrifugal force on the bucket can be calculated.

$$C.F = F - P_0 \quad (17)$$

Weight of the bucket is

$$C.F = \frac{Gu^2}{gR} \quad (18)$$

4.3. Bucket Design

In a Pelton turbine design, two parameters are important.

(i) the ratio of the bucket width to the jet diameter and

(ii) the ratio of the wheel diameter to the jet diameter

If the bucket width is too small in relation to jet diameter, the fluid is not smoothly deflected by the buckets and in consequence, much energy is dissipated in turbulence and the efficiency drops considerably.

The main dimensions of the Pelton wheel bucket are shown in Table 2.

Table 2. Dimension of Bucket with Respect to Jet Diameter

Item	Minimum Value	Maximum Value
Bucket length, L	2.28 d_o	3.3 d_o
Bucket width, B	2.8 d_o	4 d_o
Notch depth, S	0.44 d_o	0.625 d_o
Notch width, M	1.12 d_o	1.6 d_o
Bucket depth, E	0.8 d_o	1.2 d_o
Bucket height, A	1.75 d_o	2.5 d_o

The dimension of Pelton turbine bucket is shown in Figure 5.

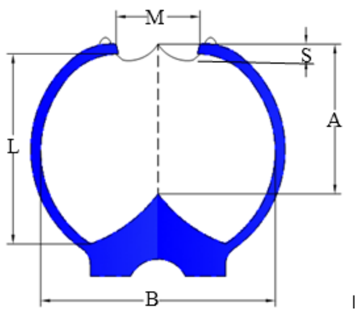

Figure 5 Dimension of Pelton Turbine Bucket

4.5 Result data of Pelton turbine Bucket

Table 3. Bucket Dimensions

Item	Minimum Value	Maximum Value
Bucket length, L	52.4mm	75.9mm
Bucket width, B	64.4mm	92mm
Notch depth, S	10.12mm	14.375mm
Notch width, M	25.76mm	36.8mm
Bucket depth, E	18.4mm	27.6mm
Bucket height, A	40.15mm	57.5mm

5. CONSTRUCTION PROCEDURES OF RUNNER

Production process of pelton turbine runner are design and drawing, pattern making, casting and assembling. Mechanical drawing can be drawn by using design data. The next step is patter making for casting. Figure 6 show that pattern is made by CNC milling machine.

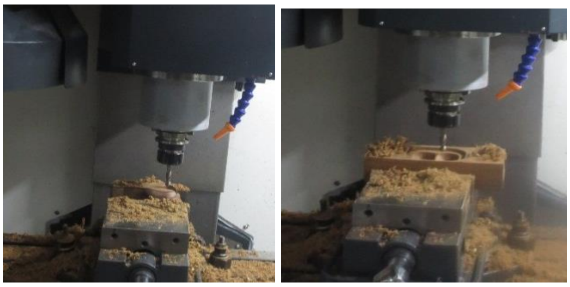

Figure 6. Pattern making

After pattern making, the next step is mould making. The proper mould for this pattern is clay mould as shown in Figure 7.

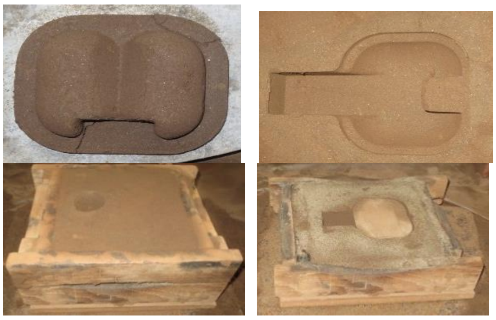

Figure 7. Mould making

. And then, casting for pelton turbine bucket is chosen by available local aluminum. Figure 8 shows the casting process and Figure 9 shows the pelton turbine bucket.

Figure 8. Casting

Figure 9. Bucket

Final step is assembly of runner as shown in Figure 10 and assembly of Pelton turbine as shown in Figure 11. To construct the turbine runner, these materials are required. They are resin, colouring, pigment, talc powder, fiber mat and hardener.

Figure 10. Runner

Figure 11. Assembly of Pelton Turbine

6.PERORMANCE TESTING OF PELTON TURBINE

Before being tested the turbine and generator assembly must be set firstly.

The effective head H is measured by the pressure gauge. Discharge is measured with the volume of the low head tank and how long it takes to fill the water The speed of turbine is measured by using tachometer. The speed of the turbine is 500 rpm. And then the load is gradually increased and result are records.

During the test, the speed was found to decrease depending on the increasing load. . The turbine is started at no load condition. At that time, the speed of turbine was 500 rpm. And then the load is gradually increased and results are recorded.

The generator output can easily be measured by using various load. The turbine is tested at five different loads on head and flow rate are constant.

The water passed through nozzle and is guided to the runner. For that turbine permanent magnet type generator is used with belt drive which speed increase three times. During the test, the voltage of the turbine drop when the load is increased.

Table 4. Test Result Table

No	Head (m)	Speed (rpm)	Volt (V)	Load (watt)	Quantity	Power (watt)
1	10	600	270	100	1	100
2	10	550	230	100	2	300
3	10	500	200	100	2	500
4	10	450	150	100	1	600
5	10	450	130	100	1	700
		Total Power				700 watt

Figure 12. Performance Testing of Pelton turbine

7. CONCLUSIONS

This turbine can be used for household in remote areas to produce 1 kW power for 1 household are easily and inexpensively. This turbine can be used to demonstrate for hydropower training at DRI. The required head is 10m to generate 1kW output power. The flow rate of this turbine is 0.02 m^3/sec and the pitch circle diameter is 0.248m. Number of poles of generator is 4 pole and the speed of turbine is 500rpm. The diameter of jet is 23mm and jet ratio is 10. The performance testing is made at DRI which is located in Yankin Township. This test result are the correct design of the runner. The turbine can be manufactured by any simple workshop. It can also be quickly and easily removed temporarily during flooding of other adverse condition.

The micro and pico hydro power plant are easily established at low cost. So, the micro and pico hydro power generation is the best method for rural electrification.

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