# Study of Centrifugal Pump Operating as Turbine in Small Hydropower Plants

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*Abstract:* This paper presents the benefits that can be obtained by replacing the conventional hydraulic turbines with reversible pumps in a micro-hydropower plant. To support these arguments the experimental data were presented collected after upgrading of such a hydropower plant located on a local medium-sized river.

*Keywords:* hydropower plant, hydraulic turbine, reversible pump, efficiency

## 1 Introduction

In many developing countries, the small hydropower stations are demand. Using pump as turbine (named here as PAT) is an attractive and significant alternative for the operation of these power plants.

Nowadays, applications of pumps as turbines have been developed in villages, farms, irrigations systems as pressure dropping valves and as small pump storage power stations [1].

Pumps are mass-produced, and as a result, have advantages for micro-hydro compared with purpose-made turbines. The main advantages are as follows:

- Integral pump and motor can be purchased for use as a turbine and generator set;
- Available for a wide range of heads and flows;
- Available in a large number of standard sizes;
- Low cost;
- Short delivery time;
- Spare parts such as seals and bearings are easily available;
- Easy installation - standard pipe fittings are used.

The main limitation is that the range of flow rates over which a particular unit can operate is much less that for a conventional turbine [2].

The field applications of conventional turbines such as Pelton, Francis and Kaplan are well known according to their heads and specific speeds.

Due to inadequate experimental data for pumps working as turbines, the field applications of these machines are not yet well defined.

Hydroelectric pumped storage arrangements are some of the most important applications of the pumps operating as turbine.

This type of arrangements is designed to improve the operation of energy systems. They are used for the frequency-power control according to the load curve and are mandatory for the power systems with large power producers having low flexibility in changing their on-off status (e.g. a nuclear power plant).

## 2 PAT characteristic

A PAT may work at off-design conditions, but most prediction methods estimated the best efficiency point (BEP) of the PAT.

Therefore, establishing the complete characteristic curves of a PAT based on its BEP is very remarkable.

Experimental data showed that the dimensionless characteristic curves of all PATs based on their BEP are approximately the same.

The efficiency of a PAT at 80 % of BEP flow will normally be lower than 120 % of BEP flow, according to Fig. 1.

A new method to predict the BEP of a PAT is based on pump's hydraulic producer data, especially the specific speed which characterizes the type of the runner and consequently [4, 5].

ISBN: 978-960-474-328-5

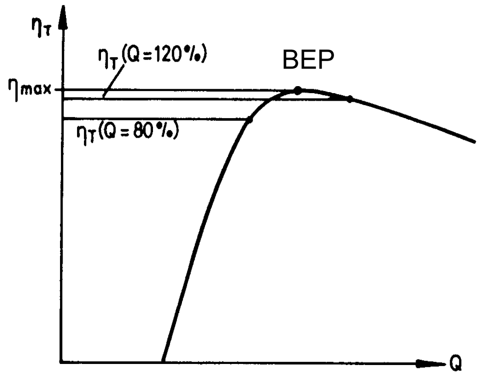


Fig.1. Typical efficiency curve for a turbine-operating pump [2]

# 3 Experimental setup

The present study approaches a micro hydropower plant initially endowed with two Francis turbines FO 230/720. The technical characteristics of the arrangement were:

- Installed power $P_i = 1.4\ MW$;
- Gross-net head $H_b = 39\ m\ /\ H_n = 37\ m$;
- Installed flow rate $Q_i = 5.8\ m^3/s$;
- Energy production (project data); $E_p = 3.5\ GW/year$.

The plant was recently retrofitted becoming a micro pump-storage hydropower plant. It has two storage tanks 37 m height difference one from another and four Brates turbo pumps of 0.35 MW installed power, designed for a pumping head of 37 mCA and a flow rate of 4000 $m^3$/h.

During periods of peak load, the system is behaving like a producer and uses the water flow from the first tank. This one is further is stored in the second tank. During the no load periods the turbines change their operation as pumps and pump water back into the first tank.

Pumps are energy consumers. They take the unconsumed energy difference necessary for the proper operation of the big producers that can maintain their power plants in operation allowing the system to keep its balance.

The current trend in pumps' design is increasing of the drive speed, which lowers the pump size. At the same time, a higher speed leads to some technology problems at construction of the pumps' components. Furthermore, the load losses increase in the hydraulic circuit of the pump.

The speed enhancing is limited by the mechanical reliability of the pump, and in some cases by the cavitations phenomenon. In this case, because the pump gauge is large and a balance between reversible pump and generator should be achieved the recommended speed is *n = 720 rot/min*.

# 4 Calculation of power characteristic curves

## 4.1 Curve of hydraulic power

The hydraulic power is defined as:

$$P_h = \rho g Q H \qquad (1)$$

Where: $\rho$ is the water density, g - the gravity, Q – the flow rate and H – the load.

Based on the measured values of the flow rate $Q_{tx}$ and load $H_x$ the hydraulic power $P_h$ was determined. The results are given in Table 1.

Table 1. The hydraulic power characteristic $P_{hx}=f(Q_{tx})$

| $Q_{tx}$[m/s] | $H_x$[m] | $P_h$[kW] |
|---|---|---|
| 0 | 49.573 | 0 |
| 0.0122 | 49.679 | 7.883 |
| 0.0244 | 49.763 | 15.714 |
| 0.0366 | 49.854 | 23.491 |
| 0.0488 | 49.923 | 31.215 |
| 0.0610 | 49.979 | 38.887 |
| 0.0732 | 50.044 | 46.505 |
| 0.0854 | 50.092 | 54.070 |
| 0.0976 | 50.149 | 63.096 |
| 0.1098 | 50.197 | 69.041 |
| 0.1220 | 50.225 | 76.447 |

## 4.2 Curve of driving power

Mechanical losses depend on the speed and power consumption, and do not depend on the actual values of the hydraulic parameters.

This type of losses occurre in the bearings and seals. For a pair of radial ball bearings the losses are considered *1%* of nominal power, while the radial-axial losses are *1.2%* of absorbed power. The power lost by friction between the disc and rotor crown is *3-7%*. Therefore the mechanical efficiency is estimated as $\eta_m=0.9$.

The driving power is defined as:

$$P_a = \rho g Q_t H_t / \eta_m \qquad (2)$$

The theoretical load $H_{tx}$ is bigger than the measured one, $H_x$ with the value of the hydraulic losses. The calculus results of the driving power are given in Table 2.

Table 2.The driving power characteristic $P_{ax}=f(Q_{tx})$

| $Q_{tx}$[m/s] | $H_x$[m] | $P_a$[kW] |
|---|---|---|
| 0 | 66.093 | $P_0$ |
| 0.0122 | 65.871 | 8.75 |
| 0.0244 | 65.649 | 17.46 |
| 0.0366 | 65.427 | 34.68 |
| 0.0488 | 65.205 | 36.79 |
| 0.0610 | 64.982 | 43.20 |
| 0.0732 | 64.762 | 51.60 |
| 0.0854 | 64.540 | 60.07 |
| 0.0976 | 64.318 | 70.10 |
| 0.1098 | 64.097 | 76.71 |
| 0.1220 | 63.875 | 85.23 |

# 5 Calculation of the efficiency characteristics

## 5.1 The hydraulic efficiency characteristic

The hydraulic efficiency is defined as:

$$\eta_h = H / H_t \tag{3}$$

The calculus of the hydraulic efficiency is given in Table 3.

## 5.2 The total efficiency characteristic

The total efficiency of the machine results as a product of the partial efficiencies that depend on the mechanical losses, hydraulic losses and volume ones.

$$\eta_t = \eta_m \eta_v \eta_h \tag{4}$$

Considering the mechanical efficiency $\eta_m=0.9$ and the volume efficiency $\eta_v=0.87$, the results for the total efficiency are as in Table 4.

Table 3.The hydraulic efficiency characteristic $\eta_h=f(Q_{tx})$

| $Q_{tx}$[m/s] | $H_x$[m] | $H_{tx}$[m] | $\eta_{hx}$ |
|---|---|---|---|
| 0 | 49.573 | 66.093 | 0 |
| 0.0122 | 49.679 | 65.871 | 0.754 |
| 0.0244 | 49.763 | 65.649 | 0.758 |
| 0.0366 | 49.854 | 65.427 | 0.761 |
| 0.0488 | 49.923 | 65.205 | 0.765 |
| 0.0610 | 49.979 | 64.982 | 0.769 |
| 0.0732 | 50.044 | 64.762 | 0.772 |
| 0.0854 | 50.092 | 64.540 | 0.776 |
| 0.0976 | 50.149 | 64.318 | 0.779 |
| 0.1098 | 50.197 | 64.097 | 0.783 |
| 0.1220 | 50.225 | 63.875 | 0.786 |

Table 4.The total efficiency characteristic $\eta_t=f(Q_{tx})$

| $Q_{tx}$[m/s] | $\eta_t$ |
|---|---|
| 0 | 0 |
| 0.0122 | 0.590 |
| 0.0244 | 0.593 |
| 0.0366 | 0.595 |
| 0.0488 | 0.598 |
| 0.0610 | 0.602 |
| 0.0732 | 0.604 |
| 0.0854 | 0.607 |
| 0.0976 | 0.609 |
| 0.1098 | 0.613 |
| 0.1220 | 0.615 |

# 6 Prediction of BEP of PAT

The PAT works in higher head and flow rate than those of the pump mode. The BEP of PATs were based on the following dimensionless parameters [1]:

$$\begin{aligned} h &= H_{turbine,b} / H_{pump,b} \\ q &= Q_{turbine,b} / Q_{pump,b} \\ p &= P_{turbine,b} / P_{pump,b} \\ \lambda &= \eta_{turbine,\max} / \eta_{pump,\max} \end{aligned} \tag{5}$$

where *H, P, Q* and $\eta$ are head, power, flow rate and efficiency.

Subscript *b* is related to BEP. The pumps with higher specific speeds have lower *h* and *q*. The

ISBN: 978-960-474-328-5 

value of $\lambda$ is almost constant for all pumps with different specific speeds. Variations of $p$ and specific speed are not proportional. For our case: $h=2.24$; $q=1.73$; $p=3.87$.

Using experimental data and pump hydraulic characteristic, turbine mode head, flow rate and power at BEP was obtained.

Efficiency curve can be obtained for each point using:

$$\eta_{turbine} = \frac{P_{turbine}}{\rho g Q_{turbine} H_{turbine}} \tag{6}$$

The maximum efficiency is given as:

$$\eta_{turbine,\max} = \frac{P_{turbine,b}}{\rho g Q_{turbine,b} H_{turbine,b}} \tag{7}$$

The value of the maximum efficiency results $\eta_{turbine,max}=0.65$

The curve estimated by this method and experimental data were in good agreement.

## 7 Conclusions

The paper presents a study about the energy efficiency gain by replacing the classic hydraulic turbines with reversible pumps in a micro hydropower plant.

A PAT works in higher head and flow rate than those of the pump mode at the same rotational speed.

Efficiencies are almost the same in both pump and turbine modes.

Experiments showed that a centrifugal pump can operate as turbine with various heads and flow rates without any mechanical problem.

After measuring all parameters, head, flow rate, output power and efficiency were calculated. The uncertainty of head, flow rate, power and efficiency were *±4.5%*, *±3.4%*, *±4.1%* and *±4.4%*, respectively.

In practice, selecting the proper PAT for a small hydro-site is in demand. Future works and more experimental data can improve all suggested methods.

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