Energy for Sustainable Development 25 (2015) 50–55

Contents lists available at ScienceDirect

Energy for Sustainable Development

Tests on a non-clogging hydrokinetic turbine

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A R T I C L E I N F O

Article history:
Received 31 July 2013
Accepted 9 January 2015
Available online 24 January 2015

Keywords:
Axial flow hydrokinetic turbine
Non-clogging
River debris
Remote villages
Electrical power supply and diesel powered genset

A B S T R A C T

Hydrokinetic turbines (HKTs) are a promising technology for electrical power supply in small remote villages located in fairly flat, high rainfall country where other renewable energy technologies such as wind, solar and conventional micro-hydro are not suitable. However, clogging by floating debris has been identified as a major problem for HKTs in many waterways, and particularly in tropical rivers. To overcome this problem, an axial flow HKT has been designed using conventional wind turbine blade element theory and modified so as to minimize clogging by allowing one or more blades to swing back and forth in its plane of rotation. A 0.8 m diameter prototype has been constructed using low cost materials and simple tools. The final design was observed to shed long stringy algae and operate normally where a maximum coefficient of performance of 0.25 and a water-to-wire efficiency of just under 20% were achieved.

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Introduction

The need for small scale electrical power supply in remote villages and the limitations of current means of supply have been documented in Anyi et al. (2010). Cheap diesel engine-powered gensets are commonly used, but fuel is expensive and difficult to transport, and these gensets typically fail after a year or two due to poor quality manufacture and/or lack of maintenance. The well-known renewable energy technologies are not suitable in high rainfall, densely forested country where (i) there is not enough wind for wind turbines, (ii) long periods of dense cloud cover limit photovoltaic production and high humidity and fast-growing fungus and vegetation can cause premature failures, and (iii) there is not enough static head for conventional micro-hydro.

Fig. 1 shows a typical village in Sarawak located right next to a large, fast-flowing river which is used for water supply, fishing and transport. Such rivers could also supply power via hydrokinetic turbines if the problem of clogging by floating debris could be overcome. According to Tyler (2011),

> *"Perhaps the greatest obstacle that confronts the implementation of commercial scale hydrokinetic devices in rivers is debris. Until recently, this problem has been largely avoided by installing devices in areas where debris is not a factor. This practice significantly limits the possible locations for deployment…."*

This is particularly true of tropical rivers which carry large amounts of vegetation during floods, but can be a problem in any waterway carrying floating debris. Fig. 2 shows driftwood piled up on a HKT pontoon and anchor cable in Alaska.

A screen in front of a turbine as proposed in Tiago (2003) is itself likely to become clogged by debris, thereby reducing or completely blocking flow into the turbine. Variants on the traditional undershot water wheel have been built and should shed debris under normal flow conditions because they are drag machines in which the paddles move with the water and debris should simply pass through with the water. Any debris sticking to the paddles will increase drag and should not adversely affect performance unless it damages the turbine or gets wound around the shaft. However these are large, cumbersome, inefficient devices requiring a very large wheel to generate useful power and a very large gear ratio to drive a generator. Existing HKTs have been reviewed in Anyi and Kirke (2010a, 2010b) and it was concluded that it should be possible to design a reasonably efficient axial flow HKT with blades that would "roll with the punches" and shed debris.

The clog-free rotor design concept

Besides aiming for a clog-free characteristic, the rotor must also be reasonably efficient and able to survive impacts. The banana-shaped blades used on some sewage treatment impellers (see for example in

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http://dx.doi.org/10.1016/j.esd.2015.01.001
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Fig. 1. A typical village in Sarawak, located right next to a river (Flicker, undated).

ITT, undated) are designed to shed debris, but they are motor-driven impellers designed for mixing, which they will do to some extent even if there is some debris on them. They are not lift type turbines designed to generate power, whose blades must be reasonably efficient to generate any power. Also, being rigidly fixed to the hub, these blades would be prone to damage from floating logs.

One possible way to avoid both impact damage and clogging would be to use flexible blades, but these would be difficult to design and construct in such a way that they operate efficiently under normal conditions but are flexible enough to avoid damage and shed debris. A simpler and better way appeared to be to mount blades on hinges so they could swing back on impact, or to allow debris to slide off. The obvious way would be to allow them to swing back in about a tangential axis as shown in Fig. 3, i.e. “cone” as shown in Fig. 4(c), with spring preload preventing the coning action under normal operating conditions. This would also limit blade loading in floods by reducing the turbine swept area causing it to shed some power, saving turbine blades and structures from over stress and damage. However the direction of flow relative to a blade traveling at a tipspeed ratio of about 4 is more tangential than axial over most of its length, so allowing blades to swing back in the plane of the rotor as shown in Figs. 3 and 4(b) should have a better self-cleaning action and would also cushion impact.

During normal operation the blades would be held in the radial position by stops, but if a blade becomes clogged to the point where it no longer generates forward torque it would be free to swing back so that the relative flow acts to slide the debris out along the blade and off the tip so that the blade again generates forward torque and swings

Fig. 2. Driftwood on hydrokinetic turbine pontoon and anchor cable in Alaska (Tyler, 2011).

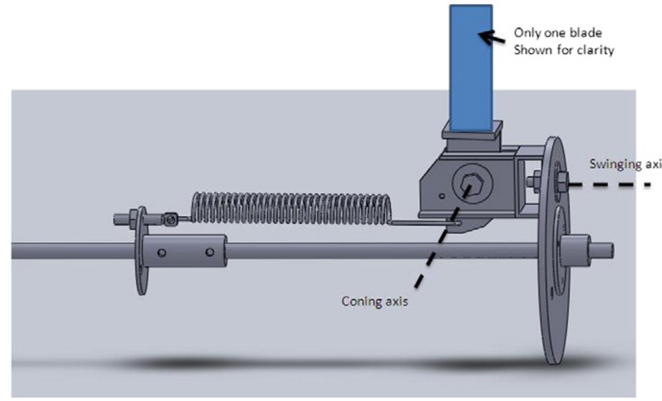

Fig. 3. Conceptual design for swing and cone blade motions.

forward into its normal operating position. However this mechanism would not limit blade loading in floods, so a combination to the two mechanisms would seem ideal.

Construction of a rotor with folding and swinging blades

After experimenting with a number of blade folding and swinging geometries, one potential design concept was chosen and further developed. Design of a blade geometry using conventional wind turbine blade element theory and its construction from timber using a simple router has been described in Anyi and Kirke (2010a, 2010b). Assuming a flow velocity of 1 m/s, a water-to-wire efficiency of 21% and a 200 W electrical output, it was determined in Anyi and Kirke (2010a, 2010b) that a turbine diameter of 1.6 m would be required.

A set of blades was designed and constructed using the techniques set out in Anyi and Kirke (2010a, 2010b), and another set was made out of cambered sheet aluminum to compare both performance and ease of construction. The coning and swinging mechanisms as originally constructed are shown in Fig. 5. There is a means of adjusting blade pitch and a means of adjusting coning spring tension. The non-rotating nose cone was intended to keep weeds out of the hub mechanisms.

Initial testing

The work was done in South Australia, the driest state of the driest inhabited continent, and in contrast to Sarawak, it was difficult to find a suitable waterway in which to test the turbine. There were no suitable laboratory facilities in South Australia and funding was not available to hire the large laboratory towing tank at the Australian Maritime College, which would have been ideal. Several possibilities were assessed and found to have either too low flow velocity or not enough flow area. The final choice was a 2.1 m wide concrete channel at Bolivar wastewater treatment plant which carries secondary treated sewage effluent (i.e. no solids, clear but nutrient-rich water with lots of long stringy sticky algae). Flow depth and velocity varied slightly with time of day, but average depth was about 1 m and average velocity was about 1 m/s. Although not ideal, this channel was available at no cost and is fairly close to the university campus, making logistics relatively simple. The 1 m/s flow velocity was considered representative of typical sites in Sarawak, but the 1 m depth meant that the original design, which called for a 1.6 m diameter turbine to deliver 200 W in a 1 m/s current, had to be reduced to 0.8 m diameter. The expected power was now reduced to about 50 W, calculated as below.

$$P = 1/2\, \rho A V^3 \times C_p \times \eta$$

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