COMPACT MICRO–HYDRO–AGGREGATES FOR STORAGE PLANTS EXPLOITING THE SECONDARY HYDRAULIC POTENTIAL

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ABSTRACT

The work shows the manner of obtaining some base prototypes for three types of microturbines so well as the results obtained after the execution and testing in laboratory.

KEYWORDS

Pelton, Axial hollow, Banki, microturbines typodimensions.

NOMENCLATURE

H – head
Q – discharge
n – rotational speed
z – number of nozzles
d – nozzle diameter
ns – specific speed
η - efficiency

INTRODUCTION

Starting from the more and more numerous inquiries for equipping some small-power storage plants with micro-hydro-aggregates working in the majority of cases in an isolated system, the research department of the company U.C.M.R.-S.A. decided to create some typo-dimensions for different types of turbines in order to cover a range of heads (H) and overflows (Q) as wide as possible and to ensure a prompt offering with a minimum execution time.

Considering the large range of possibilities regarding the characteristics of the storage plant, i.e. heads (H) and overflows (Q), to cover the entire range would mean to design and execute a very high number of typo-dimensions.

In order to reach the target goal of the company, that is a new generation of ecological typified micro-hydro-aggregates meeting the European technological and qualitative standards, we set out and realised the basic prototypes on three different types of micro-turbines. The present paper aims at presenting the prototypes with their characteristics and performances, i.e. the way in which the expansion of the operating range is achieved.

THE PELTON MICRO–TURBINE

In the case of the prototype for Pelton micro-turbines we started from the data of an existing storage plant, more precisely C.H.E. (hydroelectric power plant) Geoagiu with the following parameters:
- Calculus head: H=53,5 m
- Calculus overflow: Q=0,08 m³/s

for which we designed and executed a microturbine (Fig. 1) with the following features:

\[
D_x = 0,400 \text{ m} \\
n = 750 \text{ rpm} \\
z = 2 \text{ injectors with deflector} \\
d = \Phi 44
\]

injector needle closing time: \( t = 22 \text{ sec.} \)
deflectors driving time: \( t_1 = 2 \text{ sec.} \)

We chose a compact constructive solution using an impeller with detachable buckets, with rolling bearing cases outside the casing, the driving of the injecting needle and of deflectors being made with screw-nut mechanisms, hub-worm gear respectively, electrically driven with gearmotors at \( U=24 \text{ Vcc} \).

The position of the casing lid allows an easy access for mounting-dismantling the rotor and injectors, the solution being ecological, without risks of pollution.
The design started from a maximum efficiency model $\eta = 91\%$ and the operating range was limited on the $\eta = 87\%$ line from the universal diagram.

The prototype was tested on the stand and the results obtained confirmed the performances forwarded in the designing assignment. Considering the experience we have in designing Pelton turbine models for expanding the operating range on the same typodimension we weighed two variants:

- changing the heads and overflows range through equipping with generators with different revolutions, $n=750$ rpm and $n=1000$ rpm respectively.

- equipping with pairs of rotors-injectors according to the overflow.

As a result, we came up with eight equipping possibilities for the basic prototype as shown in **Table 1**.

The minimum overflow results in the functioning with an injector with an opening limited to the line of $\eta = 87\%$ on the universal diagram of the models, and the maximum overflow is for two injectors opened at the maximum. In the plot in **Fig. 2** we presented the operating range of the basic prototype and the range extended through different types of equipment.

<table>
<thead>
<tr>
<th>$D_c$ [mm]</th>
<th>400</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. buckets</td>
<td>17</td>
</tr>
<tr>
<td>B [mm]</td>
<td>130</td>
</tr>
<tr>
<td>d [mm]</td>
<td>44</td>
</tr>
<tr>
<td>$n_{inj}$</td>
<td>24,6</td>
</tr>
<tr>
<td>$n$ [rpm]</td>
<td>750</td>
</tr>
<tr>
<td>$H_{max}$ [m]</td>
<td>70</td>
</tr>
<tr>
<td>$H_{min}$ [m]</td>
<td>40</td>
</tr>
<tr>
<td>$Q_{min}$ [m³/s]</td>
<td>20</td>
</tr>
<tr>
<td>$Q_{max}$ [m³/s]</td>
<td>82</td>
</tr>
</tbody>
</table>

**Table 1**

**TUBULAR AXIAL MICRO-HYDRO-AGGREGATE**

The tubular axial micro-aggregate was designed and executed with the aim of equipping an isolated micro-hydroelectric power plant for the forest ranges Coșava and Nera, the storage unit having the following parameters: $Q_c = 120$ l/s, $H_c = 5$ m. Conceived in a compact constructive solution (see **Fig. 3** without pollution risks, the casing being made of a pipe with a $D_n = 350$ mm, the axial mono-block rotor with $D_n = 238$ mm with 6 blades (**Fig. 4**), fixed conical directing gear with 14 blades (**Fig. 5**), two-column fixed coil, ball bearings, the transmission of the moment from the turbine shaft to the generator being made through a bevel gear at $90^\circ$ with a ratio of gear $i = 1.22$.

The computation of the hydraulic run was made starting from a calculus overflow of $Q_c = 110$ l/s and a head of $H_c = 4.6$ m, the run obtained being analysed in TascOverflow and the estimated performances are shown in **Fig. 6** and **Table 2**.

After execution the prototype was tested in the laboratory, and the results are presented in **Table 3**.
Table 2

<table>
<thead>
<tr>
<th>Head (H)</th>
<th>[m]</th>
<th>3.5</th>
<th>4</th>
<th>4.5</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revolutions (n) [r.p.m.]</td>
<td>1230</td>
<td>1230</td>
<td>1230</td>
<td>1230</td>
<td>1230</td>
</tr>
<tr>
<td>Overflow (Q) [l/s]</td>
<td>115</td>
<td>118</td>
<td>120</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>Efficiency (η) [%]</td>
<td>59.96</td>
<td>65.09</td>
<td>65.48</td>
<td>71.11</td>
<td></td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Head (H)</th>
<th>[m]</th>
<th>1.6</th>
<th>2.4</th>
<th>2.7</th>
<th>3</th>
<th>3.2</th>
<th>3.3</th>
<th>3.8</th>
<th>4</th>
<th>4.2</th>
<th>4.4</th>
<th>4.6</th>
<th>4.8</th>
<th>5</th>
</tr>
</thead>
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<td>Revolutions (n) [r.p.m.]</td>
<td>1230</td>
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<td>1230</td>
<td>1230</td>
<td>1230</td>
<td></td>
</tr>
<tr>
<td>Overflow (Q) [l/s]</td>
<td>99.54</td>
<td>106.4</td>
<td>108.4</td>
<td>112.8</td>
<td>112.9</td>
<td>113.3</td>
<td>116.6</td>
<td>117.5</td>
<td>119</td>
<td>120.7</td>
<td>122.5</td>
<td>124.8</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>Efficiency (η) [%]</td>
<td>19.2</td>
<td>48</td>
<td>52</td>
<td>60.2</td>
<td>60.7</td>
<td>61.64</td>
<td>69.04</td>
<td>70.2</td>
<td>71.42</td>
<td>71.97</td>
<td>72.3</td>
<td>72.4</td>
<td>72.8</td>
<td></td>
</tr>
</tbody>
</table>
Comparing the estimated results with those resulted from laboratory measurements on the prototype, we remark a real efficiency better than the estimated one, with higher differences, i.e. 5% in the case of small heads and rather close at the maximum head at which it could be tested (due to the limitation of the power at the generator) i.e. 1,7% and a shift of the optimum working point towards heads and overflows higher than the proposed ones, with 8% for head and 12% for overflow, respectively. The functioning range reconsidered after the lab testing of the prototype is of: \( H = 3+5.5 \text{ m} \) and \( Q = 112+130 \text{ l/s} \).

In order to expand the operating range we designed a four-blade rotor with the same diameter and a fixed directing gear with seven blades, considering as calculus point \( H_c = 3.5 \text{ m} \) and \( Q_c = 140 \text{ l/s} \) and the estimated range for this variant is of: \( H = 1.8+4 \text{ m} \) and \( Q = 130+150 \text{ l/s} \).

**BANKI MICRO-AGGREGATE**

The research aimed at realising an experimental model, a micro-hydro-aggregate equipped with Banki turbine and asynchronous (induction) generator, destined to produce electricity, both when functioning in the national energy system and especially on an isolated network.

The following goals were aimed at:
1. The calculus, design and execution of a Banki micro-turbine, having the nominal diameter of the rotor \( D = 250 \text{ mm} \), in accordance with the hydraulic parameters of the testing stand.
2. Determining the energetic performances and plotting the universal characteristic curve of the turbine rotor.
3. Realising a micro-hydro-aggregate (M.H.A.) with Banki turbine coupled with an asynchronous generator and determining its energetic performances when operating in the national energy system or on an isolated network.

1. When designing the turbine we aimed at realising a robust and compact welded construction, allowing the integral mounting in the factory. We used stainless steels for the rotor and the commanding valve, and for the rest of the subassemblies ordinary steels and we applied electrochemical protective covering layers. The bearings were placed outside the turbine hydraulic circuit, thus avoiding water pollution with lubricants. The command of the main valve was done manually or electromechanically in accordance with the type of experiments.
2. We performed experimental tests with the micro-turbine coupled directly to a direct current generator, adopting as parameter the “φ” angular opening of the valve, and as variable the number of revolutions “n” of the experimental model through adjusting the revolution speed of the generator within the range n=150 ÷800 rpm. The results of the tests were synthesised in the universal diagram of the model, in the unitary coordinates n₁₁, Q₁₁, the energy performances being represented under the form of the relative efficiency ηᵣₑˡₑ = η/ηₘₐₓ (Fig. 7).

The optimum range for unitary revolutions is n₁₁ = 38÷47 rpm, for the unitary overflow Q₁₁ = 550÷650 l/s and for the opening of the valve φₚₒₜₜ = 19÷22°.

3. Starting from the data obtained we realised a M.H.A. model equipped with Banki microturbine and asynchronous generator, coupled through a trapezoidal belts gear. The nominal parameters of the micro-hydro-aggregate are:

- Nominal diameter of the rotor D=250mm
- The range of test heads H=2÷16 m
- The range of test overflows Q=50÷130 l/s
- Nominal number of revolutions n₁₁=425 rpm

- TURBINE:
- Generator type ASI 180 S – 42
- Nominal power Pₚ =10 kw
- Nominal number of revolutions n=1000 rpm

- ASYNCHRONOUS GENERATOR:
- Type of transmission – trapezoidal belts
- Ratio of gear i=n₁₁/n₁₁=2,5

In Fig.8 we present an ensemble view of the MHA.

The performances of the MHA which discharged electric power into the national system (S.N.) were plotted in the service characteristic curve in co-ordinates H; Q of Fig. 9 and for its working in isolated network (R.I.) in the characteristic of Fig.10. The efficiencies presented in the two characteristics are in fact total efficiencies η = η₁₁₁₁, and the electric power Pₑ represents the power at the generator terminals.

4. The test effected with the Banki MHA Banki trigger the following conclusions:

- The optimum operating range when connected to the national system is: Hₚₒₜₜ = 5,5÷8 m; ηₚₒₜₜ = 90÷110 l/s; Pₑₚₒₜₜ = 3,5÷5,5 kw; ηₜₒₜₜ = 67÷68 %.
- The optimum operating range when connected to isolated network provides: Hₚₒₜₜ = 7,5÷9,5m; Qₑₚₒₜₜ = 95÷115 l/s; Pₑₚₒₜₜ = 4,5÷6,5 kw; ηₜₒₜₜ = 62÷63 %; we remark an approx. 5-percent decrease of efficiency on isolated network compared to its functioning in the national system.
- The microturbine with the rotor diameter D = 250 mm can be used in a range of heads H = 5÷35 m, (see the table in Fig. 7.), overflows Q = 87÷230 l/s, coupling powers P₁₁ = 3,4÷62 kw, number of revolutions n = 370÷970 rpm and efficiencies η = 78÷79 %. For powers up to 15 kw, we can use trapezoidal belts gears and over that power, rotative speed multipliers or direct coupling with generators of 750 and 1000 rpm.
REFERENCES