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# AN APPROACH TO MODIFY PELTON WHEEL USING POTENTIAL ENERGY AT LOW HEAD

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***Abstract****- A Pelton-wheel impulse turbine is an energy conversion device that converts gravitational energy of elevated water into mechanical work, which can be converted into electrical energy using an electrical generator. The kinetic energy produced by the water-jet is directed tangentially to the buckets of the Pelton-wheel; generally major amount of the jet energy is used in propelling the rim of the buckets and some passes to the tail race without doing any useful work. Conventional Pelton wheel is mostly used for high-water head applications consuming only kinetic energy from the source, which consists both kinetic and potential energy; whereas, the modified Pelton wheel can operate at low-head and can be used in heavy-discharge applications using considerable amount of potential energy with the kinetic energy. Consequently, this modified Pelton wheel will open new horizon for Mini and Micro hydro power plants available in Bangladesh.*

**Keywords:** Gravitation, Jet-propulsion, Pelton-wheel efficiency, Potential-head, Water-jet,Hydropower

## 1. INTRODUCTION

The energy of falling water as a source of energy is known for a long time. This is called Hydro energy. The amount of stored hydro energy is directly proportional to the height and amount of the water above sea level. This energy is capitalized by the use of the devices, called water turbines. A turbine is a rotary engine that extracts energy from a fluid flow and converts it into useful work. The simplest turbines have one moving part, a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades, or the blades react to the flow, so that they move and impart rotational energy to the rotor. Turbines are of basically two types, such as, impulse and reaction turbine. The goal of this work is to use the impulse type water turbine say, Pelton wheel to generate electricity and to modify it on the gravitational basis. The Pelton wheel is a tangential flow free jet impulse turbine. A nozzle transforms water under a high head into a powerful jet. The momentum of this jet is destroyed by striking the runner, which absorbs the resulting force. If the velocity of the water leaving the runner is nearly zero, all of the kinetic energy of the jet has been transformed into mechanical energy, so the efficiency is high. This type of free-jet water turbine is first introduced by an American; named LesterPelton and the device is called the Pelton Wheel or Pelton turbine [7].

## 2. IMPULSE OR VELOCITY TURBINES

It is one of the major types of turbines, along with reaction turbines. Impulse turbines operate based on the concept of velocity, namely by changing the direction of a jet of either fluid or gas. This impulse in turn rotates the turbine and creates energy. A turbine that is driven by high velocity jets of water or steam from a nozzle directed on to vanes or buckets attached to a wheel. The resulting impulse (as described by Newton's second law of motion) spins the turbine and removes kinetic energy from the fluid flow. Before reaching the turbine, the fluid's pressure head is changed to velocity head by accelerating the fluid through a nozzle. This preparation of the fluid jet means that no pressure casement is needed around an impulse turbine. The conduit bringing high-pressure water to the impulse wheel is called the penstock. This was strictly just the name of the valve, but the term has been extended to the conduit and its appurtenances as well, and is a general term for a water passage and control that is under pressure, whether it serves an impulse turbine or not.

A practical impulse turbine was invented in California around 1870. Afterwards, the buckets were modified to split buckets in 1880 which are now universally used to produce power [7].

### 2.1 Conventional Pelton Wheel

A Pelton wheel is an impulse turbine that has at least one free jet. The jets release water into an aerated space where it is caught by a series of buckets or cups located on the runner, the rotating piece of the turbine that is used to convert the water's energy into mechanical energy. Typically, these buckets are divided into two sections so they are able to deflect water away from the oncoming jets. A Pelton wheel also has a cutaway on the lower lips of the buckets, which allows a subsequent bucket to move ahead before it stops the water jet that has moved the previous bucket. As a result, the buckets enter the water jet more smoothly.

## 3. WORKING PRINCIPLE OF PELTON TURBINE

The water from the reservoir flows through a penstock which contains a nozzle at the outlet. The nozzle increases the kinetic energy of the penstock water. At the outlet this nozzle produces a water-jet. This water-jet strikes on buckets of the runner and transfers its kinetic energy to the bucket's wheel. The general formula of any hydraulic system is:

$$P = \eta\rho Q g H \quad (1)$$

Where,
$P$ is the mechanical power produced at the turbine shaft in watts.
$\eta$ is the hydraulic efficiency of the turbine.
$\rho$ is the density of the water in $\mathrm{kg/m^3}$.
$g$ is the acceleration due to gravity in $\mathrm{m/s^2}$.
$Q$ is the volume flow rate passing through the turbine in$\mathrm{m^3/s}$.
$H$ is the effective pressure head of water across the turbine in meter.
For an impulse turbine of pelton wheel type, the mechanical power can be changed by means of changing $\eta$, $Q$ and $H$ inputs as $g$ and $\rho$ are constants.
A Pelton turbine consists of a set of specially shaped buckets mounted on a periphery of a circular disc. It is turned by jets of water which are discharged from one or more nozzles and strike the buckets. The buckets are split into two halves so that the central area does not act as a dead spot incapable of deflecting water away from the oncoming jet.

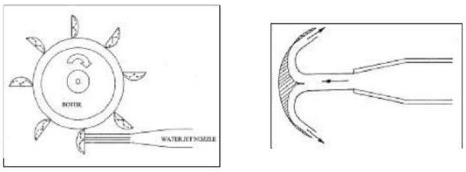

Fig.1: Impingement of jet and flow at outlet [1]

The cutaway on the lower lip allows the following bucket to move further before cutting off the jet propelling the bucket ahead of it and also permits a smoother entrance of the bucket into the jet.
The Pelton bucket is designed to deflect the jet through 165 degrees (not 180 degrees) which is the maximum angle possible without the return jet interfering with the following bucket for the oncoming jet [4].

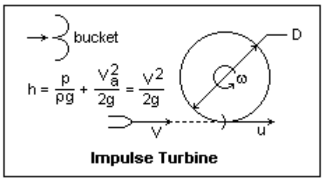


Fig. 2: Energy conversion in impulse turbine [2]

A diagram of a Pelton wheel is shown on the figure. The wheel of pitch diameter Dhas buckets around its periphery, so spaced that the jet always strikes more than one at a time. The buckets have the form shown at the upper left, where the water enters at a splitter and is diverted to each side, where the velocity is smoothly reversed. Bucket sizes are from 2.5 to 4 times the jet diameter. The total head supplying the nozzle is h, the sum of the pressure head and the approach velocity head. The theoretical jet velocity is $V = \sqrt{(2gh)}$. Let's analyze an ideal wheel, and assume that this is actually the jet velocity. The peripheral velocity of the runner is u.

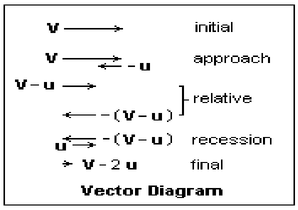


Fig.3: Vector diagram of velocity transformation [2]

The vector diagram above shows how the velocity is transformed by the runner. For simplicity, we assume that all velocities are in the same straight line. The relative velocity of approach to the runner is V - u. We assume that this velocity is reversed, so that the final velocity is V - 2u.
The force F on the runner is the rate of momentum change, or
$F = \rho[V + (V - 2u)]Q$
$\quad = 2\rho(V - u)Q \quad (2)$

Where, $\rho$ is the density and $Q$ the volume rate of flow of water.
The torque on the runner,

$$T = FD/2 = \rho D(V - u)Q \quad (3)$$

## 4. MODIFICATION OF THE PELTON WHEEL DESIGN

Pelton wheel is generally used for high head and low discharge applications. But it can be used for the low head also by adding some modifications in design. Splitters are used to increase the efficiency of the outlet of the water jet so that water can leave the bucket with a minimum velocity which is theoretically assumed tends to zero. The special modification is to increase the depth of the buckets which is not done in the usual pelton wheel buckets. In case of conventional Pelton wheel, only kinetic energy of the jet impinged from the nozzle, is used but there is no application of gravity in the turbine action. In this gravitational low head Pelton wheel, both the kinetic and gravitational energy of the jet are used. The weight of this stored water per second in the bucket is the amount of potential energy per second from water jet.
Furthermore, this potential energy is converted into kinetic energy as this water filled bucket freely (assumed) falls. It is also possible to extract kinetic energy from the penstock nozzle discharge by means of a jet strike on the conventional Pelton-wheel vanes of the runner. This hydro system is good for a low-head and heavy-discharge application. Apart from this, gravitational energy of stored water is further extracted during emptying of bucket water by means of jet-propulsion under water head. This jet propulsion works on a runner wheel taking place due to the Gravitational-Force on bucket's stored water and results in a water jet discharge. Stored water of bucket enables

delivery of two kinds of gravitational work on the runner wheel. They are in the form of kinetic energy conversion during its under-gravity free falling and in the form of jet-propulsion during its discharge from bucket-cup under gravitational pulling. In addition, as like Pelton-wheel, there is a provision for jet impulse on buckets.

### 4.1 Design of Pelton Wheel

The designing of the Pelton wheel consists of some design inputs, assumptions and design parameters.

**Design Inputs:**

Pressure head, H = 1.5 m

Power developed, P = 1W

**Assumptions:**

Co-efficient of velocity of the nozzle, $C_v=0.98$

Overall efficiency, $\eta_{turbine}$ = 85%

Ratio of peripheral velocity to jet velocity, $U/C_{actual}$ = 0.48

**Designed Parameters:**

Diameter of the wheel = D

Diameter of the jet = d

Size of bucket i.e. Length = A

Width = B

Depth = C

Number of buckets = Z

**Calculations:**

Actual velocity of the jet, $C_{actual} = C_v\sqrt{(2gh)}$

=4.34 m/s

Speed of the runner, $U = C_{actual}\times 0.48$

$=2.08m/\,C_v$

=0.43 to 0.48

Flow rate, $Q = P/\rho gH\eta_{turbine}$

= 0.388L/s

Diameter of jet, $d=\sqrt{(4Q/\pi C_{actual})}$

= 1.2cm

Diameter of the wheel, D =16×1.2

=19.2 or, 20cm here. D/d=16

Number of buckets, Z = $11+D/2d$

=11.83 or, 12

Size of Bucket: length, A = 2.8d to 3.5d

Or, A = 4cm

Width, B = 2.3d to 2.8d

Or, B = 3cm

Depth, C = 2.5cm

Wheel velocity, $U = \pi DN/60$

Or, N= 198.625 rpm

= 3.31 rps

The Specific Speed of a turbine is the speed in RPM at which a similar model of the turbine would run under a head of 1m. When of such a size as to develop 1 W. Note the suffix "s" is used to denote the values associated with the Specific Turbine.

For specific speed of turbine, $N_s= (N\sqrt{P})/(H^{(5/4)})$

=119.625 rpm

Specific speed is higher for the low head and high discharge. On the other hand it is lower for the high head and low discharge. It is a very important criterion for selecting a turbine for the same geometrical and dynamically similar turbines.

RPM of runner, $N = (U\times 60)/(\pi\times D)$=3.3 rps

So, wheel diameter, D = 20 cm

Jet diameter, d = 1.2 cm

Buckets, Z =12

Bucket length, A = 4cm,

Width, B=3cm,

Depth, C=2.5cm

Specific speed, $N_s$ = 119.65 RPM.

### 4.2 Experimental Setup

A modified Pelton wheel is made which is consisting of runner, bucket with splitters, shaft, gearing arrangement, a small generator or dynamo etc. Data is collected using measuring instruments such as stop watch, beaker, tachometer, multimeter etc. A water tap (flow control valve) from laboratory is used as a nozzle to conduct the experiment.

Fig.4: Manufactured pelton wheel (Front & Side view)

### 5. RESULTS AND DISCUSSION

In the analysis of experimental data, it was found that maximum power produced 0.347 watt when maximum voltage is 2.01V for the maximum discharge of 106 mL/s.

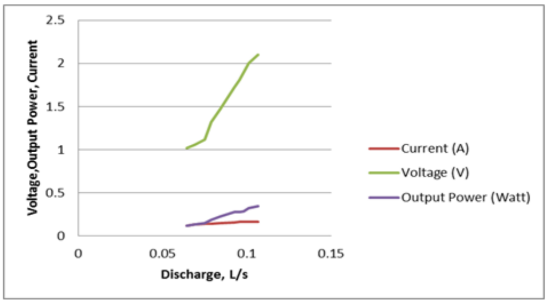


Fig. 5: Voltage, Output Power, Current Vs. Discharge graph

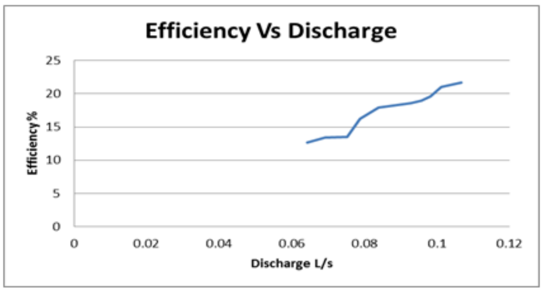


Fig. 6: Efficiency Vs. Discharge graph

Different types of graphs among discharge, voltage, power and efficiency are plotted using the data from this experiment. From the graph of figure 5, we can see that each parameter is increasing with the increment of discharge.

From efficiencyvs. discharge graph of figure 6, we can also notice that the efficiency of the turbine is increasing significantly along with the discharge. It is due to that the inertia of wheel becomes more negligible with the increment of the discharge. When data was taken for this experiment, the discharge was not so heavy. So the system loss was not recovered fully. It is noteworthy that the maximum efficiency was achieved is 21.65% for the maximum discharge.

So, it can be said that to get high efficiency, the turbine is needed to be operated in high discharge applications. Improved gearing arrangement & larger buckets could give better efficiency as well.

## 6. FUTURE SCOPES AND RECOMMENDATIONS

It can be recommended to minimize the inertial losses to increase the efficiency. Tachometer should be attached to read the rpm continuously. The shaft should be kept straight as much as possible to keep the outputconstant.

This type of turbine with large scale design can be used in large discharging canals or water exhausting system of different industries for producing power to electrify the isolated rural areas. For example, it is possible to use the cooling water exhaust of a thermal power plant to produce about 1kW of power that can be used for electrification purposes.

Pelton turbines are not used at lower heads because their rotational speeds become very slow and the runner required is very large and bulky. If runner size and low speed do not pose a problem for a particular installation, then a Pelton turbine can be used efficiently with fairly low heads.

If a higher running speed and smaller runner are required then there are two further options are available such as increasing the number of jets and using twin runners.

## 7. CONCLUSION

A modified gravitational Pelton-wheel is more effective for low-head and heavy discharge applications. For the same head condition, heavy electrical generators can be used for the modified gravitational Pelton-wheel than the conventional Pelton-wheel. The energy content in the runner shaft is lower in the conventional Pelton wheel. The modified wheel is more competent than the conventional impulse and reaction turbines. The development and fabrication of this turbine is not so tough in industrial aspects due to the available fabrication techniques of welding in the industrial workshops. However, it is not so easy to fabricate manually rather than industrial aspects. The more efficient wheels require accurate design and precise fabrication techniques. Due to the larger bucket sizes, it requires precise balancing of mass and reducing the losses due to bearing and wind resistance to get the maximum efficiency. However, it is desired that the much better and efficient Pelton wheel will be designed in future improving the bucket design to utilize the maximum energy of water jet.


## 8. ACKOWLEDGEMENT

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## 10. NOMENCLATURE

| Symbol | Meaning | Unit |
|---|---|---|
| $P$ | Mechanical powerproduced at the turbine shaft | (Watt) |
| $\eta$ | Hydraulic efficiencyof the turbine | [-] |
| $\rho$ | Density of the water | ($Kg/m^3$) |
| $g$ | Acceleration due to gravity | ($m/s^2$) |
| $Q$ | Volume flow ratepassing through the turbine | ($m^3/s$) |
| $H$ | Effective pressure head of wateracross the turbine | (m) |
| $N_s$ | Specific speed of turbine | (rpm) |
| $N$ | Wheel velocity | (rps) |
| $C_v$ | Co-efficient of velocity | [-] |
| $V$ | Theoretical jet velocity | (m/s) |
| $u$ | The peripheral velocity of the runner | (m/s) |
| $C_{actual}$ | Actual velocity of the jet | (m/s) |