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Effect of channel geometry on the performance of the Dethridge water wheel

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ABSTRACT

Dethridge water wheel is a simple hydraulic machine originally invented for measuring volume of flow supplied to the farms. The wheel has been in widespread use for more than a century for the application of water charges in irrigated farmlands. The Dethridge water wheel resembles distinct characteristics making it a suitable device for utilising very low-head sites within irrigation canals, small streams and at the outlets of the waste water treatment plants for pico-hydropower generation. In this paper, performance characteristics of the Dethridge water wheel model is studied in different channel geometry settings. Different wheel to channel width ratios and gradual transition shapes were tested. The wheel performance improves in the channel width that is two to three times greater than the wheel width. The gradual transition shape has however insignificant impact on the performance of the wheel.

1. Introduction

Most of the very low-head sites for pico-hydropower are within redundant mill sites, weirs, irrigation networks and waste water networks. These sites with existing civil infrastructure, predictable flow rate and useful head represent significant future development potential for low-head hydropower development. Abandoned old mill sites have existing diversion structure and suitable head for very low-head hydropower. Flow in irrigation canals is usually diverted through a diversion canal, have a wide distributary network and are also often equipped with small drops to reduce bed erosion. With predictable and almost constant flow rate, waste water networks are also highly potential for hydropower [1,2]. The outflow discharged into the river at the outlet of waste water treatment plants generally have very low-head difference and almost constant flow rate. These resources offer a considerable scope to harness small scale hydropower [3–7]. However, technology suitable for employing these very low-head resources is still economically challenging.

Recent studies have shown that conventional technologies such as water wheels are suitable devices for very low-head sites [8–12]. Special interests would be for decentralised rural areas where water wheels would constitute economically and ecologically viable source of power generation [13]. The simple design, easy maintenance and ability to easily handle foreign objects make the water wheels an attractive source of power for decentralised rural applications.

One of the suitable water wheels for very low-head application is the Dethridge water wheel. It was originally invented for measuring volume of flow delivered from the outlets of the irrigation canal to the farm for application of water charges. The wheel has been in widespread use for more than a century in the irrigated farmlands of Australia, to some extent in the USA and in Asian countries [14]. Unlike conventional water wheels, the big hub of the Dethridge wheel acts like a dam and creates a head drop by itself. This distinct characteristic of the wheel could be utilised for hydropower from sites with very low-head differences. The simple and robust design of the wheel makes it even more suitable for its application in rural areas of the developing countries. Physical model tests of Dethridge water wheel have shown an efficiency of around 60% and ample amount of power output that could be utilised for simple applications like lighting, listen to the radio broadcasts, and battery charging facilities [15].

Channel geometry is an important performance and economical criteria to be considered for the implementation of the Dethridge water wheel in practice. The objective of this paper is to study the effect of channel geometry on the performance of the Dethridge water wheel. Tests on the Dethridge water wheel physical model were carried out to identify the optimal wheel to channel width

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ratio and channel transition shapes. Wheel width (b) to channel width (B) ratios of 1:1, 1:2, 1:3 and 1:4 were investigated. Furthermore, gradual contraction and expansion profiles on the upstream and downstream of the channel were tested. The physical model is described, the method of measurement, uncertainty calculation and data analysis are presented, and the performance characteristics of the wheel at different settings are compared and discussed.

2. Methodology

2.1. Test rig

The physical model of the Dethridge water wheel is tested in a rectangular flume. The flume is 20 m long, 1 m wide and 1.5 m deep and houses a model of the Dethridge wheel with shroud, shaft, torque transducer, speed sensor, stilling tubes, an inlet tank at the upstream and a control weir at the downstream. Side walls of the flume are made up of a glass and the bottom is a smooth concrete floor. Water was supplied through a pump of 50 l/s maximum capacity. The general layout of the test rig is shown in Fig. 1.

The Dethridge wheel model has a radius (R) of 30 cm (Fig. 2). The hub of the wheel is made up of PVC piping, which has a radius $r = 20$ cm and width $b = 25$ cm. The wheel is covered with 20 mm thick PVC side covers on both sides to ensure the stability of the wheel and to avoid the accumulation of water inside the hub which would otherwise retard the wheel motion. The gap between the sides of the housing and the wheel, and the bottom gap are 1 mm. The bottom curved shroud profile makes an angle of $\beta = 70^\circ$ to the center of the wheel. Six steel blades of 2 mm thickness are mounted along the circumference of the hub of the wheel. The blades are 10 cm long (l) and are bent in V-shape to acquire an angle of $\alpha = 127^\circ$. At the apex of each blade, an air vent is located to facilitate the filling and emptying of adjacent compartments as they enter and exit the water surface. The apex of the V is leading in the direction of rotation. Both sides of the blades are chamfered to match the fillets at the junction of the side walls and the floor. The blades are painted to reduce the surface roughness and to prevent corrosion. A stainless steel shaft of diameter 20 mm and 45 cm long was used.

2.2. Measured variables and methods

Flow rate (Q) delivered to the test flume is measured using a magnetic flow meter from Krohne Aquaflux F with IFC 110 F signal converter. This is a measure of volumetric mass flow rate through the wheel control volume including the amount of leakage flow through the side and bottom clearance gaps. The total head (H) acting on the wheel is the difference in the total heads between the upstream and downstream of the wheel. The elevation head ($z_1 - z_2$) is 0. Water levels (h_1) and (h_2) were measured at the immediate upstream and downstream of the wheel control volume. To measure the water levels, two stilling tubes were installed and depth gauges were used for the manual reading of the flow depth values. The subscripts 1 and 2 refer to the upstream and the downstream, respectively. The mean velocity of the flow is then calculated from the known area of the flow ($A_1 = Bh_1$; $A_2 = Bh_2$) and the flow rate ($v_1 = Q/A_1$; $v_2 = Q/A_2$), where B is the channel width. The total head H is therefore given by,

$$H = \left(z_1 + h_1 + \frac{v_1^2}{2g}\right) - \left(z_2 + h_2 + \frac{v_2^2}{2g}\right)$$
$$= \underbrace{(z_1 - z_2)}_{\text{elevation head}=0} + \underbrace{(h_1 - h_2)}_{\text{pressure head}} + \underbrace{\left(\frac{v_1^2}{2g} - \frac{v_2^2}{2g}\right)}_{\text{velocity head}} \tag{1}$$

The shaft torque (τ) is generated as a result of the energy transfer between the fluid and the rotating wheel. The shaft torque was transmitted to the torque transducer shaft through the Polyurethane synchronous belt drive. The measured torque therefore included mechanical losses due to the bearings and the belt drive. The torque on the wheel shaft was measured using the torque transducer from HBM model T22. The rotational speed (N) was measured using a solid shaft pulse encoder of make IFM model RB1015. The speed of the wheel was varied by applying load on the wheel through a Hysteresis braking system from Magtrol model HB-140M-2. The brake system operates at a higher speed range so a gearbox from Bretzel GmbH was used to step up the shaft speed at the brake end. The brake was electrically operated through a power supply of Magtrol make model 5210. Output signals from all the measurement instruments were collected into a junction box and fed to the computer using a LabVIEW based program. For each constellation, data were acquired for approximately one to 2 min and the mean value were taken for analysis. The detailed description of the test rig and measurement system is presented in Paudel [15].

The performance variables were measured for flow rates of

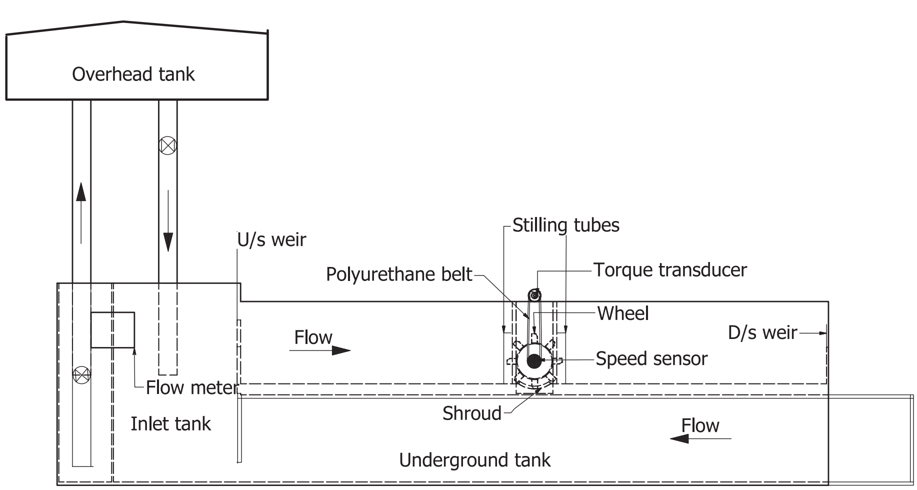

Fig. 1. Schematic sketch of the test facility.