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Effects of impeller diameter and rotational speed on performance of pump running in turbine mode

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ABSTRACT

The major limitations of mini/micro hydropower schemes is the higher cost of small capacity hydro turbines. Also, it is very cumbersome, time consuming and expensive to develop the site specific turbines corresponding to local site conditions in mini/micro hydro range. In such plants, small centrifugal pumps can be used in turbine mode by running in the reverse direction. The efficiency of pump as turbines (PATs) is usually lower than the conventional hydro turbines; however, there may be substantial decrease in the capital cost of the plant.

Hydropower plants usually runs at part load for several months in a year due to insufficient water availability for the power generation. The application range of PAT can be widened if its part load and/or maximum efficiency can be improved. In the present study, experimental investigations are carried out on centrifugal pump running in turbine mode to optimize its geometric and operational parameters e.g. impeller diameter and rotational speed. The experiments were performed in the wide range of rotational speeds varying from 900 to 1500 rpm with original (∅ 250 mm), 10% trimmed (∅ 225 mm) and 20% trimmed (∅ 200 mm) impellers. Impeller trimming led to improvement in efficiency at part load operating conditions. The performance of PAT was found better at the lower speeds than that at the rated speed. The effects of blade rounding were studied in all the cases and it led to 3–4% rise in efficiency at rated speed with the original impeller. The empirical correlation is also developed for prediction of efficiency in terms of impeller diameter and rotational speed in non-dimensional form.

1. Introduction

Hydropower is probably the oldest and most reliable source of energy on the earth. Large hydropower plants require construction of large scale dams, long-term investments, extensive and time consuming construction processes. The reservoir behind the dam can flood enormous valuable agricultural lands and agricultural activities [1]. These factors make large hydropower plants unfavorable in many cases. Nevertheless, small hydropower plants (SHP) are free from such issues and provide option of decentralized power generation particularly in remote, rural and hilly areas.

In India, the plants having overall capacity up to 25 MW are called small hydropower plants. The SHP is further categorized as pico (below 5 kW), micro (5.1–100 kW) and mini (101 kW to 2 MW) hydropower [2]. Application of micro hydropower plants has gained worldwide attention during the last decades of the 20th century [3]. Although Micro hydropower plants are by no means comparable to large hydropower projects as far as their power generation capacity is concerned; however, their simple design and relatively simple manufacturing processes, low price per kilo watts, easy installation with simple construction, cheap and easy maintenance and their insignificant or rather non-riverine impacts have made them attractive particularly to the countries with abundant micro hydro potential [1].

The major hindrance in the development of mini/micro hydropower schemes is the higher initial cost of the conventional turbines in low capacity range. The cost of electro-mechanical components in typical large hydro schemes is around 20% but in micro-hydro it is relatively higher and varies from 35% to 70% of the total project cost depending on size, rating and local ecology [4,5]. One of the main objectives of the small hydro researchers worldwide is to decrease the cost of electro-mechanical equipments and its standardization in low capacity range. Many investigators have explored the possibility of using different turbines in

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Nomenclature

Amp	ampere
BEP	best efficiency point
BR	blade rounded
D	impeller diameter (m)
DC	direct current
g	acceleration due to gravity (m/s^2)
H	head (m)
I	current (A)
IS	Indian standard
kW	Kilowatt
m	meter
mm	milli meter
MNRE	ministry of new renewable energy
MW	megawatt
n	rotational speed (rps)
P	Power (W)
p	static pressure (N/m^2)
PAT	pump as turbine
psi	pound per square inch
Q	discharge (m^3/s)
R	radius of blade rounding (m)
rpm	revolutions per minute
rps	revolutions per second
SHP	small hydropower plants
t	blade thickness (m)
TW h	terawatt-hour
UR	unrounded
V	fluid velocity (m/s)
v	voltage (V)
z	datum head (m)

Greek symbols

Δ	change in parameter
η	efficiency
π	power number
ρ	density of water (kg/m^3)
ϕ	discharge number
$\varnothing$	impeller diameter
ψ	head number

Subscripts

1	at inlet of PAT
2	at outlet of PAT
g	generator
i	input
o	overall, output
r	rated value
s	shaft
t	turbine

mini/micro hydro range e.g. cross flow turbine, propeller turbine, Pelton turbine, small Francis turbine etc. [6–8]. However, these options are subjected to complicated arrangements like large size, necessity of belt drive, multi-jet arrangement and/or higher cost [9].

One of the cost-effective and attractive alternatives for mini/micro hydropower plants is to utilize the pump as turbine. Use of centrifugal pump in turbine mode facilitate various advantages associated with the pump e.g. mass production, low maintenance and installation costs, less complicated to operate than turbines, available for a wide range of heads and flows, short delivery time, available in a large number of standard sizes, easy installations, ease of availability of spare parts, etc. [10,11]. The performance of pump running as turbine is usually inferior to conventional hydro turbines. However, use of PATs can significantly reduce the initial cost of the hydropower plant [12] as well as of water distribution network [13]. For low capacity power plants (up to 100 kW) there is substantial reduction in the capital investment of the plant, typically of the order of 10–1 or even more, depending on the capacity of the plant [14]. Hence, the concept of utilizing PAT is favorable due to lower cost of pumps used in turbine mode; particularly for rural, remote and hilly areas.

Virtually any type of pump e.g. axial flow, mixed flow, radial flow, double suction as well as multistage pumps can be used in turbine mode for power generation. However, from techno-economic considerations use of single stage end suction centrifugal pump, working in the range of low to medium head, is recommended by many of the researchers in low capacity range [14–18]. The performance of pump in turbine mode very closely depends on its performance in pump mode.

Many investigators have suggested the relations for prediction of PAT efficiency either based on efficiency in pump mode [19–26] or based on specific speed in pump mode [27–31]. Few researchers have also derived the relations based on experimental approach [15,17,32] to predict the PAT behavior. However, the deviations between performance predicted by these methods and experimental results were found to be around ±20% or even more [9,33]. They concluded that the efficiency in turbine mode may vary from +2% to −8.5% compared to efficiency in pump mode [34]. In the present study, experimental investigations are carried out to improve the PAT performance by optimizing its geometric and operational parameters e.g. impeller diameter and rotational speed. An empirical correlation (in non-dimensional form) for prediction of PAT efficiency, based on impeller diameter and rotational speed, was developed by regressing the experimental data.

2. Experimental setup

For the present study, centrifugal pump with rated head, discharge and speed of 20 m, 0.0292 m^3/s and 1400 rpm respectively was selected for the experimental setup. At rated parameters, the maximum efficiency of the pump in pump mode was obtained as 77.5% [35]. Six numbers of backward curved vanes having inlet and outlet blade angles as 24° and 19° were provided in the pump impeller. The experimental test rig was developed at Institute of Technology, Nirma University, Ahmedabad as shown in Fig. 1. The experimental setup consisted of service pump, flow regulating valve, bypass line arrangement, electromagnetic flow meter, PAT with draft tube, pressure transmitters, DC shunt generator with load bank, tailrace channel, underground reservoir and piping system.

In the present study, draft tube was designed and fabricated as per IS 5496:1993 [36]. The service pump was taking water from the underground reservoir and supplying to the PAT which was recirculated through tailrace channel. To measure the electric power generated, digital voltmeter and ammeter were connected with resistive load in parallel and series respectively. The major specifications of different components of the experimental setup are given in Table 1.