# 85 YEARS OF CONTINUOUS OPERATION OF A HPP. PART 1 – STEADY OPERATION REGIMES

Georgiana DUNCA[1], Raluca Gabriela IOVĂNEL[2], Răzvan ROMAN[3]

*Built between 1928 and 1930 to supply with electrical energy the town of Bucharest, Dobrești Hydro-Power Plant (HPP) had until 1960 the biggest power output (4×4 MW) in Romania. Currently, from annual energy production point of view (50 GWh/year), it is the second HPP within the Curtea de Argeş Subsidiary, after Vidraru HPP. Excepting the normal maintenance periods and small failures, the Dobrești HPP has been in operation with very good efficiency for the last 85 years. This paper presents the experimental analysis of Dobrești HPP behaviour in steady operating regimes. The study is carried out in order to determine the efficiency of the HPP hydro units, which are equipped with horizontal Pelton turbines.*

**Keywords**: measurements, steady operation, efficiency, hydropower.

## 1. Introduction

The worldwide concern is to use low pollution technologies in order to reduce environmental impact [1, 2]. As the largest renewable source of energy in the world with about 20% of the electricity production, hydropower plays an important role in the process [3]. The environmental impact of their operation is an important aspect for the scientists [4-7]. Another aspect is the refurbishment or commissioning of hydro units which includes on site efficiency measurements in order to verify the efficiency claimed by the manufacturer [8-11]. The efficiency of hydraulic turbines is also periodically investigated to assess deterioration or malfunctioning.

The aim of this paper is to determine the real efficiency characteristics of three out of the four Pelton turbines that equip the Dobrești Hydro-Power Plant (HPP), for two different water levels in the upstream reservoir - Scropoasa. For the steady regime analysis the discharge $Q$, the head $H$ and the electrical power output $P_G$ were measured, according to IEC 41 [12].

[1] Lecturer, Dept. of Hydraulics, Hydraulic Machinery and Environmental Engineering, University POLITEHNICA of Bucharest, Romania, e-mail: georgianadunca@yahoo.co.uk
[2] Teaching Assistant, PhD Student, Dept. of Hydraulics, Hydraulic Machinery and Environmental Engineering, University POLITEHNICA of Bucharest, e-mail: raluca.iovanel@gmail.com
[3] PhD Student, Dept. of Hydraulics, Hydraulic Machinery and Environmental Engineering, University POLITEHNICA of Bucharest, e-mail: razvanroman@ymail.com

## 2. The power station and the experimental setup

### 2.1. Site description

Dobrești hydroelectric power station was built between 1928 and 1930 in order to supply the energy demand of Bucharest city, marking the beginning of the Romanian hydropower engineering development. Together with HPP Moroieni and HPP Scropoasa use the hydro power potential of Ialomița River.

The power plant is equipped with four identical horizontal Pelton turbines, each having two nozzles. The main characteristics of the turbines are 4 MW power output, 285 m rated head and a maximum discharge of 1.75 $m^3/s$. The rotational speed of the turbines is 500 rpm.

### 2.2. Measuring and computation procedure

To achieve the objective of the present work, the following electric and hydraulic parameters of the hydro units were measured: generator power output $P_G$, turbine discharge $Q$, turbine inlet pressure $p_1$, upstream reservoir water level $Z_{lake}$, nozzle piston displacement $s$ [13].

The electrical power output, $P_G$ was measured using the two wattmeter method, with an electrical parameters monitoring system, having an accuracy of 1.5%. For the discharge measurement, $Q$, a 1% accuracy ultrasonic flow meter was mounted on the turbines main inlet pipe, before the distributor. The turbines inlet pressure, $p_1$ was measured by a pressure transducer with a precision of ±0.6%. The water level in the upper reservoir of the plant, $Z_{lake}$, was recorded using the power plant systems and the displacement of the nozzle piston, $s$, was measured with a precision of ±1 mm.

The measurements were done for each turbine in single operation. The different operational regimes of the hydro unit were obtained by varying the power output, $P_G$. The measurement procedure was done for two water levels in the upper reservoir, corresponding to two values for the reference net head, $H_{nc}$.

The efficiency of the turbine-generator assembly, $\eta_{T+G}$, was calculated

$$\eta_{T+G} = \eta_T \cdot \eta_G = \frac{P_G}{\rho g Q H_n} \tag{1}$$

where $g$ – gravitational acceleration; $\rho$ – water density.

Then, considering the generator efficiency known, the turbine efficiency resulted:

$$\eta_T = \frac{\eta_{T+G}}{\eta_G} \tag{2}$$

The net head of the turbine was determined according to [12] as

$$H_n = \frac{p_1}{\rho g} + \left(Z_{M1} - Z_2\right) + \frac{v_1^2}{2g} = \frac{p_1}{\rho g} + Z + \frac{v_1^2}{2g} \tag{2}$$

where $p_1$ is the measured pressure at the turbine inlet section; $Z_{M1}$ – pressure transducer elevation; $Z_2$ – mean elevation of the contact points of water jets with runner; $v_1$ – mean velocity in the pressure sensor section (figure 1).

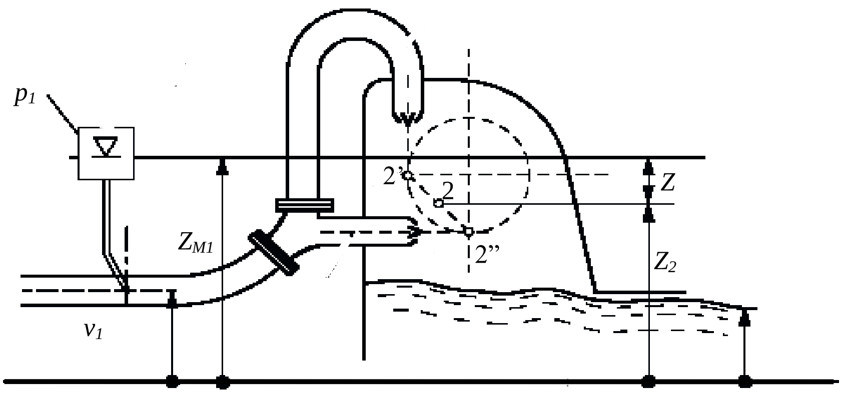


Fig. 1. Pelton turbine reference levels for net head computation [12]

### 3. Results and discussions

The results of the analysis are presented as turbine-generator unit efficiency curves corresponding to one value of the turbine net head considered as reference value, for each turbine. All the quantities are presented considering a relative discharge obtained as a ratio between the measured value and the maximum value recorded for each unit, $Q^* = Q/Q_{max}$. Therefore the net head $H_n^*$ was computed using this relative discharge and the efficiencies are presented as relative values, $\eta^*$.

Usually, during efficiency measurements the net head corresponding to one upper reservoir water level varies around an average value. Thus, to obtain the operation characteristics of the units' valid to one reference net head, all the results are transposed to this averaged net head.

The conversion of the measured relative discharge $Q^*$ and power output $P_G$ to the computational values, $Q_c^*$ and $P_c$, that correspond to the reference net head, $H_{nc}$, is done assuming a constant efficiency of the unit $\eta^*$

$$\eta_{T+G}^* = \eta^* = \frac{P_G}{\rho g Q^* H_n^*}; \tag{4}$$

$$Q_c^* = Q^* \left( \frac{H_{nc}}{H_n^*} \right)^{1/2}; \tag{5}$$

$$P_c^* = P_G \left( \frac{H_{nc}}{H_n^*} \right)^{3/2}. \tag{6}$$

The measurements were carried out for two reference net heads $H_{nc1}$ and $H_{nc2}$. The difference between the turbine rated head and $H_{nc1}$ and $H_{nc2}$ was approximatively 13.5 m and 16.5 m respectively. For illustration of the computed and transposed results, in table 1, are presented the data for hydro unit 1 (HU 1) at $H_{nc1}$.

The measurement of any operating parameter is always associated with uncertainty due to the variability of the measured parameter or to measurement errors. Usually, the uncertainties in determining the efficiency of a hydraulic turbine are estimated at about 1-2%. The uncertainties of the turbine efficiency determination are calculated considering all the uncertainties for each measured quantity, and refer to the measurements quality.

*Table 1*

**Computed and transposed results for HU 1, $H_{nc1}$.**

| Computed parameters | | | | Transposed parameters | |
|---|---|---|---|---|---|
| $Q^*$ | $P_G$ | $\eta_{T+G}^*$ | | $Q_c^*$ | $P_c^*$ |
| – | MW | – | | – | MW |
| 0.124 | 0.385 | 1.060 | | 0.124 | 0.384 |
| 0.275 | 1.108 | 1.374 | | 0.275 | 1.105 |
| 0.472 | 1.959 | 1.416 | | 0.473 | 1.960 |
| 0.604 | 2.655 | 1.504 | | 0.604 | 2.666 |
| 0.725 | 3.105 | 1.466 | | 0.726 | 3.133 |
| 0.856 | 3.605 | 1.445 | | 0.858 | 3.658 |
| 1.000 | 4.154 | 1.429 | | 1.004 | 4.249 |

Thus, the uncertainty obtained for the efficiency is estimated as a function of the three parameters taken into account for units efficiency determination, discharge, $\varepsilon_Q$, net head, $\varepsilon_{Hn}$ and power output, $\varepsilon_{PG}$:

$$\varepsilon_\eta = \pm\sqrt{\varepsilon_Q^2 + \varepsilon_{H_n}^2 + \varepsilon_{P_G}^2} \tag{7}$$

In case of turbine head, the uncertainties are calculated considering the precision of the discharge and pressure measurements, $\varepsilon_Q$ and $\varepsilon_p$.

$$\varepsilon_{H_n} = \frac{\varepsilon_Q\left(v^2/2g\right) + \varepsilon_p\left(p/\rho g\right)}{\left(v^2/2g\right) + \left(p/\rho g\right)} \tag{8}$$

For the testing conditions in the present analysis, according to (8) one get an uncertainty for the net head of 0.61% and according to (7), a total uncertainty for efficiency determination of ± 1.9%. After computing the data for all three hydro units operating in steady state at two water levels in the upstream reservoir, the efficiency characteristics and uncertainty domains are presented in figs 2–3.

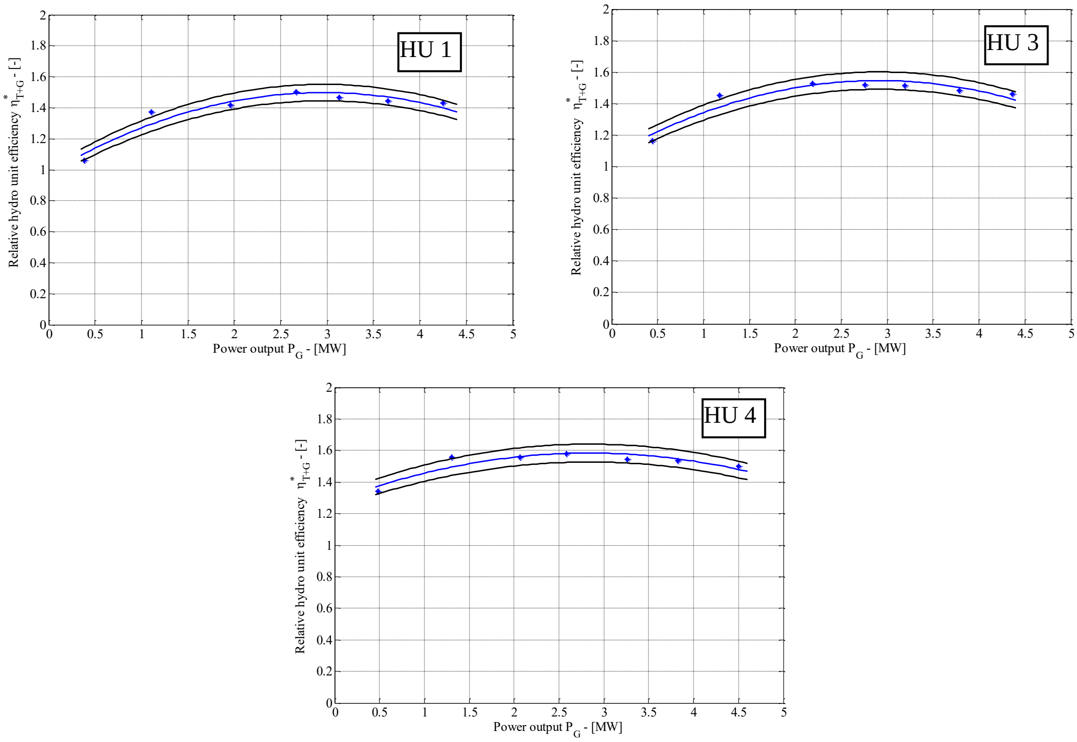


Fig 2. Efficiency curves for Dobrești HPP hydro units and the confidence interval at $H_{nc1}$ = 298.5 m.

The relative efficiency varied for $H_{nc1}$ and $H_{nc2}$ as follows:

- in case of unit 1: 1.1-1.5, and 1.18-1.48 respectively;
- in case of unit 3: 1.2-1.55, and 1.2-1.52 respectively;
- in case of unit 4: 1.38-1.58, and 1.3-1.55 respectively.

The relative efficiency curves show an unstable functioning of the turbine-generator assemblies when the generator output power reaches 1 MW. The efficiency value for this case is outside the confidence interval. This might indicate an erroneous measurement for the main operating parameters, justified by a strong variation of these parameters.

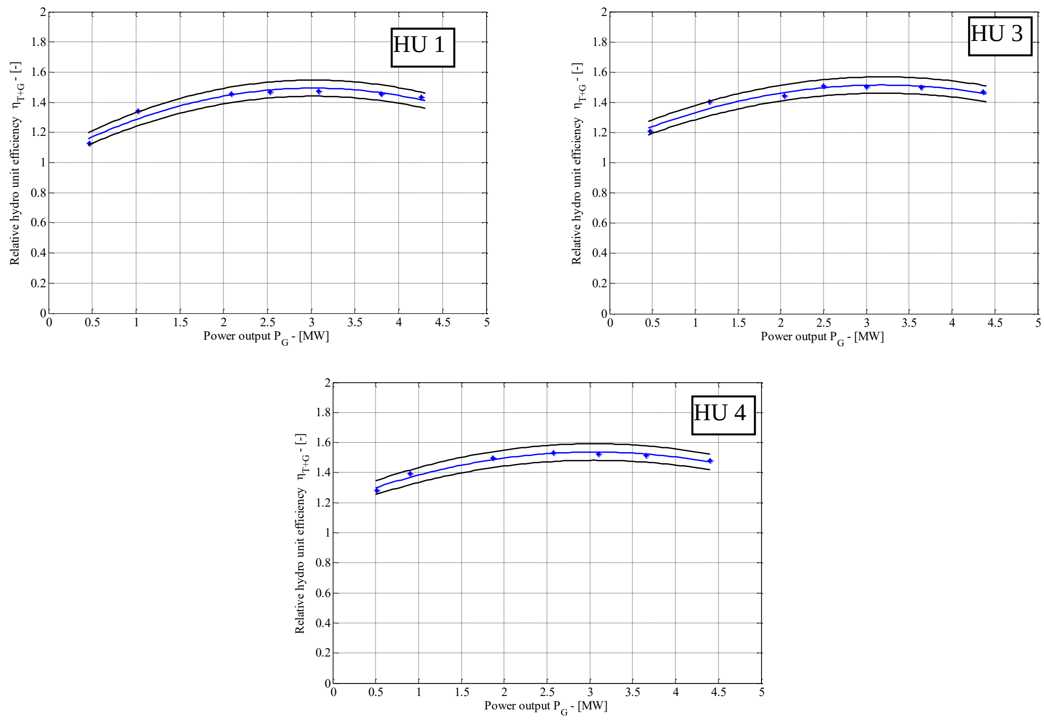


Fig 3. Efficiency curves for Dobrești HPP hydro units and the confidence interval at $H_{nc1}$ = 301.5 m.

## 4. Conclusions

The analysis in this paper presents the efficiency characteristics of three Pelton turbines belonging to one of first HPP built in Romania. The main operating parameters were determined for two different head values, $H_{nc1}$ and $H_{nc2}$ in order to evaluate the efficiency of the hydro units after 85 years of continuous operation of the HPP.

The efficiency values obtained for the first net head value, $H_{nc1}$ are higher than those obtained for the second one, $H_{nc2}$. This is expected since the turbines were designed with a rated head of the turbine at the best operational point. Unfortunately, there are no original efficiency curves from the turbine manufacturer, so a comparison with the initial state was not possible.

The best efficiency point is found at around 2.5 MW. For the first head, $H_{nc1}$, the maximum relative efficiency is 1.58, whereas in the second head case, $H_{nc2}$, the maximum relative efficiency is 1.55.

The study shows that all turbines have a stable functioning and a small efficiency variation if the power output stays in the 2-4 MW interval, so as a general recommendation is to operate Dobrești Hydro-Power Plant in between these values.

**Acknowledgements**

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/134398 and by the Executive Agency for Higher Education, Research, Development and Innovation, PN-II-PT-PCCA-2013-4, ECOTURB project.

## R E F E R E N C E S

[1]. *Diana Tuţică, A. Badea and G. Darie*, "CHP functionality in the case of Energy Market tendencies", in U.P.B. Sci. Bull., Series C, **vol. 75**, no. 4, 2013, pp. 263-268.

[2]. *Mihaela Norişor, G. Darie, V. Cenuşă, R. Pătraşcu and E. Minciuc*, "CCS economic integration issues in a Steam Power Plant", in U.P.B. Sci. Bull., Series C, **vol. 76**, no. 2, 2014, pp. 259-268.

[3]. *Diana Maria Bucur, G. Dunca, M. J. Cervantes, C. Călinoiu and E. C. Isbăşoiu*, "Simultaneous transient operation of a high head hydro power plant and a storage pumping station in the same hydraulic scheme", in IOP Conference Series: Earth and Environmental Science, **vol. 22,** 2014, paper 042015.

[4]. *Diana Maria Bucur, F. Bunea, G. D. Ciocan, G. Băran and E. C. Isbășoiu*, "Water parameters evolution in a hydroelectric site", in Environmental Engineering and Management Journal, **vol. 9**, 2010, pp. 1539-1544.

[5]. *Florentina Bunea, S. Houde, G. D. Ciocan, G. Oprina, G. Baran and I. Pincovchi*, "Aspects concerning the quality of aeration for environmental friendly turbines", in IOP Conference Series: Earth and Environmental Science, **vol. 12**, no. 1, 2010, paper 012035.

[6]. *Liana-Ioana Vuţă, G. E. Dumitran*, "Assessment of water quality at the Romanian Black Sea shore", in UPB Sci. Bull, Series D, **vol. 75**, no. 2, 2013, pp. 195-206.

[7]. *Gabriela Elena Dumitran, L. I. Vuţă*, "Solutions for ensuring fish migration in hydropower sites", in UPB Sci. Bull, Series D, **vol. 77**, no. 3, 2015, pp. 193-204.

[8]. *Diana Maria Bucur, G. Dunca, E. C. Isbășoiu, C. Călinoiu and O. T. Roşioru,* "Analysis of operating parameters during normal and transient regimes of a high head Hydro Power Plant", in U.P.B. Sci. Bull., Series D, **vol. 74**, no. 1, 2012, pp. 51-58.

[9]. *Georgiana Dunca, D. M. Bucur, P. P. Jonsson and M. J. Cervantes*, "Discharge measurements using the pressure-time method: different evaluation procedures", in U.P.B. Sci. Bull., Series D, **vol. 76**, no. 4, 2014, pp. 195-202.
[10]. *Diana Maria Bucur, G. Dunca, C. Călinoiu and E. C. Isbăşoiu, "*Experimental investigation over in site operational characteristics of a hydro generator", in U.P.B. Sci. Bull, Series D, **vol. 77**, no. 1, 2015, pp. 205-212.
[11]. *D. Zlatanovici, R. Zlatanovici, C. Cicirone, S. Dumitrescu, C. Izbăşoiu and D. Bucur*, "Assessment of the hydrogenerators state, based on their history of life analysis", in Scientific Bulletin of the Electrical Engineering Faculty, **no. 1** (12), 2010, pp. 54-59.
[12]. *** IEC 41 International Standard – Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and pump turbines, 3rd ed., **vol. 41**, International Electrotechnical Commision, Geneva, Switzerland, 1991.
[13]. *Diana Maria Bucur, G. Dunca et al.*, "Efficiency measurements and hydraulic losses at Dobrești HPP units", Research Report, 2011.