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Analytical Prediction Models for Evaluating Pumps-As-Turbines (PaTs) Performance

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Abstract

The hydropower sector is moving to the small-scale generation due to the exploitation of the majority water reservoirs with the aim of providing electrical energy in rural zones. Pump-as-Turbines (PaTs) is one of the most interesting technology due to their use for recovering energy in different industrial applications. Several studies aimed to study the performance of the tested PaTs and to describe their performance curves. The efficiency of these machines at their Best Efficiency Point (BEP) is comparable as much as the pump mode. In this work, a general analytical method for forecasting PaTs performance in turbine mode was investigated.

Keywords: Pump-as-Turbine; Analytical method; Best Efficiency Point; Efficiency; Performance curves

1. Introduction

The need to produce energy is one of the most important issues for human life. Through the years, the development of the new energy systems through the exploitation of different available natural sources has been carried on. The energy production technologies based on both carbon and oil overtook the natural sources becoming the primary energy sources worldwide; however, this phenomenon brought to an increase of harmful pollutants in the atmosphere [1] and to a steep increase of the carbon dioxide concentration. For this reason, renewable sources started to be investigated with particular regards to water resources. The use of water was one of the first methods for energy production, moving from the large-scale plants [2] to the small-scale ones due to the exploitation of all

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the available geodetic altitudes and the maturity of the technology. One of the most used technology in the small-scale hydropower sector, that is taking the field in these last years due to its versatility for being used for both energy production/recovery, its cost and availability, is the Pump-as-Turbine (PaT) technology. In order to take advantage of its pros, many improvements were performed: Zhu et al. [3] carried out a complete study for optimizing a medium-high head PaT taking into account the interaction between the blades, the water and the channel shape. Rezghi et al. [4] studied the effects of the transient flow inside the PaTs that occur in waterways due to the pressure fluctuations. In parallel with these studies, several researches were performed to forecast their performances in turbine mode. Theoretical formulas were provided by Williams [5], Stepanoff [6], Krivchenko [7], Sharma [8] and McClaskey [9] based on experimental data and assuming that the efficiency achieved by a PaT in turbine mode at the Best Efficiency Point (BEP) is the same as that achieved in pump mode operating at the same running conditions. These formulas allow to evaluate the flow rate and the head exploited by the PaTs running at their BEP in turbine mode. The following step is to define a trend line for evaluating their performance in turbine mode: Singh et al. [10], using data obtained by three tested pumps having different specific angular speeds and other data collected by Derakshan et al. [11], developed an optimization routine for forecasting the performance of the centrifugal pumps running in turbine mode. Yang et al. [12] described an analytical method and performed both CFD simulations and laboratory tests of a single stage centrifugal pump running in turbine mode in order to validate the analytical results previously obtained. Furthermore, Yang et al. [13] studied the effect of a PaT impeller trimming through laboratory tests and numerical simulations. Along the same line, Jain et al. [14] performed laboratory tests on a PaT varying its rotating speed and trimming the initial diameter until 80% of its initial size in order to improve its efficiency at part loads. Bozorgi et al. [15] compared the results obtained by CFD simulations, using NUMECA® software, with those obtained in the laboratory tests in order to validate the simulated ones. Tan et al. [16] presented a prediction of PaTs performance running in turbine mode referring to nine previous methods available in literature and taking into account the specific angular speed and the specific diameter as main evaluation parameters. Giosio et al. [17] studied both design and PaT performance suitable for both rural micro-hydro environments and energy recovery installations, although its off-design performance is not so high due to the fixed geometry and the absence of an inlet flow guidance. Finally, Barbarelli et al. [18] performed a one-dimensional numerical code able to predict both design characteristics and performance of a PaT used in a determined application. The aim of this paper is to collect the running data of 32 PaTs that were studied and analysed in the previous works [10-18] in order to define analytical equations for forecasting the main magnitudes involved on the PaTs performance evaluation. Non-dimensional analysis was performed taking into account all the physical data of the PaTs in order to study the behaviour of those machines that operate in fluid dynamic similarity conditions. However, the non-dimensional analysis is not sufficient to generalize the performance prediction of the PaTs because it is not able to distinguish the typology of the analysed machine, so each non-dimensional magnitude of PaTs was divided by the same magnitude achieved by the machine at BEP running in turbine mode. Using this method, an objective analysis that is independent not only of the physical dimensions and of rotating speeds but also of the design typology of the machine is performed in order to forecast the performance of a higher number of PaTs.

2. Research and methods

2.1. Data collecting and data analysis

In this work, data related to laboratory tests performed on 32 PaTs [10-18] were analysed and the main characteristics of the machines were evaluated. The ranges of the different physical magnitudes involved in this study of PaTs are the following: the flow rate ranges from 0.008 m^3/s to 0.222 m^3/s, the head ranges from 1.99 m to 99.52 m, the rotating speed ranges from 750 rpm to 2445 rpm, the impeller diameter ranges from 0.165 m to 0.300 m, the specific speed ranges from 0.17 to 2.39 and, finally, the efficiencies ranges from 0.43 to 0.87.

2.2. Non-dimensional analysis

Characteristic, power, efficiency and flow coefficient vs efficiency curves of the 32 tested PaTs were also developed. These curves were drawn taking into account the rated running conditions in turbine mode. A non-