Bucket Design of Water Wheel for Electricity Generation

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Abstract -- This paper introduces the way of converting from hydraulic energy to mechanical energy and producing 6 kW electricity by using overshot water wheel for low cost and preserving of fuel. In this paper, the design flow rate of water is 0.5522 m^3/s and the net head is 2.7431m. The diameter of the wheel is 2.133 m and the width of the wheel is 0.5124m. The power depends on the diameter of the wheel and torque of the wheel applied by gravity is 3549.91 N-m. Wheel's width is more than 10% of the flume width so that water may enter without splashing and air in the bucket escape efficiently. In this paper, power of the overshot water wheel is derived from the potential energy of the water. Due to the slow rotation of the wheel, the speed up transmission system is needed to drive the generator. In general, overshot water wheels are relatively efficient mechanically and are easily maintained. Their slow speed and high torque make them a good choice to operate for essential purposes.

Indexed Terms: bucket, hydraulic energy, mechanical energy, transmission system

I. INTRODUCTION

Hydropower is converted to mechanical power by using of water wheel to reduced manpower. Water wheels are preferable for rural area and mountainous regions in generating electricity as their low cost compare with engine and turbine. Vertical wheels, horizontal axis, are more preferable than horizontal wheels. Overshot water wheel rotated when falling water strike the paddle, blades or buckets.

And the wheel also has the advantage when buckets are used because the weight of water in bucket also causes rotation. The overshot water wheels are suitable for small scale hydropower plant in rural area.

A water wheel is a means of extracting power from the flow or fall of water and also known as hydropower. The three basic types of water wheel are undershot, breasts hot and overshot. A vertically mounted water wheel that is rotated by water striking paddle or blades at the bottom of the wheel is said to be undershot. It can only be used where the flow rate is sufficient to provide torque and suited to shallow streams. Breastshot wheel rotated by falling water striking buckets near the center of the wheel's edge. They are preferred for steady, high volume flow. A vertically mounted water wheel that is rotated by falling water striking buckets near the top of the wheel is called overshot.

The mechanical power from an overshot wheel is determined by the wheel's size, head and water flow rate but does not require rapid flow. They are ideally suited to hilly regions. The main issues that should be considered in a preliminary site selection are measurement of usable head and flow rate of water. The most effective and reliable head measurement is water fill tube method. This method is helpful for low head site, because it is cheap and reasonably accurate. The theodolite method is expensive and heavy for head measurement. But capable of fast and accurate work where the ground is fairly clear. For measuring the discharge, sources of information such as rainfall records, size of catchments area and local knowledge are also needed. The bucket measurement is simple way of measuring the discharge. The whole flow to be measured is diverted into a bucket or barrel and the time is take for the container to fill is record. Weir and stick gauge method requires construction of a weir across the stream to measure discharge [6].

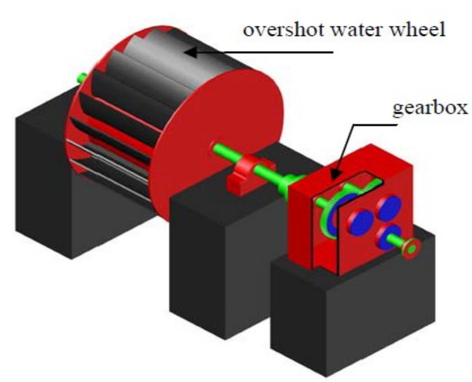

Fig. 1: Overshot Water Wheel Layout

II. BASIC COMPONENTS OF OVERSHOT WATER WHEEL

The overshot waterwheel is used with head of 3~9 meter and flow rates from 0.3~9 cu m pre seconds. Water is guided to the wheel through a wood or metal flume. A gate at the end of the flume controls the water flow to the wheel.

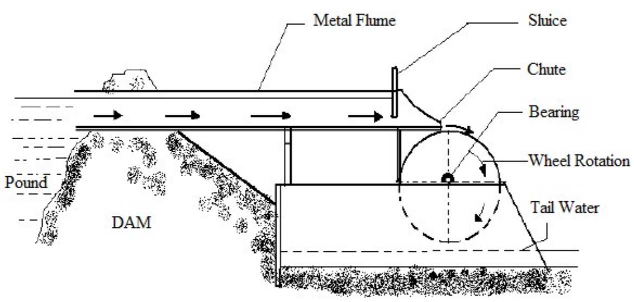

Fig. 2: Simple Overshot Water Wheel Layout

Wheel width should be 10 percent greater than the width of the flume. Overshot wheels are simple to construct. A smaller wheel may be made of a solid disc of wood or steel. Construction of a wheel involves three basic parts which are disc or spokes of the wheel itself, the buckets that hold the water and the mounting frame work.

III. DESIGN CONSIDERATION FOR OVERSHOT WATERWHEEL

To determine the potential power of the water flowing in a river or stream, it is necessary to determine both the flow rate of water and the head through which water can be made to fall.

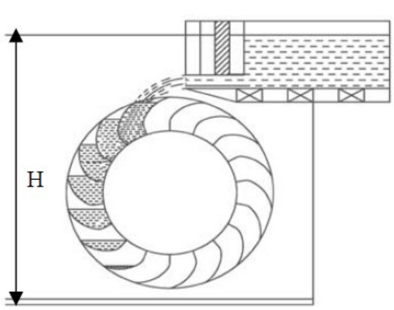

Fig. 3: Water Wheel Head

It is a power conversion system, absorbing power in the form of head and flow, delivering power in the form of electricity or mechanical shaft power.

$$P_{input} = \gamma \, Q \, H \quad (1)$$

where, γ = specific weight of water (N/m^3)
Q = designated discharged (m^3/s)
H = head (m)

The overshot water wheel derives its name from the manner in which it is activated by the water. From a flume mounted above the wheel, water pours into operates by gravity. The water filled buckets on the downward side of the wheel over balance the empty buckets on the opposite side and keep the wheel moving slowly. Overshot water wheels are relatively efficient mechanically and are easily maintained. Their slow speed and high torque make them a good choice to operate for other purposes [5].

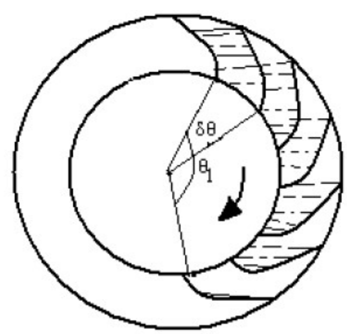

Fig. 4: Angle of Wheel's Rotation

The torque is applied solely from the gravitational potential energy of the water. There will be assumption that these buckets at angle θ, where $0 < \theta \leq \theta 1$, are filled with water and that all the others are empty. There are *n* buckets each occupying an angle $\delta\theta$ around the rim. So equation become

$$n\delta\theta = 2\pi \quad (2)$$

The mass of water in each bucket is δm.

$$\delta m = \frac{\rho Q \delta\theta}{\omega} \quad (3)$$

where, ρ = water density (kg/m^3)
Q = flow rate of water (m^3/s)

$\delta\theta$ = space between two constitutive bucket in degree

ω = water wheel angular speed (rad/s)

The torque applied about the waterwheel axle by the weight of water is δG.

$$\delta G = \delta m \, g \, R \sin(\theta) \qquad (4)$$

where, R = wheel radius (m)
g = gravitational force (m/s^2)
δm = mass of water per bucket (kg)
θ = location of the filled bucket (degree)

For large n, the total torque is as fallows.

$$G = \frac{\rho g Q R}{\omega} \int_0^{\theta_1} \sin\theta \, d\theta \qquad (5)$$

Above equation becomes,

$$G = \frac{\rho g Q R}{\omega} [1 - \cos\theta_1] \qquad (6)$$

The equation of motion is

$$I\dot{\omega} = \dot{G} - G_1 \qquad (7)$$

where, I = moment of inertia of wheel and water (m_4)
ω. = change in angular velocity (rad/s^2)
G = Torque (N-m)
Gl= Torque due to load (N-m)

For steady state, $I\mathring{\omega}=0$
Angular speed becomes

$$\omega = \frac{\rho g Q R}{G_1} [1 - \cos\theta_1] \qquad (8)$$

where, ω = angular speed (rad/s)
ρ = density of water (kg/m^3)
g = gravity (m/s^2)
Q = water flow rate (m^3/s)
R = water wheel radius (m)
Gl= torque due to load (N-m)

The power output is
Poutput= ω Gl (9)

The efficiency becomes

$$\eta_{wheel} = \frac{P_{output}}{P_{input}} = \sin^2\left(\frac{1}{2}\theta_1\right) \qquad (10)$$

IV. BUCKET CURVATURE

For highest efficiency, water must be delivered to the wheel from a chute placed as closed to the wheel as possible and arranged so that the water falls into the bucket just after they reach upper dead center. The relative speed of the bucket and the water are very important. The water in the flume will flow to the end where it will fall and gravity causes it's down ward speed to increase. By using the water trajectory method, the arching line will be get.

$$V_{wt} = \frac{x}{\sqrt{\frac{2y}{g}}} \qquad (11)$$

where, V_{wt}= sprouting velocity (m/s)
x = horizontal water displacement (m)
y = vertical water fall (m)
g = gravity (m/s^2)

The curve of the blade can be chosen from a circle. The common center point is O for circle with radius r1 and r2. The bucket angle is less than 16˚ at the entrance of wheel by Banki design [3].

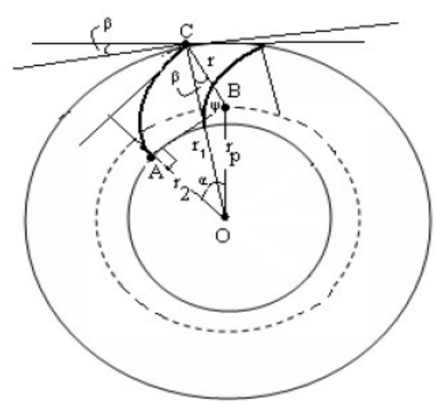

Fig. 5: Bucket Curvature

where,
r1 = outer radius of water wheel (m)

r2 = inner radius of water wheel (m)
rp= radius of pitch circle (m)
r = radius of bucket arc (m)
β = angle of tangent to the wheel circumference
ψ = angle of arc AC

From Δ OAB,

$$r_p^2 = r^2 + r_2^2 \quad (12)$$

From Δ OCB,
By using parallelogram rule,

$$r_p^2 = r_2^2 + r^2 - 2r_1 r \cos\beta \quad (13)$$

By equating equation (12) and (13),

$$r = \frac{(r_1^2 - r_2^2)}{2r_1 \cos\beta} \quad (14)$$

By using sin rule for Δ OAB,

$$\frac{r}{\sin\alpha} = \frac{r_p}{\sin 90} \quad (15)$$

By using cosin rule for Δ OCB,

$$r_1^2 = r_p^2 + r^2 - 2r_p r \cos(\alpha_1 + \varphi) \quad (16)$$

The angle of arc AC, ψ, will be get.

V. DESIGN OF SHAFT

The overshot water wheel shaft will transmit the rotary motion of the blade or bucket to the generator from the drive system. Shaft has a circular cross section end is subject to either pure torsion or bending. The wheel is uniform load on the shaft. The power is delivered to the shaft by some tangential force. The resultant torque or twisting moment set up within the shaft permits the power to the various machine elements such as gears and pulleys linked to the shaft. These members are mounted on the shaft by means of keys. The material selection must be taken into account during the design analysis. The diameter of the shaft can be calculated by the following ASME-Code equation [7].

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (17)$$

where,
Mt = torsion moment (N-m)
Mb= bending moment (N-m)
Kb = combined shock and fatigue factor applied to bending moment
Kt= combined shock and fatigue factor applied to tensional moment

Flexible shafts are commercially available but are of limited torque-carrying capacity. Bearing can be basically classified into ball, roller, taper and needle bearing. The type of bearing and load on the bearing is preliminary for the life of bearing from table SKF ball and roller table.

To design the overshot water wheel, there will be some assumptions in theoretical analysis. The Table I show the known data and Table II also expresses the result data from calculation.

Table 1: SPECIFICATION DATA

Known Data	Value	Unit
Wheel's diameter, D	2.133	m
Flume depth, h	0.61	m
Head, H	2.7431	m
Depth of bucket, Bh	0.3048	m
Discharge angle of wheel, θ1	150	°

Table 2: RESULT DATA FROM CALCULATION

Result Data	Value	Unit
Spouting velocity, v	3.459	m/s
Wheel's speed, u	3.21687	m/s
Wheel's revolution, N	29	rpm
Bucket's space, Bs	0.335	m
Pitch circle radius, rp	0.82	m
Radius of bucket arc, r	0.3014	m
Angle of arc, ψ	70°45′	
Torque of wheel, G	3549.91	N-m
Blade pitch, P1P2	0.26	m
Shaft diameter, d	58	mm

The following Figure (6) and (7) are the configuration of overshot water wheel assembly and cross section view of overshot water wheel based on the result data from calculation.

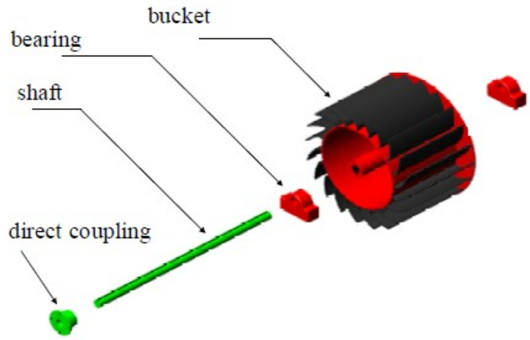

Fig.6 Assembly of Overshot Water Wheel

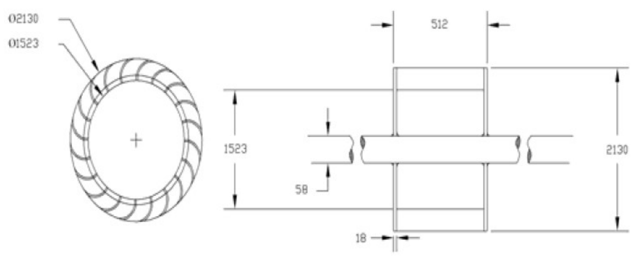

Fig.7 Cross sectional View of Overshot Water Wheel

VI. RESULTS FROM EXPERIMENT

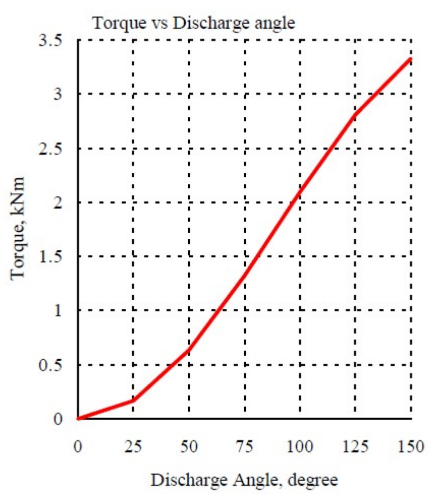

Fig.8 Torque versus Discharge Angle

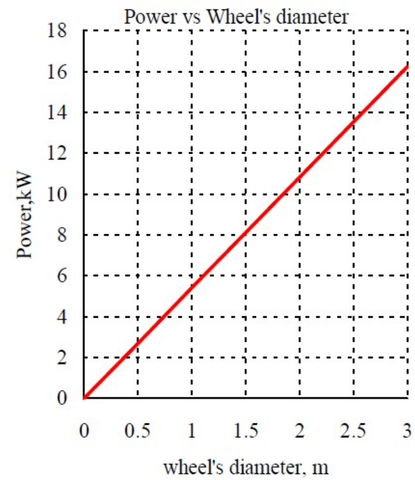

Fig.9 Power versus Wheel's Diameter

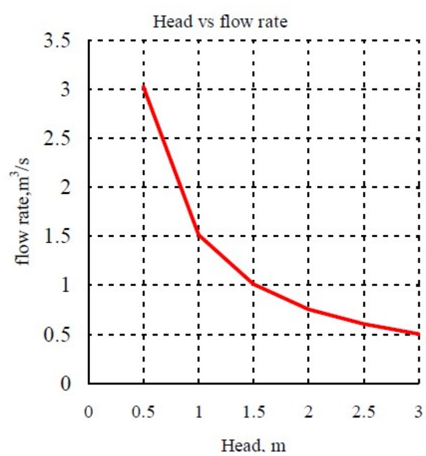

Fig.10 Head versus Flow Rate

The above figures show the graphs of torque and angle of rotation or discharge angle, and variation of power and wheel's diameter when water flow rate is constant, and power constant, the water flow rate also vary depend on the head.

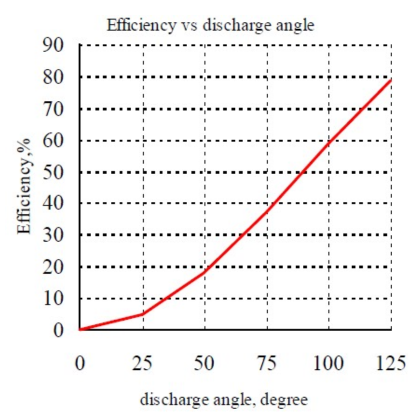

Fig.11 Efficiency versus Discharge Angle

This figure show the efficiency of overshot water wheel depends on the angle of discharge increase or spill angle. There is an assumption that the wheel is power by gravity, by the weight of the water alone.

VI. CONCLUSION

In hydropower plant, hydro wheel and turbine are one of the most important parts to generate electricity. Overshot water wheel is use to convert the hydraulic energy to mechanical energy. The slow rotation of water wheel leads to high gearing ratio when trying to generate electricity. Overshot water wheel is high in torque depending on the flow rate of water and diameter of water wheel. When the water is discharge at bottom dead center, overshot water wheel will get high torque and almost full power. In design consideration of overshot water wheel, centrifugal force due to the wheel rotation should be taken into account.

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