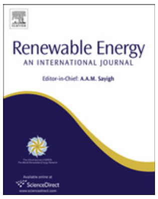
Renewable Energy 34 (2009) 35–47

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene



# Axial-flow turbines for low head microhydro systems

K.V. Alexander [a,*], E.P. Giddens [b,1], A.M. Fuller [a]

[a] *Department of Mechanical Engineering, University of Canterbury, PB 4800, Christchurch, New Zealand*
[b] *Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand*

ARTICLE INFO

*Article history:*
Received 19 December 2007
Accepted 22 March 2008
Available online 25 July 2008

*Keywords:*
Microhydro
Hydropower
Renewable energy
Home energy
Low head
Remote power generation

ABSTRACT

This paper describes the design of four different specific speed microhydro propeller turbines operating at heads between 4 m and 9 m, and their application to a wider range of heads and outputs by scaling. The features are specifically tailored for ease of manufacture and uniquely resistant to debris blockage. Test machines are described and test results given; hydraulic efficiencies of over 68% have been achieved in all test models despite the fact that these turbines' blades are planar, further simplifying manufacture. Theoretical models show how closely these flat blades can be made to approach the ideal blade shapes. Outline drawings are given with key dimensions for each reference model, along with the equations for scaling to arbitrary sites. These turbines are the axial flow members of a family of turbines developed to cover the microhydro range from 2 m to about 40 m of head.

## 1. Introduction

This paper is one of a group of papers describing a University of Canterbury project that sets out to provide a properly configured range of microhydro systems, from radial- to axial-flow designs, based on a modular concept and aimed in particular at third-world sites where regional workshops might be capable of undertaking much of the manufacture themselves. With that in mind, the scope of this paper is a subset of the microhydro project at the University of Canterbury. This paper's scope is specifically the propeller, or axial-flow, turbines. Future papers will cover the University's radial- and mixed-flow designs. A particular goal is to provide well-grounded but lowest-cost options for the communities who possess an adequate hydro resource and access to basic fabrication facilities, but who are confined to less reliable, sustainable, or economical power generating technologies due to a lack of design knowledge. Earlier papers have given an overview and justification of the modular approach [1,2] and the analysis leading to the most economic choice of penstock [3]. The selection of the most economic penstock dictates the turbine size. The combination of discharge, available head, and a fixed generator speed allow calculation of the site's specific speed. If that value falls in the range of this paper's designs, then one of the turbines described in this paper is likely a suitable choice for development.

Microhydro is typically used to describe sites of output below about 20 kW. Above that is minihydro, where the scale of investment is such that professional input is proportionally smaller and there is some advantage in building custom-made systems. The area of particular interest for the project discussed here is specific speeds above those of the Pelton wheel. Pelton wheels are simpler to implement than reaction turbines of similar power output, and are therefore quite popular relative to other types of microhydro machines. However, their applicability is limited to high-head sites. A number of Pelton wheel solutions are already available [4]. This project aims to complement these and other existing microhydro solutions by providing efficient designs for a broader range of sites. The exact scope of this project in terms of head and discharge is shown in Fig. 1.

The development of turbines suitable for operation in the bounded region of Fig. 1 has been the main task of the project, including Francis (radial-flow), mixed-flow, and propeller (axial-flow) machines.

## 2. Turbine forms and scaling

It is well known that different forms of turbine are required for different conditions; the classic range of turbine forms relevant to this project is shown in Fig. 2. The forms are classified by their specific speeds, where in this instance the specific speed is defined as

---

[*] Corresponding author. Tel.: +64 3 3667 001x7385; fax: +64 3 364 2078
*E-mail addresses:* keith.alexander@canterbury.ac.nz (K.V. Alexander), amf88@student.canterbury.ac.nz (A.M. Fuller).

[1] Recently deceased.

0960-1481/$ – see front matter
doi:10.1016/j.renene.2008.03.017

**Notation**

| | |
|---|---|
| $_1$ | subscript denoting leading edge station |
| $_2$ | subscript denoting trailing edge station |
| $f(\ldots)$ | function of stated variables |
| $g$ | gravitational acceleration (m/s$^2$) |
| $_h$ | subscript denoting location on blade/hub intersection (Fig. 5) |
| $H_R$ | head ratio, site/reference |
| $H$ | turbine head (m) |
| $j$ | counter |
| $k$ | constant for free vortex flow |
| $L_R$ | length ratio, site/reference |
| $\dot{m}$ | mass flow rate (kg/s) |
| $N$ | runner rotational speed (rev./min) |
| $N_S$ | specific speed |
| $P_i$ | hydraulic power into the turbine from the penstock (W) |
| $P_r$ | power out of the runner (W) |
| $P_R$ | power ratio, site/reference |
| $P_d$ | power measured at the dynamometer (W) |
| $Q$ | flow rate (l/s or m$^3$/s as noted) |
| $Q_R$ | discharge ratio, site/reference |
| $r$ | general radius (mm) |
| $_{ref}$ | subscript denoting parameter of a reference machine |
| $_{site}$ | subscript denoting parameter of machine scaled to match a real site |
| $_t$ | subscript denoting location on blade tip (Fig. 5) |
| $T_r$ | runner torque (Nm) |
| $v_a$ | axial flow velocity (m/s) |
| $v_c$ | circumferential flow velocity (m/s) |
| $\alpha$ | angle CCW around scroll casing, from inlet/casing intersection, as viewed from generator end, for use with Eq. (26) (degrees) |
| $\beta$ | blade angle relative to the impeller plane (degrees) |
| $\delta$ | deviation angle (degrees) |
| $\eta_t$ | turbine hydraulic efficiency (does not include $\eta_m$) |
| $\eta_m$ | combined bearing, shaft seal, and transmission efficiency |
| $\pi$ | 3.14159… |
| $\theta$ | angle clockwise around runner axis from the setup point “O” (degrees) |
| $\rho$ | density of water (kg/m$^3$) |
| $\omega$ | runner rotational speed (rad/s) |
| $\psi$ | blade set-up angle (degrees) |

$$N_S = \frac{N\sqrt{P_r}}{H^{5/4}} \tag{1}$$

Note this definition’s departure from Nechleba’s version with the use of an indirectly calculated power—that absorbed by the runner—rather than the power measured directly by the dynamometer [5, p. 71]. As with Nechleba’s, and other “practical” forms of specific speed, it is not a dimensionless number. In this case, the SI units are

$$N_S = \frac{(\text{Newtons})^{1/2}}{(\text{seconds})^{3/2}(\text{meters})^{3/4}}$$

Therefore, its use is restricted to comparison with machines characterized in the same way. It is worth noting here an interpretation of the term “specific speed” which may help clarify its meaning and relevance for comparison of hydraulic machines. To paraphrase the source, “The specific speed of any turbine equals the speed of a geometrically similar turbine working under the head of 1 m, when the latter turbine has such dimensions that it delivers under the head of 1 m a unit of power” [5, p. 70]. A definition of $N_S$ based on runner power was adopted because the four reference turbines covered in this paper were developed in parallel with matching bearing and transmission designs. As part of each machine’s development, the efficiency of transmission components has been measured, which allows isolated analysis of hydraulic performance.

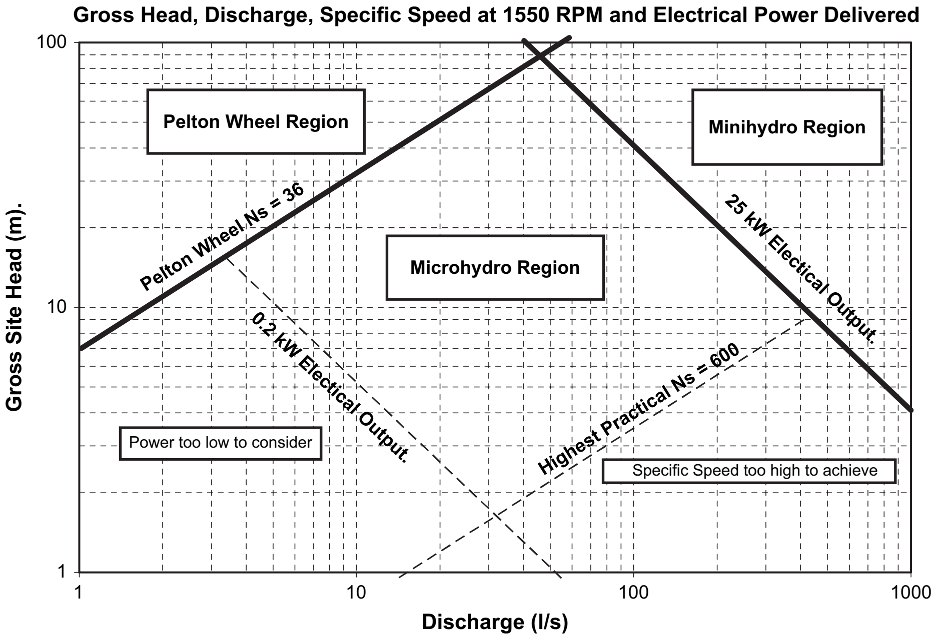


**Fig. 1.** The site head and discharge ranges defining the microhydro and neighbouring regions.