

## ANALYSIS OF OPERATING PARAMETERS DURING NORMAL AND TRANSIENT REGIMES OF A HIGH HEAD HYDRO POWER PLANT

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*The purpose of the present work is to determine the operating parameters for the two 75 MW units of a high head hydro power plant from Romania.*

*During the experimental investigation, the discharge  $Q$ , the head  $H$  and the generated electric power  $P$  were measured, in order to determine global efficiency of the units.*

*After processing data it could be seen that the two units have different hydraulic behaviour, the hydraulic losses of the first unit being higher than those corresponding to the second unit.*

*Transient regimes are also studied, experimental and numerical, for three situations of sudden load rejection from maximum power output*

**Keywords:** high head hydro power plant, operating regimes, parameter measurement

### 1. Introduction

One of the most important objectives of the hydraulic machineries and installations testing is defining the hydraulic turbines operation parameters in the hydro power plants in which they are located.

After a long time of operation these parameters must be evaluated and the real performances of the hydro units should be determined.

These kind of tests is regulated by IEC – 41, *Code international concernant les essais de réception sur place des turbines hydrauliques*, Geneve, Suisse, 1991, International Standard – Field Acceptance Tests to Determine the Hydraulic Performance of Hydraulic Turbines, Storage Pumps and Pump –

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Turbines, Geneve, 1991 [1]. This standard is also translated and assimilated in Romania.

## 2. Experimental work

The experimental work was performed in a high head hydroelectric plant, for two Francis turbines FVM 85-470, with the following parameters: rotational speed  $n = 600$  rot/min, discharge  $Q_i = 22,8 \text{ m}^3/\text{s}$ , and design head  $H = 470 \text{ m}$ .

During the experimental investigation the turbines discharge  $Q$ , pressure at turbine inlet,  $p_1$ , upstream and downstream water level and power output,  $P$ , were recorded in order to determine the unit operating parameters, for different operating regimes of the hydro power plant, and to obtain the characteristic curve  $\eta = \eta (P)$  [2].

### 2.1. Discharge measurement ( $Q$ )

For discharge measurement was used a portable flowmeter. It was connected to a data acquisition module

### 2.2. Head measurement ( $H$ )

The turbine head was determined using the following equation

$$H_n = z_1 - z_2 + a + \frac{p_1}{\rho g} + \frac{V_1^2 - V_2^2}{2g} \quad (1)$$

where the quantities have the meaning from the figure 1.

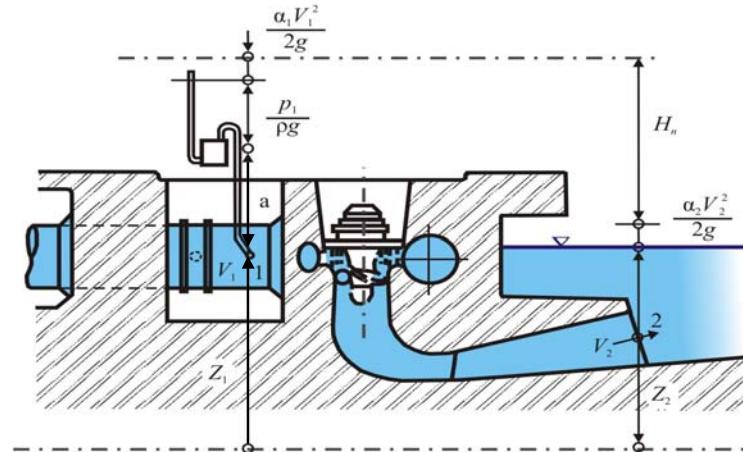


Fig. 1. – Francis turbine hydraulic head

where  $p_1$  is the pressure in the turbine inlet pipe, at the spiral casing inlet measured with a pressure transducer.

The pressure transducer and the flow meter were connected each to a data acquisition module and the entire data acquisition chain was lead by means of a LabVIEW program.

### 2.3. Electric power ( $P$ )

The electric power was measured by means of an electric quantities monitoring system.

## 3. Equations

### 3.1. Net head

The net head of turbine is determined with equation (1) where:

- $z_1 + \frac{p_1}{\rho g}$  is hydraulic head at the spiral case entrance;
- $z_2$  is water level in the downstream watershed;
- $\frac{V_1^2 - V_2^2}{2g}$  is kinetic head;
- $a$  is pressure transducer distance from the spiral case entrance (point 1).

### 3.2. Absolute efficiency

To determine the absolute efficiency the following equation is used

$$\eta = \frac{P_{gc}}{9,81 \rho Q H_{nc}} [\%]. \quad (2)$$

### 3.3. Computed results

The final purpose is to represent the efficiency curve  $\eta = \eta(P)$  or  $\eta = \eta(Q)$  for a certain turbine head.

In order to have all the quantities corresponding to the design head the following transposing equation were used, according to the CEI code (SR EN 60041).

The design head represents a constant ( $H_{nc}=ct$ ) for an entire set of measured quantities

$$Q_c = Q_{mas} \left( \frac{H_{nc}}{H_n} \right)^{1/2} \quad (3)$$

$$P_{gc} = P_{g mas} \left( \frac{H_{nc}}{H_n} \right)^{3/2} \quad (4)$$

where “c” indicates the design quantities [1].

## 4. Data processing

### 4.1. Steady operating regimes

The turbines characteristic curves  $\eta(P_g)$  obtained after computation of the recorded data are presented in figures 2, 3 and 4.

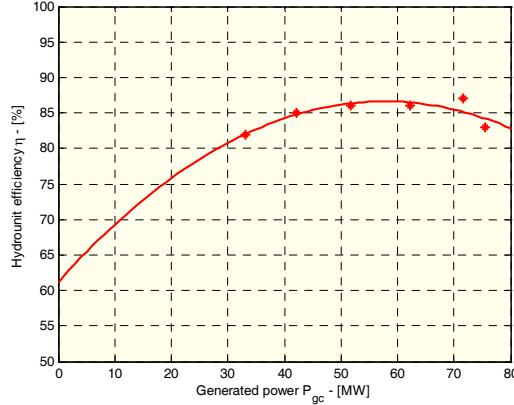


Fig. 2. – Efficiency curve  $\eta(P_g)$  for hydrounit 1, for a net head of  $H_{nc1} = 457$  m

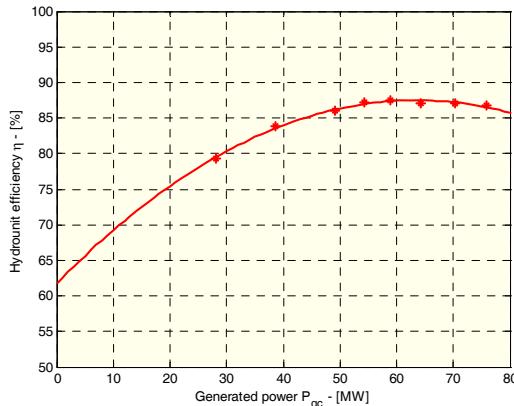


Fig. 3. – Efficiency curve  $\eta(P_g)$  for hydrounit 2, for a net head of  $H_{nc2} = 459$  m

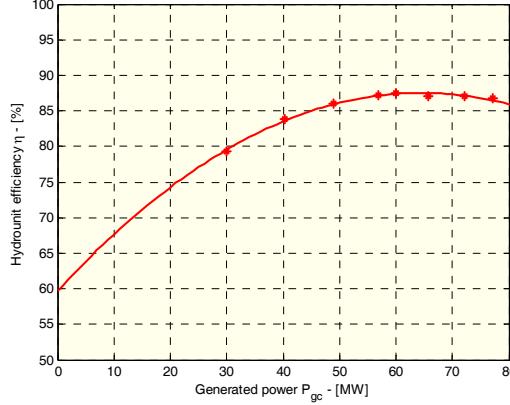


Fig. 4. – Efficiency curve  $\eta(P_g)$  of the two hydro units operating together, for  $H_{nc} = 435$  m

First of all, it can be seen that the two units have a different behaviour taking into account the hydraulic head losses, for unit 1 they being bigger than for unit 2. It can be noticed that the best operating domains (recommended domains), for this head value, are:

- $42 \text{ MW} \leq P_g \leq P_g. \text{ Max.}$  for unit 1, when it operates alone;
- $49 \text{ MW} \leq P_g \leq P_g. \text{ Max.}$  for unit 2;
- $47 \text{ MW} \leq P_g \leq P_g. \text{ Max.}$  for unit 1, when it operates with unit 2.

In these domains the efficiency variation is 2%.

## 4.2. Unsteady operating regimes

In order to rational and full use of rivers hydropower potential in modern hydroelectric design practice there have been adapted complex hydro schemes, which include secondary catchments which are connected with the headrace and may act as several surge tanks. The analytical study of the hydroelectric plant in operation can only provide approximate results. Therefore in this case solving the equations that describe water flow in ducts will be carried out using the numerical methods.

A hydroelectric development will be considered with  $n$  surge tanks along the headrace, these surge tanks having also a discharge contribution  $Q_i$  (the secondary intakes).

The differential equations that describe the flow in the site are [3]

$$\begin{cases} \left\{ \frac{l_i}{g} \frac{dV_i}{dt} + kV_i |V_i| \right\}_{i-1,i} + (z_i + k'W_i |W_i|)_i = (z + R)_{i-1} \\ \left( A_{0,i} V_i \right)_{i-1,i} = \left( A_i \frac{dz}{dt} \right)_i + A_{0,i+1} V_{i+1} - Q_{a,i}, \quad (i = 1, 2, \dots, n) \end{cases} \quad (6)$$

These equations can be solved only numerically.

The variation in time of the free surface level in the surge tank was analyzed, for the following cases (table 1).

Table 1 – Power output at sudden load rejection

No.	HPP	
	HA in operation	P [W]
1	HA1	74,2
2	HA1	73,8
	HA2	74,2
3	HA1	73,9

The numeric results were compared with the experimental results, obtained using a pressure transducer located at the surge tank base (fig. 5). The results are presented in figures 6, 7 and 8.

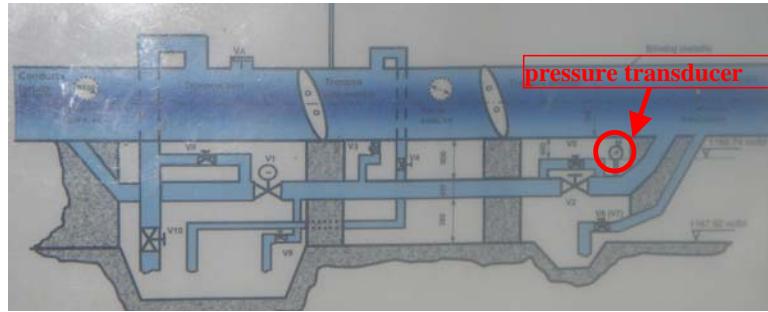


Fig. 5. Pressure transducer location used to measure the surge tank free surface level variation

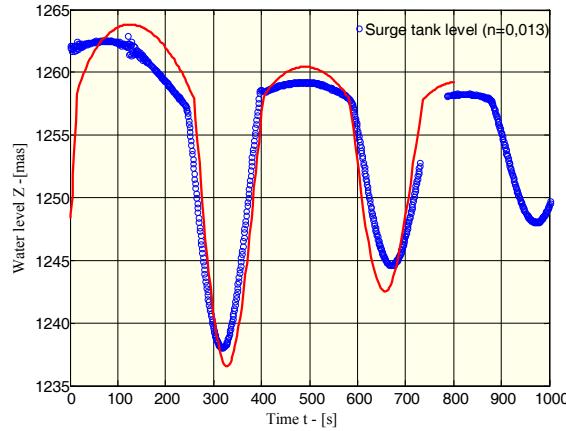


Fig. 6. Surge tank water level variation for the first analyzed case, obtained numerically (red curve) and experimentally (blue curve)

It is noted that numerical results are consistent with data obtained by measurement. However the computed oscillations amplitude in the surge tank is greater than obtained experimentally. This can be explained by the underestimation of hydraulic losses in the program developed to simulate this phenomenon [4, 5].

Thus, it can be seen that the level oscillations in the surge tank attenuate faster than shown by calculation, in about 30 minutes the real amplitude having a maximum decrease of up to 10 m (from 14 m to 4 m, if the worst case of manoeuvre, the second case) compared to the computed oscillation amplitude with a maximum decrease of 8 m in the same case.

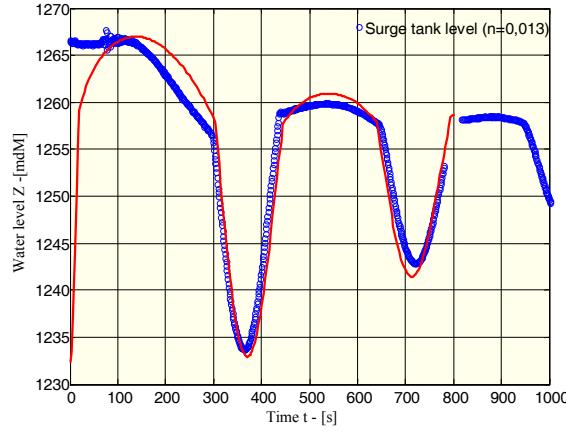


Fig. 7. Surge tank water level variation for the second analyzed case, obtained numerically (red curve) and experimentally (blue curve)

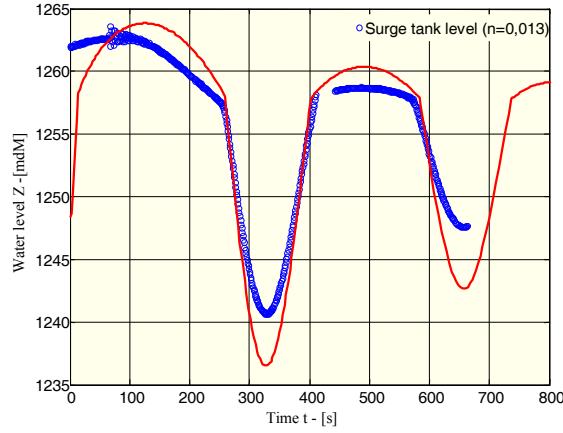


Fig. 8. Surge tank water level variation for the third analyzed case, obtained numerically (red curve) and experimentally (blue curve)

It may be considered that the maximum and minimum hydraulic jumps in this surge tank are well taken, fact demonstrated both numerically and experimentally. This analysis was used also to obtain a computational program that was validated by comparison with experimental results. This program can be used to estimate the surge tank behaviour in case of sudden manoeuvres in the HPP.

## 6. Conclusions

The aim of the analysis was obtaining the hydro units efficiency and to determine the transient regimes behaviour. The analyse was carried out for a power output domain between the minimum power of  $P_{min} \approx 30$  MW and the maximum power of  $P_{max} \approx 76$  MW.

The units efficiency resulted between 0.8 și 0.875, which are the normal limits. If a value of  $\eta_g = 0.975$  is adopted for the generator efficiency, the hydraulic turbine will have the efficiency between  $\eta_T^{\min} \approx 0.82$  and  $\eta_T^{\max} = 0.90$ , values that correspond to the exploiting characteristic of the turbine presented by the turbine supplier.

Regarding the unsteady regime analysis, it was observed that the surge tank has a good behaviour during the sudden manoeuvres in the HPP [6].

Also, it was pointed that the computed water level variation in the surge tank is greater than obtained experimentally. This was explained by the underestimation of hydraulic losses in the program developed to simulate this phenomenon.

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