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Design and cost analysis of low head simple reaction hydro turbine for remote area power supply

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ABSTRACT

This paper is aimed at exploring the performance characteristics of a simple reaction hydro turbine for power generation. Using principles of conservation of mass, momentum and energy, the governing equations have been identified for an ideal case of no frictional losses. The paper also describes the conception of a cross-pipe rotor for remote area electricity production. Using the ideal governing equations an optimized geometry of the rotor was selected for the working head of 5 m. Theoretical analysis of the self-governing characteristics has been presented. Experiments were carried out for 2, 3, 4 and 5 m head and evaluated against theoretical results. Split pipe turbine model is presented with detail layout, while different methods of experimentation are explored for different output requirements with varied heads. Various losses in the system are discussed, quantified and included in the graphical format. It is also demonstrated that the experimental power outputs do not have the same tendencies as theoretical predictions and decreases due to jet interference beyond a certain rotational speed as it passes the maximum power point.

1. Introduction

With the increase in awareness about the importance of a sustainable environment, it has been recognized that traditional dependence on fossil fuel extracts a heavy cost from the environment. Hence keeping in mind that the world is currently heavily dependent on fossil fuels which are rapidly diminishing, the role of renewable energy has been recognized as great significance for the global environmental concerns. Hydro-power is a good example of renewable energy and its potential application to future power generation cannot be underestimated.

Water energy being a clean, cheap and environment friendly source of power generation is of great importance for sustainable future; being aware of this fact, still major of the hydro energy is under utilized. The main reason being initial investment in building huge dams and large power stations, the second reason is these large dams are not environment friendly. Additionally, most of the low head water sources are yet to be explored. The cost of the commercially available low head water turbines is considerably high per kilowatt output, more research need to be done on lowering the cost of these low head hydro-power systems. Use of these low head water sources will help in de-centralization of power supply and helping remote area power supply [1]. Thus Barker's Mill/Hero's turbine was acknowledged to be the best option for cheap turbine [2].

This paper will focus mainly on the manufacturing and experimentation of a simple reaction water turbine working on the same principle of Barker's Mill under the micro-hydro range for low head applications. Simple manufacturing methods using locally available material and skills with cost analysis will be presented. The performance of the test unit will be explored and evaluated as well as identify potential areas for improvement.

2. Basic design and costing

Two types of simple reaction turbine designs have been discussed in the following notes: split pipe turbine and cross-pipe turbine. This paper will only discuss the performance analysis of split pipe turbine design.

The idea of split pipe reaction turbine is influenced by the "Savonius wind rotor" [3,4]. The split pipe reaction turbine shown in Fig. 1 is manufactured by cutting a plastic pipe into two halves and then off-set the centers by 6 mm and joint the top and bottom plates. This is thought to be the simplest method for manufacturing a simple reaction turbine and hence the name "split pipe reaction turbine". Grey PVC pipe with wall thickness of 6.5 mm and nominal diameter of 250 mm was used. Table 1 discusses the simple costing of split pipe turbine.

Another turbine has been designed and manufactured using standard galvanised pipe fittings which is shown in Fig. 2. This

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Nomenclature

A_n	area of each nozzle (m^2)
d_n	nozzle diameter (m)
n_f	number of faces
n_n	number of nozzles per face
g	acceleration due to gravity (m/s^2)
H	head (m)
H_c	centrifugal head (m)
$\dot{m}$	mass flow rate of water in turbine (kg/s)
$\dot{V}$	volume flow rate (m^3/s)
ρ	density of water (kg/m^3)
R	radius of the rotor (m)
T	torque (N-m)
$\dot{W}$	output power (W)
ω	angular velocity of the rotor (rad/s)
U	tangential velocity of the nozzles (m/s)
V_a	absolute velocity (m/s)
V_r	relative velocity (m/s)
k	factor for viscous losses

turbine is made from 3″ cross at the center with the two arms made out of 3″ adapter fittings. Each arm carries a 3″–2″ reduction elbow to direct the flow in the tangential direction to the rotor diameter. Standard 15 mm solid stream jet nozzles are attached to both the elbows at the exit, this helps to recover the maximum possible thrust from the exiting flow [5]. Table 2 discusses the simple costing of cross-pipe turbine.

3. Experimental set up

The experimental test rig as shown in Fig. 3 was constructed based on previous studies [6] and experiments and was built purposely. In the experimental test rig we are trying to simulate actual flow conditions using a 7.5 kW water pump (Onga pump) which has a maximum flow rate of 300 l/min. The supply pressure and the flow rate to the turbine can be controlled using two gate valves on the upstream to the water pump; one valve is attached on the by-pass line and other is on the main supply line, we also have programmable speed controller which when connected to the pump power supply can be used to control the flow rate and pressure. Mechanical flow meter (operating range 5 l/s to 50 l/s) is installed after the by-pass on the supply line to measure the actual flow through the turbine. A pressure gauge is installed just before the entry port to the turbine to measure the actual supply pressure (range 0–100 kPa).

As shown in Fig. 4, water enters through the entry port where a V-ring lip (Forshida, Sweden) seal prevents water leakage. The seal works under pressure from the supply water; under very low (up to 5 kPa) pressure some leakage is observed. As the supply pressure increases the sealing ability improves, above 10 kPa it was observed that there was absolutely no leakage at the entry port. But the result of high pressure on the seal is higher frictional losses between the seal and the entry port which has been discussed further in Section 7.

The turbine is connected to a 1.5 kW 1750 RPM DC motor (Baldor motors) using a simple key and grub screw arrangement. The output of the DC motor passes through a variable electric load and an analogue and digital voltmeter and ammeter. As an electric load, potentiometers ranging from 50 W to 1000 W and load bank with globe bulbs in series and parallel combination were used for the performance analysis. Several tests were carried out on split pipe reaction turbine to determine the performance characteristics under low heads ranging from 2 m (approx. 20 kPa) to 5 m (approx. 50 kPa). The test results gave a better understanding of power generating capacity, rotor efficiency and of the overall system efficiency.

4. Governing equations

Assuming that losses related to flow of water from source, piping, rotor and nozzle are neglected, mechanical losses such as windage losses due to rotation of the rotor and frictional losses of the bearings are also disregarded. Assuming water to be incompressible appropriate equations have been derived with reference to Fig. 5 [7].

$$U = R\omega \quad (1)$$

$$V_a = V_r - U \quad (2)$$

With the centrifugal head

$$H_c = \frac{\omega^2 R^2}{2g} \quad (3)$$

Ideally kinetic energy should be equal to sum of potential energy and energy due to centrifugal head (assuming negligible fluid friction).

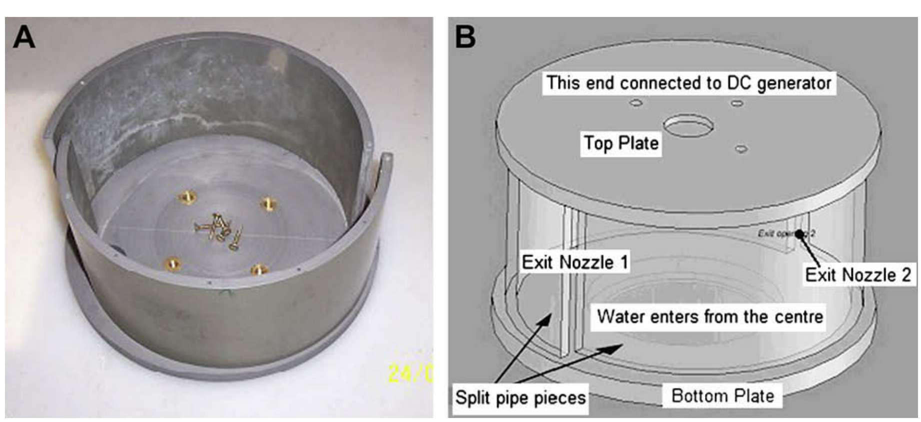

Fig. 1. Split pipe reaction turbines.