Renewable Energy 60 (2013) 739–745

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

Technical note

Lost wax casting process of the runner of a propeller turbine for small hydroelectric power plants

E. Chica*, S. Agudelo, N. Sierra

Department of Mechanical Engineering, Faculty of Engineering, University of Antioquia, Calle 67 No. 53-108, Medellin, Colombia

ARTICLE INFO

Article history:
Received 16 October 2012
Accepted 23 June 2013
Available online

Keywords:
Pico propeller turbine
Small hydropower
Rural electrification
Numerical simulation
Lost wax casting process
Rapid prototyping

ABSTRACT

The runner blade of a propeller turbine has a complex profile and an uneven thickness, which causes severe and unpredictable problems during the manufacture procedure. This paper describes the manufacture procedure which includes advance computer solidification simulation, lost wax casting process and machining processes of the runner of a pico hydraulic propeller turbine.

The runner was manufactured in C99350 nickel bronze alloy. This alloy possesses high toughness along with excellent resistance to cavitation and erosion. The runner can be a viable option for electricity generation in not interconnected zones (NIZ) of the national interconnected electric system in developing countries and can be manufactured locally.

1. Introduction

The access to basic energy services has been identified as a necessary prerequisite for sustainable development, since it can lead to improvements in household health, education and income levels. However, a high percentage of remote areas or rural households in developing countries lacks access to electricity due to low population densities, highly dispersed location of populated areas, reduced number of service hours (8 h on average), defaults in payments and customers with low incomes. Some of these remote areas are characterized by social and economic marginality, deficient or null infrastructure and, in some cases, a difficult situation because of the armed conflict. Today, the electrical installed capacity of these zones is low and is produced using conventional autonomous generation (mainly diesel plants), small hydroelectrics or photovoltaic plants. The main difficulties in the electricity generation in these areas are the access and cost of the fuel due to their unique geographical characteristics, where long distances separate sparsely populated areas of the urban ones [1].

There is a large potential for renewable energy resources to supply electricity to rural households, for example small hydroelectric power plants (pico hydro) schemes, with an output of less than 5 kW employing a propeller turbine, can be a cost-effective option for the electrification of remote rural communities with adequate water resources. The cost of the necessary pico hydro equipment per unit of energy is high when the pico hydraulic turbine is designed according to the specific conditions of water potential of the site of operation in order to get the highest efficiency; however, is lower than that of diesel generators, wind turbines or photovoltaic systems, especially when the equipment is manufactured locally, the manufacturing processes are standardized and the population is trained for the operation and maintenance of equipments [2]. Moreover, electricity generation with a propeller turbine not only brings light into people lives in the locality, but also gives energy and water security to population, makes people economically more stable, reduces the physical workload for women, enables the mechanization of rural industries and decreases environmental damage from cutting wood for fuel and heat. Furthermore, no waste by-products are produced unlike the energy generation based on fossil sources [2–5].

A propeller turbine has a runner with three, four, five or six blades with complex profile and uneven thickness, in which the water passes through the runner in an axial direction with respect to the shaft. The pitch of the blades may be fixed or movable. The runner is the most relevant component in a completed propeller turbine device; the other elements (as the manifold, the housing, the guide vanes or the turbine shaft) play a complementary role in the process for energy production [6].

* Corresponding author. Tel.: +57 4 2198553; fax: +57 4 2195550.
E-mail addresses: echica@udea.edu.co (E. Chica), seragude@udea.edu.co (S. Agudelo), nataliasierra@udea.edu.co (N. Sierra).

0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.06.030

The geometrical shape and dimension of the blades have a significant influence on the performance of the turbine; therefore, using an accurate and effective manufacture process is essential [6]. Metal-casting techniques constitute an important process for manufacturing the runner because of the high viscosity of liquid metals that facilitates flow into complex shapes [7].

This paper provides a manufacturing procedure for the propeller or runner of axial-flow turbine using lost wax casting process. For this purpose, the main geometric characteristics of the runner are previously determined based on a theoretical and technical analysis of internal flow in the turbine.

Modern engineering tools, such as SolidCast and Flowcast, are used to simulate casting poured in nickel bronze alloy of the runner, showing how the molten metal will flow through gating systems and fill the casting cavity in the mold.

2. Materials and methods

The process begins with CAD design and solid modeling of a propeller turbine according to the specific conditions of water potential of the site of operation in order to get the highest efficiency, followed by an extensive fine tuning using tools, such as Computation Fluid Dynamics (CFD) and Finite Element Analysis (FEA). These advanced tools makes it possible to know exactly how a turbine will perform before manufacturing begins.

Based on statistical studies of Kaplan turbines schemes, found in the literature [6,8–10], correlations are established between the geometry of the runner (the runner external diameter, D_e, or runner diameter, the runner internal diameter, D_i, or hub diameter), the mechanical power produced (P), the rotational speed (N), the specific speed (Ns), the net head (H) and the rated flow (Q). With these correlations it was possible to determinate the main geometric characteristics of the runner.

In Fig. 1 the assemble of the propeller turbine of 5 kW can be seen. This was designed for a head of 4.5 m, a flow of 0.2698 m^3/s and a fixed operating speed of 900 rpm. A moderate hydraulic efficiency of 60% was assumed according to the efficiency curve for a propeller turbine (a Kaplan with fixed blades and fixed inlet guide vanes) shown by the Renewables First company [11], and axial flow turbine selection charts given by K.V Alexander et al. in 2009 [6]. The main components are the runner, the casing, the generator, the shaft, the guide vanes, the transmit power system and the draft tube [6,8,10,12].

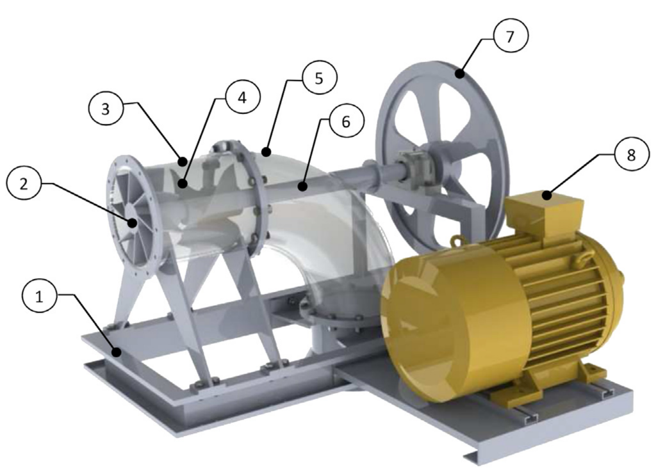

Fig. 1. Assembling of propeller turbine. 1–Support, 2–Guide vanes, 3–Casing, 4–Runner, 5–Draft tube, 6–Shaft, 7– Transmit power system, 8–Generator.

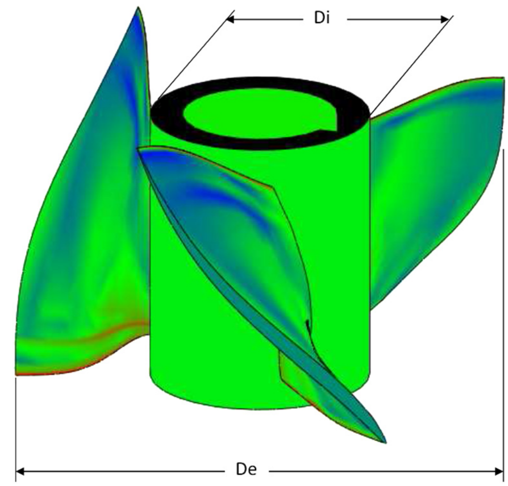

Fig. 2. Runner of propeller turbine.

For the design of the profile of blades a type Gottingen N-428 was chosen. The selection was made following the recommendations from several authors, such as Adolph [9] and Pfleiderer [13], for applications in turbines and axial pumps. The characteristics of the blade were obtained from the Institute of Aerodynamics of Gottingen, Germany. In Fig. 2 the runner can be seen. The design of the blade not only depends on the stress analysis, but also on other several factors, which play a significant role. The leading edge is thicker than the trailing edge for a streamlined flow. Furthermore, the blade should be as thin as possible to reduce cavitation effects. The blade is thicker near the runner internal diameter becoming thinner towards the tip. The wing theory is also an important factor in defining the shape of the profile and the distortion of the blade. The external diameter (D_e) is 240 mm and internal diameter (D_i) is 84 mm.

The Lost Wax Casting Process is used to manufacture the runner. The step by step process is presented here.

- Step 1. Making the mold

This step is by far the most critical. All the details which appear on the runner must be captured in the mold. For smaller

Fig. 3. Prototype of runner.