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The effect of an angle on the impact and flow quantity on output power of an impulse water wheel model

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Abstract

Nowadays, the world is more focused on hydraulic energy, which scientists have initiated thorough analyses of hydropower resources. The potential of wind power generation is immense. It is an historical source of energy but wind power is not applicable in this case. In India, water can be used for both - as a source of electricity and for irrigation and agricultural use. Impulse type water wheels were employed until flow is accessible. According to available literature, there are three types of water wheels and the application of a particular type of water wheel depends upon the stream of water. In this article, an extremely uncomplicated category impulse water wheel is fabricated. To fabricate this water wheel, little engineering is required. The experimental results obtained indicate that intensity of generated power depends upon the angle of water impact on the turbine blade, height, quantity of water flowing in pipe etc. The aim of this article is to suggest an alternative source of economical and environmentally friendly green energy for a small quantity of fluid flowing. There are various sources of small quantity water such as large society storage tank water, sewer line water, canals water and many more. The construction cost of water wheels is not as much since it does not have an intricate blade profile.

Keywords: water head, impulse, water wheel, angle, flow quantity, green energy, prototype, fabrication

List of symbols

P = Power in Watts
η = Hydraulic Efficiency
ρ = Density of Water
Q = Volume of Water flowing in turbine
H = Water pressure head
F_x = Force exerted by water Jet
a = Cross-sectional area of Water Jet
d = Diameter of Jet
V_1 = Velocity of Jet at Inlet of Turbine Blade
V_{w1} = Velocity of the whirl at inlet in m/s.
V_{w2} = Velocity of the whirl at outlet in m/s
W_J = Work done by Jet on Turbine
β = Angle of Vane at outlet

Introduction

Water wheels are the oldest machines used for various purposes. Initially, water wheels were made from wood and efficiency of the wheels was very small because design of such water wheels was based on random selection of material, shape, dimensions etc.

Among all the renewable energy sources available, small hydropower is considered as the most promising source of energy. In many parts of the country, especially hill states, streams coming down the hills possess sufficient potential energy that can be utilized. The water wheels are used to convert the potential energy of water to mechanical energy. Flowing water is directed onto the blades of water wheels, creating a force on the blades which in turn, rotates the shaft (Khurana *et al.*, 2012).

In the modern scenario, the development of the water wheel is based on the principle of hydraulic engineering, proper material selection, consideration of aerodynamic forces etc. Therefore, the efficiency of modern water wheels has increased sharply. The development of steam engines and hydraulic turbines also has been a milestone in the development of water wheels. Nowadays, water wheels are rarely used but there is large scope for water wheels in the modern era for utilizing small water flow and salvaging kinetic energy (Muller *et al.*, 2004).

Table 1: Different types of water wheels with their parameters
(Muller 2004)

S. no.	Type of water wheel	Position of water entering	Head difference	Flow rates
1	Overshoot	Upstream water level above the level of wheel axes	2.5m-10m	0.1 m^3/sec-0.2 m^3/sec
2	Breast	Upstream water level in the level of wheel axes	1.5m-4m	0.35 m^3/sec-0.65 m^3/sec
3	Undershoot	Upstream water level below the level of wheel axes	0.5m-2.5m	0.5 m^3/sec-0.95 m^3/sec

There are three types of water wheels namely, overshoot, breast wheel and undershoot. The difference between the three wheels is indicated in Table 1.

In the starting phase of the development of the water wheel, its various parts were made from hard wood. The specification of a water wheel has been shown in Table 2.

Table 2: Water wheels different parts, materials and dimensions
(Ibrahim et al., 2006)

S. no	Part name	Material	Dimensions
1	Wheel	Hard wood	150 cm-300cm
2	Water Chamber	Hard wood	25cm -35cm
3	Bearing	Steel	20cm -25 cm
4	Blade shaft	Hard wood	20cm-30cm
5	Blade Number	Hard wood	25-30
6	Blade Angle	-	30^0
7	Water Flow Angle	-	30^0

Because of the ecological and environmental restrictions in energy production, the use of small hydropower resources will be economical in future. Standard pumps could be considered as a low cost alternative for water wheels (Diana *et al.,* 2010).

The manual drawing of these characteristics is a long and, sometimes, a subjective process. Particular software will increase the speed and the quality of the process (Dorian *et al.,* 2004).

In modern engineering, water wheels are initially designed by CFD analysis and then the actual model can be fabricated. The efficient application of advanced CFD is of great practical importance, as the design of hydraulic turbines is custom-tailored for each project (Drtina *et al*., 2006). The parameters that should be considered for water wheel design are head difference, flow volume, different geometry of vanes etc. (Sonaje *et al.,* 2013).

A detailed study of the available literature for water wheels was conducted. According to a literature review and results presented by numerous scientists, indicate that efficiency/effectiveness of water wheels depends upon various factors. Some of the factors are the geometry of the blade, type, material etc. so as to minimize losses. But the most important factor is an economical consideration. India is a developing nation therefore there is a necessity to develop a low cost/maintenance water wheel. The suggested prototype is a low cost water wheel and applicable for wide range of flow quantity/head.

Prototype model and its description

An extremely simple prototype model has been fabricated. This model is very straightforward without considering any blueprint factors in cavity/blade design. Because the blades are uncomplicated, they are very cheap, and the efficiency of these water wheels changes marginally for small quantities of water flow. The dimensions of a proto-type water wheel are listed in Table 3.

Table 3: Dimensions of a prototype water wheel

S. no	Water wheel component name	Dimension
1	Shaft diameter	8 mm
2	Shaft length	300 mm
3	Turbine blades	8
4	Blade length	50.8 mm

Figure 1 shows a schematic diagram of a water wheel. The various components of a water wheel are a water wheel holding stand, two ball bearings for holding the rotating shaft, blades of the water wheel, dynamo-meter to convert potential energy into electrical energy, water pipe and water jet. The output power of the dynamo-meter can be measured with the help of an Ampere meter/voltmeter. The water wheel holding stand grasps water wheel shocks and vibrations for noiseless operations. The dimensions of the water wheel have been included in Table 3 with the diameter of the pipe through which water is flowing is 20 mm. Water of the test setup is collected in a separate tank and the difference in the water level specifies the flow quantity of water in the impulse water wheel. For protection, the entire experimental setup has been covered up by a transparent fibre glass sheet.

Result and discussion

With the help of a fabricated prototype water wheel, the effect of the angle of impact and flow quantity on output power had been calculated. The water wheel consumes hydraulic energy of the water and converts it into mechanical energy and then to electrical energy. There are various types of losses; some of those losses are leakage loss, mechanical

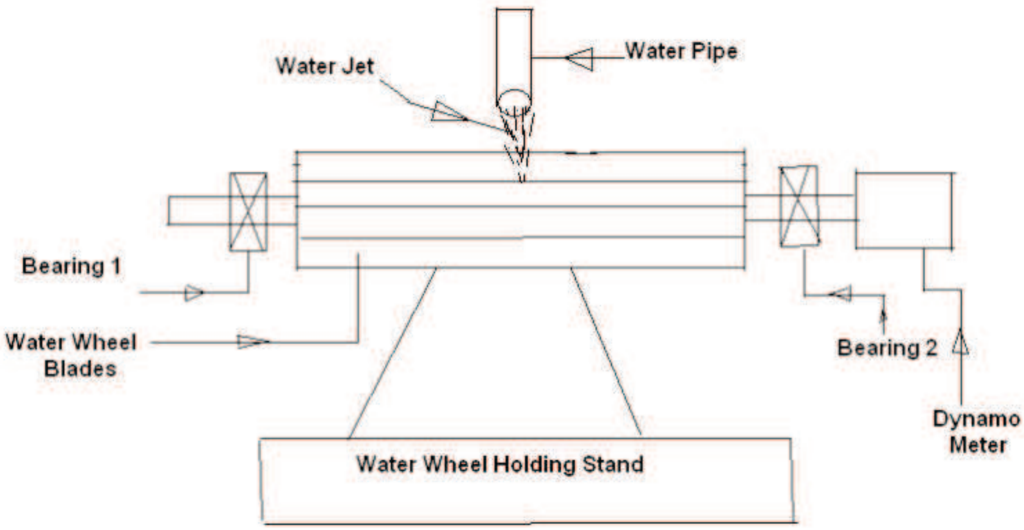

Figure 1: Schematic diagram of a prototype water wheel

loss, electrical loss etc. The basic equations which can be used to find hydraulic energy had been discussed by Tyagi (2012). Some equations which play a vital role for finding hydraulic energy are written from Equation 1 to Equation 7.

The total power available in falling water:

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

The force exerted by the water jet on buckets (vanes) of the runner in the direction of motion is given as:

$$F_X = \rho a V_1 [\overline{V_{W1}} + \overline{V_{W2}}] \tag{2}$$

The work done by the jet on the runner per second is as follows:

$$W_j = F_X \times u = \rho a V_1 \left[V_{w1} + V_{w2}\right] \times u \tag{3}$$

Kinetic Energy (K.E.) of the jet per second is given as:

$$\text{K.E.} = 1/2 \rho a V_1 \times V_1^2 \tag{4}$$

Hydraulic efficiency η_h = Work done by jet per second ÷ K.E. of jet per second.

$$\eta_h = \rho a V_1 \left[V_{w1} + V_{w2}\right] \times u \div 1/2 \rho a V_1 \times V_1^2 \tag{5}$$

$$\eta_h = 2(V_1 - u)[1 + \cos\beta]u \div 1/2 \rho a V_1 \times V_1^2 \tag{6}$$

$$\{V_{w1} = V_1 - u\},\ V_{w2} = (V_1 - u)\cos\beta - u\}$$

For maximum efficiency u is $= 1/2 V_1$,

$$\eta_{h\max} = 1 + \cos\beta / 2 \tag{7}$$

Figure 2 demonstrates the deviation in output power for different values of pressure heads. In this diagram, three impact angles have been considered, and these angles are 90 degree, 75 degree, and 60 degree respectively. The outcome achieved by experimental analysis demonstrates that output power is directly related to the angle of impact on the blade of the water wheel. The results in Figure 2 also indicate that after a certain value of water head output power is approximately constant for particular dimensions of the water wheel. After a certain value of pressure head, there is no effect of increasing pressure on output power because a critical velocity of the water wheel is achieved. In the water wheel, the critical velocity is the parameter where the wheel attains the maximum velocity for a particular type of wheel. The value of the critical velocity depends upon numerous parameters, some of which are: wheel dimensions, and geometry of water wheel blade.

Figure 3 shows the variation of the water wheel output power versus flow quanity of water. The result obtained in Figure 3 indicates that after 1.5 l/s of water, there is no effect or only a marginal effect on output power. Again, water jet impact angles are similar to those discussed in the Figure 2. The result obtained in Figure 2 illustritates that the critical velocity for the prototype wheel had been attained at 1.5 l/s; and above this quantity there is no positive effect on output power.

Figure 4 shows the variation of output power versus angle of impact of water jet for different values of the incident angle when the head and water discharge are fixed at 110 mm and 1.1 l/s respectively. In this experiment, the angle of impact of the water jet varies from 0 degree to 180 degrees. The value of the output power varies almost linearly from zero to maximum from 0 to 90 degree and then reduces from maximum to zero from 90 to 180 degree. For given parameters the maximum value

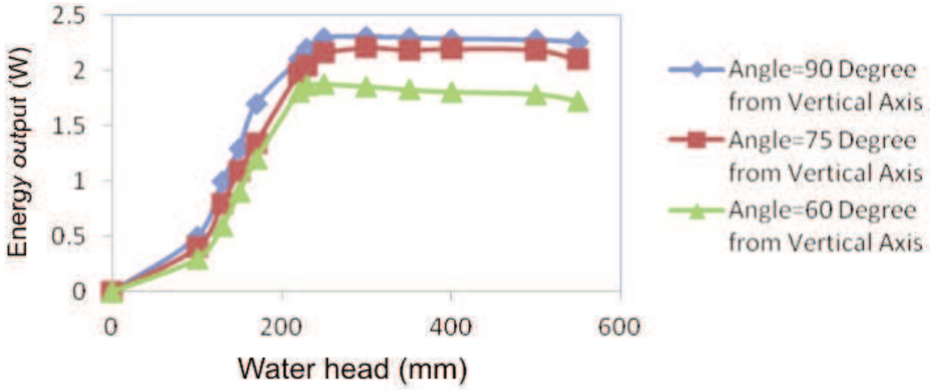

Figure 2: Variation of energy output (W) versus water head (cm) for different values of water head and discharge of water of 1.1 l/s

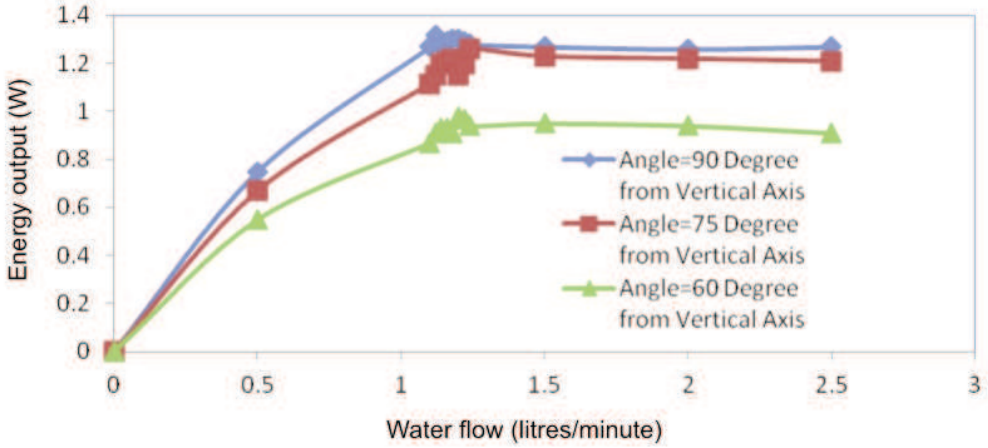

Figure 3: Variation of energy output (W) versus water discharge l/s for different values of water discharge and head of water of 110 mm

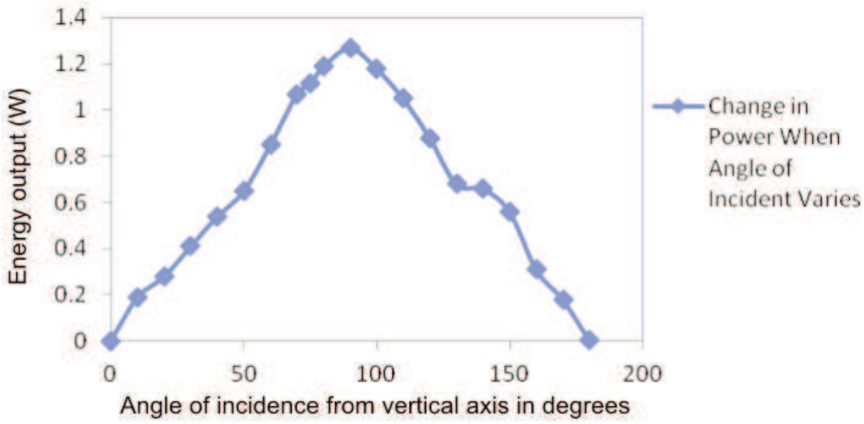

Figure 4: Variation of energy output (W) versus angle of impact in degree for different values of angle of incidence for head and discharge of water of 110 mm and 1.1 l/s

of output power is 1.27 watts, when the angle of impact is 90 degree.

Figure 5 shows experimental results for the water wheel model efficiency versus ratio of quantity of fluid to maximum quantity of fluid for a water head of 110 mm. The efficiency and fluid quantity ratio graph have been drawn for incident water jet angles of 90 degree, 75 degree, and 60 degree respectively. Above a ratio of quantity of fluid to maximum quantity of fluid of approximately 1.5 efficiency was approximately constant.. Above that value, the effect on output power is neglible.

Conclusions

A detailed study on the design of the simplest model water wheel has been investigated. In an experimental study, it was found that to make optimum use of resources such as blade manufacturing cost, available water head etc., the simplest type of water wheel will be a milestone for developing countries.

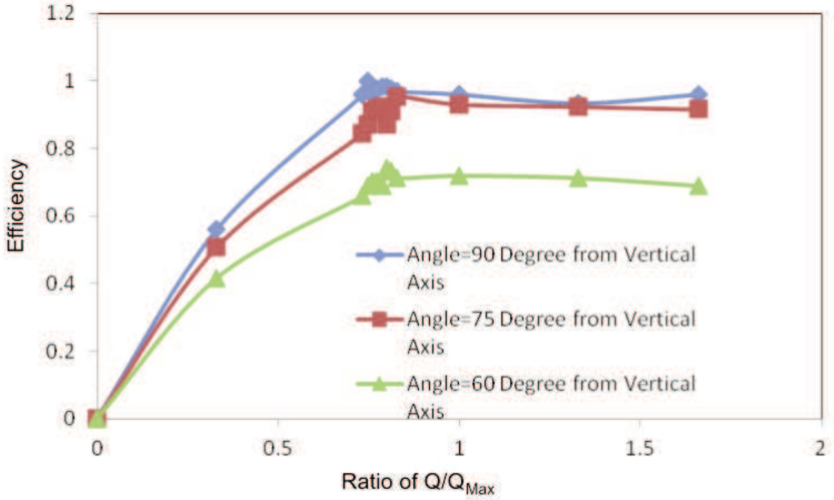

Figure 5: Variation of efficiency versus ratio of quantity of fluid to maximum quantity of fluid for different values of angle of incidence for a water head of 110 mm

Efficiency measurements were conducted for large range of water flow and for different angles of incidence. The results obtained by a proto-type water wheel indicate that water wheels generate maximum power when the angle of incidence of the water is 90 degrees from the blade. Efficiency measured by experiments indicates that the water wheel gave maximum power over a broad range of flows. This type of water wheel is very cost effective because it may be deployed for a blade on a water wheel without any curvature.

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