

# Determination of the performance of the Kaplan hydraulic turbines through simplified procedure

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**Abstract.** A simplified procedure has been developed, compared to the complex one recommended by IEC 60041 (i.e. index samples), for measurement of the performance of the hydraulic turbines. The simplified procedure determines the minimum and maximum powers, the efficiency at maximum power, the evolution of powers by head and flow and to determine the correct relationship between runner/impeller blade angle and guide vane opening for most efficient operation of double-regulated machines. The simplified procedure can be used for a rapid and partial estimation of the performance of hydraulic turbines for repair and maintenance work.

## 1. Introduction

This paper represents the commissioning of the hydro-units from the Retezat downstream River, which was carried out before 1989 and was commissioned in an emergency regime, without samples that would confirm their real technical state.

The technical documentation prepared by the designer gives all the constructive and functional parameters [1], [2] that define the technical condition of each equipment, requiring experimental measuring of some of these parameters at the moment of commissioning.

The simplified procedure for calculating the performance of the Kaplan's hydraulic turbines consists of: the measurements are made at the existing head of the plant; the turbine has automatically adjusted runner blades combined with automatically adjusted wicket gates, cam being the one existing in the regulator; the power of the hydro-unit increases in stages from minimum to maximum by changing the opening of the wicket gates; the efficiency is calculated only at maximum power, this being the efficiency guaranteed by the turbine supplier [3-8].

Index samples are the total tests performed in the hydroelectric plant on the hydro-aggregate to determine the flow and efficiency as relative sizes. The index efficiency is calculated from the specific hydraulic energy and the power measured by primary methods and the flow rate measured by the secondary method, according to IEC 60041 standard.

- A system for acquiring, monitoring and diagnosing the operation of hydro-aggregates has been developed, which highlights their performance before starting repairs and after repair [9].
- Through measurements and assessments made with AMDS (Automated Monitoring and Diagnostic System), an important contribution has been made to experimental research on the operation of hydraulic turbines. Complex experiments were carried out prior to the start of the



repair of the hydro-aggregates for rehabilitation and commissioning after repair, in order to monitor whether the re-assurance provided in the technical documentation was performed.

- Capital repairs, refurbishments and warranty tests require index proofing before and after repairs, in line with the recommendations of IEC 60041 standard. Upon the express request of the customer, the simplified procedure for performance determination can be used, index samples being used only when unrealized efficiency after retrofitting.

## 2. Methodology. Equipment using for measurement

The experimental researches have been carried out for a longer period of time, at each rehabilitation of hydro power groups, respectively before dismantling (BD) and after the commissioning (AC) [9].

At each hydro-aggregate, the table shows the results of the measurement of the measured quantities. These tables include: turbine power, turbulent flow, head and course of the wicket gates.

At each power stage, measurements are made for 3 minutes after stabilizing the hydro-aggregate operating mode. The acquisition rate of the measured quantities is 25kS/s. The values shown in the table are the average values of the measured process parameters for 3 minutes.

The power of the turbine ( $P_T$ ), resulted from the active power measured with the electrical parameters analyser and process parameters, relative to the generator efficiency known in the electrical documentation. The Q flow was measured with flowmeters Winter Kennedy installation, installed in the plant. The verification of the facility and its calibration was carried out by the CCHAPT in some samples.

The head (H) resulted from the difference in the  $H_{am}$  and  $H_{av}$  levels, so is the gross head. At the hydropower plants where the measurement were made, the differences between net head and grosshead are negligible. The course of the wicket gates was measured with the linear transducer.

Turbine efficiency could be determined with relationship [9]:

$$\eta_T = \eta_H = \frac{P_T}{\rho \cdot g \cdot H_n \cdot Q_T} \quad (1)$$

where:

$P_T$  – power of the turbine;

$H_n$  – gross head;

$Q_T$  – flow;

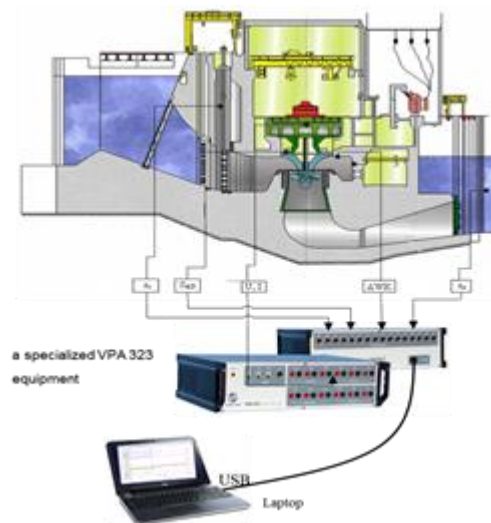
$\rho$  – density;

$g$  - gravitational acceleration.

The Automated Monitoring and Diagnostic System (AMDS) [10], [11] designed and built within CCHAPT Resita (Figure 1), consists of the following components: transducers for the measurement of the upstream ( $z_i$ ) and downstream ( $z_e$ ) level; transducer for the measurement of the course of the wicket gates (SAD); transducer for measuring the pressure difference in the spiral case ( $\Delta WK$ ); reducers for current and voltage measurement to determine the active power (U, I); a specialized VPA 323 equipment for the acquisition and processing of signals for the testing, monitoring and diagnosis of reactive hydraulic turbines; process interface for specialized equipment to acquire electrical and process parameters.

Transducers for the measurement of the upstream ( $z_i$ ) and downstream ( $z_e$ ) level, for the measurement of the course of the wicket gates ( $S_{AD}$ ) and for the measurement of the pressure difference in the spiral case ( $\Delta WK$ ) were installed in the accessible areas of the hydroelectric plant and connected to the analogue inputs behind the specialized equipment of the electrical and process parameters.

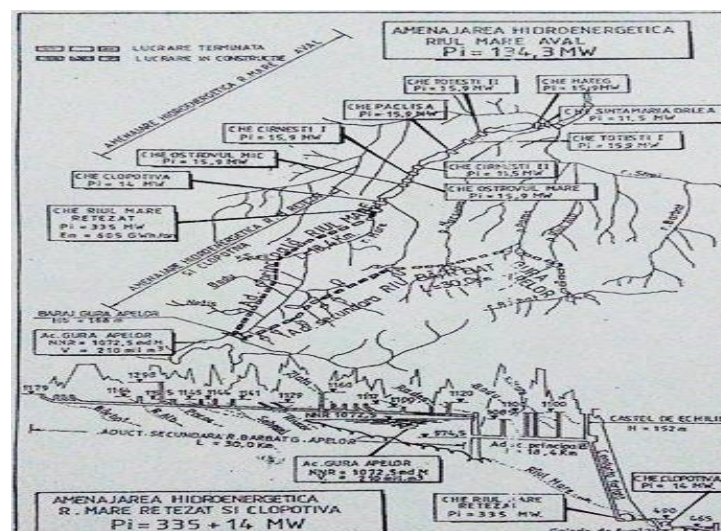
In order to obtain the active power the voltage on the three phases (UR, US, UT) and the current on the three phases (IR, IS, IT) were measured to be connected to the specialized equipment of the electrical and process parameters on the AC inputs(a.c.) of 100V / 600V, 5A, [12].



**Figure 1.** Automated Monitoring and Diagnostic System (AMDS)

### 3. Experimental results

Hydropower development The Retezat downstream (Figure 2) has a total installed capacity of 134.3 MW and provides an average annual energy output of 193.4 GWh. The arrangement located in the Hateg's depression, between the Clototiva hydropower plant and the confluence of the Great River Strei, contains 3 accumulations (Ostrovul Mic, Paclisa and Hateg) carried by the dam and the hydro power plant is on retention area and 6 hydro power plant placed on the channel (Ostrovul Mare, Cârnesti I, Cârnesti II, Totesti I, Totești II and Orlea). All hydropower plants are equipped with two Kaplan turbines [9], [13], [14].

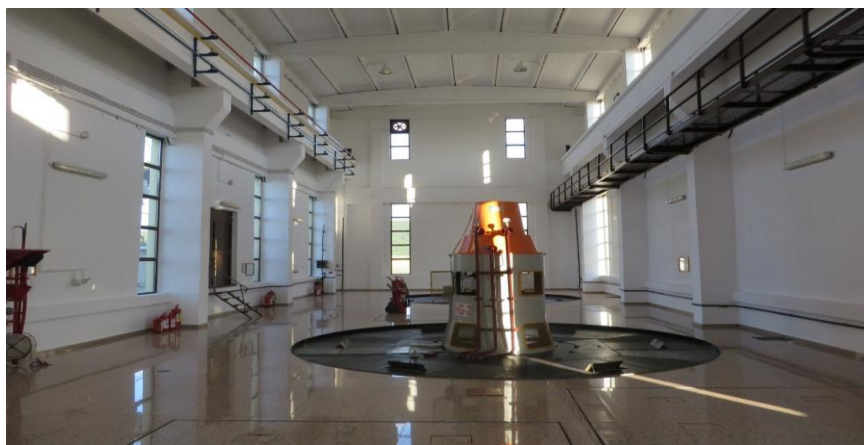


**Figure 2.** Great Retezat River downstream

Will be present 2 hydro aggregates before dismantling and after commissioning, together with experimental research results [15], [16].

- General data and main technical features for KVB turbine type 8.4 - 21 to HEPP Paclisa HA<sub>2</sub>.
- Technical specifications :
  - Turbine type: 6-pallet,
  - CHE type: retention front
  - maximum net head:  $H_{max} = 21$  m.c.a

- net calculation head:  $H_c = 19.3$  m.c.a.
- minimum net head:  $H_{min} = 17,0$  m.c.a.
- maximum coupling power:  $P_{max} = 8400$  kW
- maximum flow:  $Q_{max} = 45$  m<sup>3</sup> / sec.
- maximum suction height:  $H_{s,max} = - 2.75$  m
- rotor diameter:  $D1 = 2750$  mm
- rated speed:  $n = 214.3$  rpm
- Maximum turbine output power corresponding to characteristic net heads:
  - $H_{max}$ :  $P_{maxmax} = 8400$  kW
  - $H_c$ :  $P_{maxC} = 7603$  kW
  - $H_{min}$ :  $P_{maxmin} = 6027$  kW

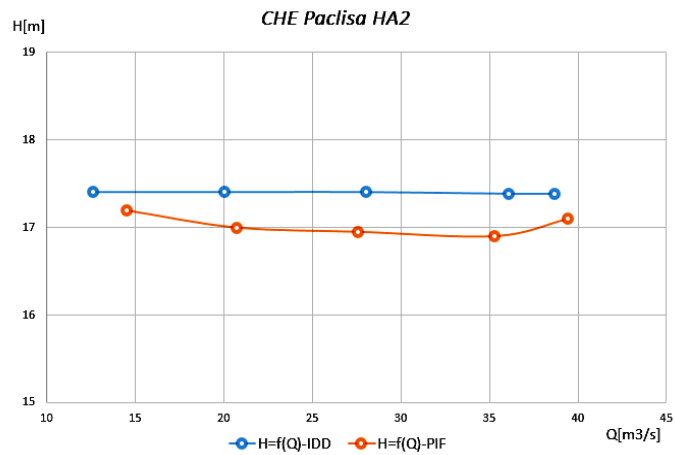


**Figure 3.** HEPP Paclisa HA2

Figure 3 shows the machine room at CHE Paclisa HA<sub>2</sub> where the measurements were made and Table 1 presents the results of the experimental investigations at this hydro-aggregate before disassembly and after commissioning.

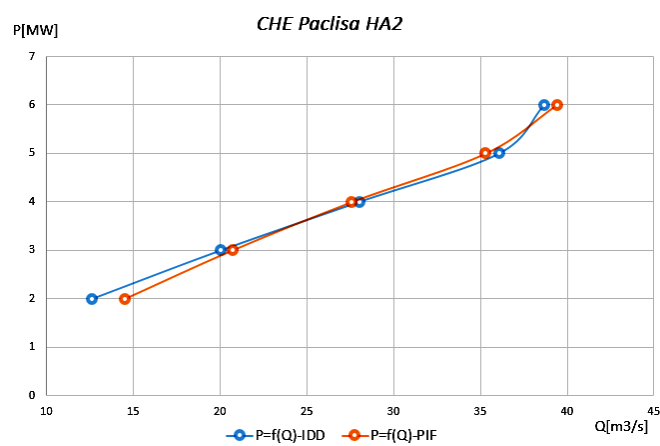
**Table 1.** Process parameters measured at HEPP Paclisa HA<sub>2</sub>

Measurements BD				Measurements AC			
$P_T$ [ MW]	$Q$ [m <sup>3</sup> /s]	$H$ [m]	$S_{AD}$ [%]	$P_T$ [ MW]	$Q$ [m <sup>3</sup> /s]	$H$ [m]	$S_{AD}$ [%]
2	12.6	17.41	53.16	2	14.5	17.2	57.3
3	20.02	17.41	67.8	3	20.7	17	68.3
4	28.02	17.41	79.3	4	27.6	16.95	78.9
5	36.1	17.39	93	5	35.3	16.9	91.9
6	39.2	17.39	99.6	6	39.4	17.1	99.7



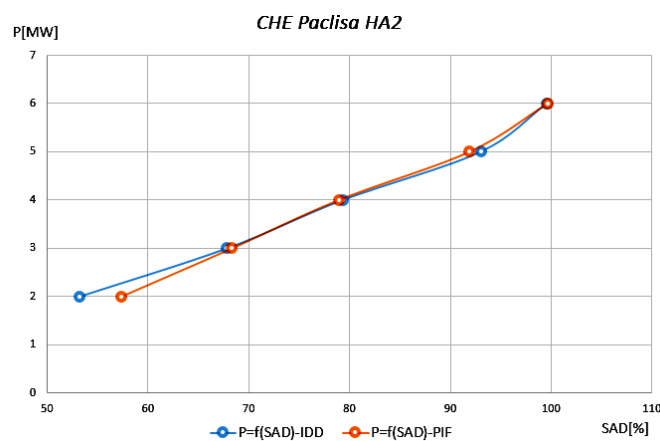
**Figure 4.**  $H=f(Q)$  – Head depending to flow

Figure 4 shown that both before and after repair, the turbine operates at the minimum net head, but a head stability can be observed.



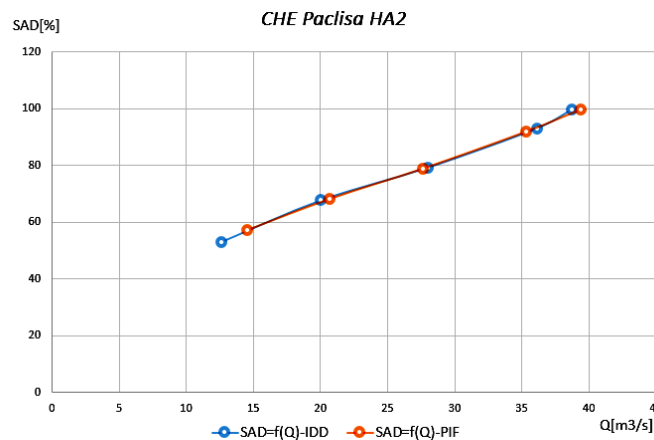
**Figure 5.**  $P=f(Q)$  – Power depending to flow

Figure 5 shown that active power is guaranteed at maximum net head, both before disassembly and commissioning.



**Figure 6.**  $P=f(SAD)$  – Power depending to open wicket gate

Figure 6 shown that in both cases, the wicket gates is opened to the maximum, with guaranteed power at the minimum head.



**Figure 7.** SAD=f(Q) – Open wicket gate depending to flow

In Figure 7 it can be seen in the  $SAD = f(Q)$  characteristics that the kinematics of the wicket gate is the same in both situations.

Knowing density  $\rho$ , gravitational acceleration  $g$ , gross head  $H_n$ , flow  $Q_T$  și power of the turbine  $P_T$  the turbine efficiency can be determined according to the relationship (1), both before disassembly (BD) and after commissioning (AC) at the maximum measured power.

Where:

- water density at temperature  $T=21^\circ\text{C}$  is:  $\rho = 998,20 \text{ kg/m}^3$
- gravitational acceleration is:  $g = 9,8054 \text{ m/s}^2$

- Turbine efficiency will be:

**BD** Efficiency at maximum power

$$\eta_T = \eta_H = \frac{P_T}{\rho \cdot g \cdot H_n \cdot Q_T} = 89,82 \% \quad (2)$$

**AC** Efficiency at maximum power

$$\eta_T = \eta_H = \frac{P_T}{\rho \cdot g \cdot H_n \cdot Q_T} = 90,98 \% \quad (3)$$

Measurement were made in the area of minimum head.

The efficiency obtained after retrofitting is the guaranteed field and is higher than before the retrofitting.

- General data and main technical features for KVB turbine type 8.4 - 21 to HEPP Cârnesti I HA<sub>1</sub>.
- Technical specifications :
  - Turbine type: 6-pallet,
  - CHE type: retention front
  - maximum net head:  $H_{\max} = 21 \text{ m.c.a}$
  - net calculation head:  $H_c = 19.3 \text{ m.c.a}$ .
  - minimum net head:  $H_{\min} = 17,0 \text{ m.c.a}$ .
  - maximum coupling power:  $P_{\max} = 8400 \text{ kW}$
  - maximum flow:  $Q_{\max} = 45 \text{ m}^3 / \text{sec}$ .
  - maximum suction height:  $H_{s.\max} = - 2.75 \text{ m}$
  - rotor diameter:  $D_1 = 2750 \text{ mm}$
  - rated speed:  $n = 214.3 \text{ rpm}$
- Maximum turbine output power corresponding to characteristic net heads:



- Hmax: Pmaxmax = 8400 kW
- Hc: PmaxC = 7603 kW
- Hmin: Pmaxmin = 6027 kW

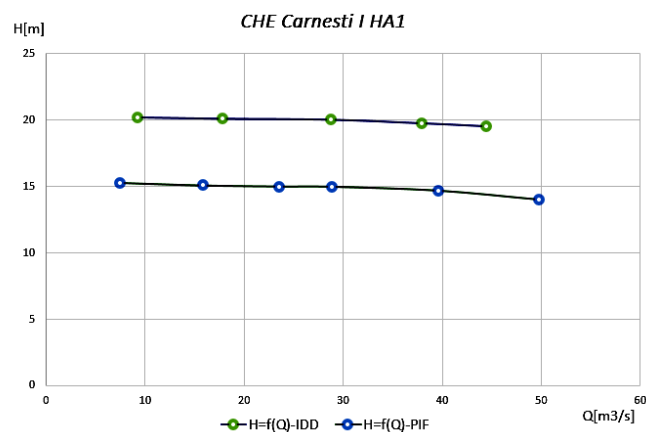


**Figure 8.** HEPP Cârnesti I HA1

Figure 8 shows the machine room at HEPP Cârnesti I HA1 where the measurements were made and Table 1 presents the results of the experimental investigations at this hydro-aggregate before disassembly and after commissioning [17-19].

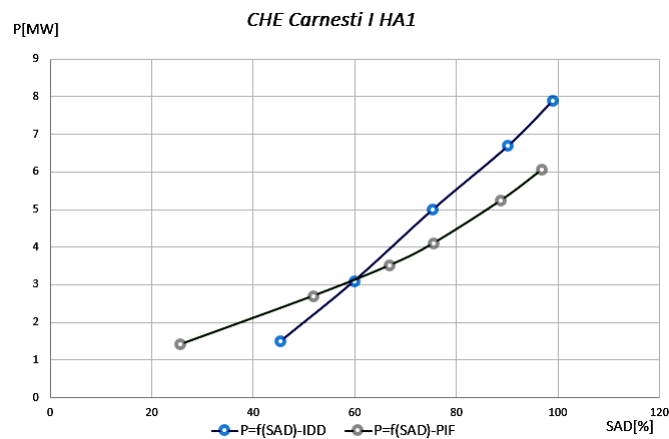
**Table 2.** Process parameters measured at HEPP Cârnesti I HA1

Measurements BD				Measurements AC			
$P_T$ [MW]	$Q$ [m <sup>3</sup> /s]	$H$ [m]	$S_{AD}$ [%]	$P_T$ [MW]	$Q$ [m <sup>3</sup> /s]	$H$ [m]	$S_{AD}$ [%]
1.5	9.2	20.24	45.4	1.41	7.4	15.3	25.66
3.1	17.8	20.14	59.84	2.7	15.8	15.1	51.78
5	28.7	20.06	75.27	3.52	23.5	15.02	66.9
6.7	37.9	19.78	90.1	4.11	28.8	15	75.54
7.9	44.4	19.55	98.9	5.25	39.6	14.7	88.8
				6.06	49.8	14	96.8



**Figure 9.**  $H=f(Q)$  – Head depending to flow

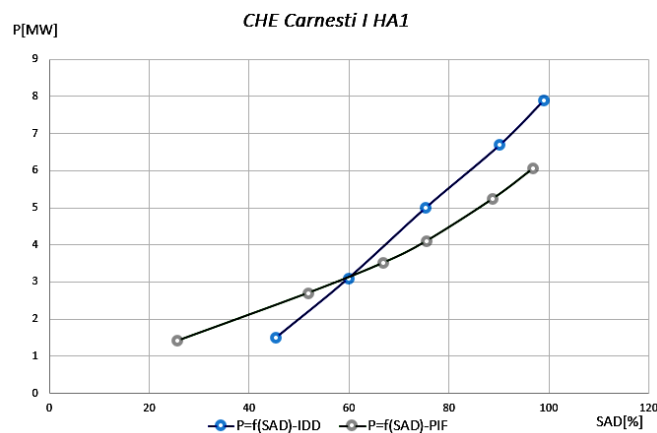
From Figure 9 it's shown at the BD, the turbine was operating at the net head, falling into the parameters of the technical documentation drawn up by the designer, and at the AC the head is below the minimum.



**Figure 10.**  $P=f(Q)$  – Power depending to flow

From Figure 10 it's shown evolution of powers from minimum to maximum is in accordance with the great difference of heads.

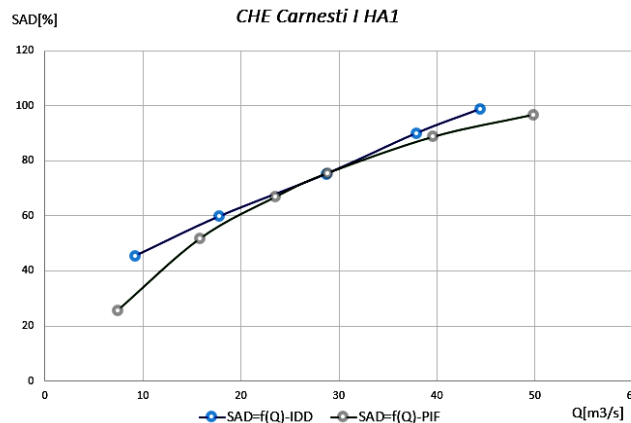
From Figure 11 it's shown the evolution of active powers by opening the guiding blades is similar with Figure 10.



**Figure 11.**  $P=f(SAD)$  – Power depending to open wicket gate

From Figure 12 it's shown there is no significant difference in the kinematics of the wicket gate before and after repair.





**Figure 12.** SAD=f(Q) – Open wicket gate depending to flow

Knowing density  $\rho$ , gravitational acceleration  $g$ , gross head  $H_n$ , flow  $Q_T$  și power of the turbine  $P_T$  the turbine efficiency can be determined according to the relationship (1), both before disassembly (BD) and after commissioning (AC) at the maximum measured power [20-22].

Where:

- water density at temperature  $T=21^\circ\text{C}$  is:  $\rho = 998,20 \text{ kg/m}^3$
- gravitational acceleration is:  $g = 9,8054 \text{ m/s}^2$

- Turbine efficiency will be:

**BD** Efficiency at maximum power

$$\eta_T = \eta_H = \frac{P_T}{\rho \cdot g \cdot H_n \cdot Q_T} = 92,98 \% \quad (4)$$

**AC** Efficiency at maximum power

$$\eta_T = \eta_H = \frac{P_T}{\rho \cdot g \cdot H_n \cdot Q_T} = 88,8 \% \quad (5)$$

The two efficiency can not be compared, the measurements were made at totally different heads. Before to retrofitting  $H=19.55\text{m}$ , very close to the net head and after retrofitting  $H=14\text{m}$ , much less than the minimum guaranteed head. In this case after commissioning, the net head wasn't assurance.

#### 4. Conclusions

The operating characteristics were automatically generated from the measured parameters. At HEPP Paclisa hydro power station no. 2, was measured in the minimum head area. The efficiency obtained after retrofitting is in the range guaranteed by the turbine supplier. At HEPP Cârnesti I hydro power station no. 1, efficiency can not be compared, the measurements were made at totally different heads. The functionality of this power plant need optimizations to assurance the net head, because all of this hydro power plants it works in cascade mode.

The simplified procedure can be used for a rapid and partial estimation of the performance of hydraulic turbines for repair and maintenance work. If the simplified procedure, when used after retrofitting, efficiency is lower than those guaranteed, they must be checked by complex index samples, recommended by IEC 60041 and corrected the cam combinatorial.

Complex index samples, require an experimental investigation of at least three heads, resulting in at least five days of withdrawal of the hydro-unit from the operation, namely one day of mounting measuring equipment, three days of testing and one day of dismantling the equipment.

The simplified procedure requires only two days to withdraw the hydro-unit from the operation, one day for mounting measuring equipment and one day for testing and dismantling the equipment.

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