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The results from index tests performed on the Kaplan turbines

The index tests are normally used during the commissioning and operation of the hydraulic turbines. This paper presents a few results obtained from index tests performed on the Kaplan turbines. These tests were realised by Research Centre in Hydraulic Automation and Heat Transfer (CCHAPT) from "Eftimie Murgu" University of Resita.

1. Introduction

The index tests represent the all measurements performed on the hydro units in the hydro power plant for to determine the discharge and the efficiency as the relatively values. They are used during the commissioning and operation of the hydraulic turbines (IEC 545, 805 and 60041) and can be considered as a part of field acceptance tests only when the relative discharge measuring method is calibrated by a method accepted in [1].

An index value represents a value witch was measured with uncalibrated devices (measuring apparatuses witch were are not calibrated with primary methods).

The relative value represents an index value divided by a same value. For example the relative efficiency is an index efficiency divided by a reference index efficiency (for instance the maximum value).

Applications [1]

- to determine the relationship between runner blade angle guide vane opening (for double – regulated turbines);
- additional test during a field efficiency test;
- to determine the performances as expressed by the relative values of power, discharge and efficiency;
- to check the power guarantee if the parties involved agree;
- to extend information on performance outside the guaranteed range;

- to assess the change in efficiency and/or power due to cavitation, wear, repair or modification;
- to optimized the operation of the power station;
- to compare the index test results on the prototype with the results expected from the model tests.

2. Index tests specified measurements

For to determine the discharge efficiency, as the relative values, during the index tests will be performed the following measurements:

Relative discharge measurement

In accordance with [1] for to determine the relative discharge will be used following methods:

- relative discharge measurement by differential pressure methods.
  The Winter – Kennedy method witch represent the discharge by $Q = k \cdot \Delta h^n$, where Δh is the reading of a differential manometer connected between the two taps. In [1] is presented the location of the taps for the all turbine types.
  Measurement of the pressure difference between the taps located in a converging part of the penstock.
  Measurement of the pressure distance between the taps located in a suction tube for the pump regime;
- relative discharge measurement by acoustic method;
- other methods.

It may be used to give an index discharge from stroke characteristics, differential pressure in a band, in a divergence etc, measurement by means of one single current-meter suitably located.

Specific hydraulic energy measurement

The specific hydraulic energy E, head $H = \frac{E}{g}$, are determined in accordance with [1].

Power measurement

The power of hydraulic turbine and the power of hydro unit are determined in accordance with [1]. In some cases it is sufficient to use the apparatuses existing on the board of instruments.

Speed measurement

The rotational speed of the hydraulic turbine is determined in accordance with [1]. In some cases it is sufficient to use the apparatuses existing on the board of instruments.

Machine openings

For the wicket gates opening and the runner blade angle are realised high accuracy calibration. This openings are correlated with the servomotors strokes.

Computation of results

For the each index tests are measured the following values: the index discharge Q_i, the specific hydraulic energy E (the head H), the power of hydro units P, the rotational speed n and the wicket gates and runner blades openings. With these values will be computed:

- relative turbine efficiency

$$\eta_{rel} = \frac{\left(\frac{\mathrm{P}}{\mathrm{E} \cdot \mathrm{Q_i}}\right)}{\left(\frac{\mathrm{P}}{\mathrm{E} \cdot \mathrm{Q_i}}\right)_{ref}}, \qquad (1)$$

- relative pump efficiency

$$\eta_{rel} = \frac{\left(\frac{\mathrm{E} \cdot \mathrm{Q_i}}{\mathrm{P}}\right)}{\left(\frac{\mathrm{E} \cdot \mathrm{Q_i}}{\mathrm{P}}\right)_{ref}}, \qquad (2)$$

- relative discharge

$$\mathrm{Q_{rel}} = \frac{Q_i}{Q_{iref}} \qquad (3)$$

Q_{iref} is often estimated assuming the absolute value for the maximum relative efficiency. This efficiency maybe, for instance the maximum guaranteed efficiency at the head measured during the test.

Uncertainty of measurement

The errors witch can affect the index tests are computed in accordance with [1].

3. The results from index tests performed on the Kaplan turbines

CCHAPT Resita has realised and participate at the all index tests performed on the hydro units from the Romanian hydro power plants.

Measuring procedure

The measuring procedures are the following stages:

- Preparation. In this stage the equipment (measuring instruments, wires, signal recording devices, PC) will be installed and calibrated. The Winter – Kennedy taps and trash rack will be cleaned.
- Measuring on cam operation. From minim to maximum power will be measured minimum 5 points. The power steps are equal, figure 1.

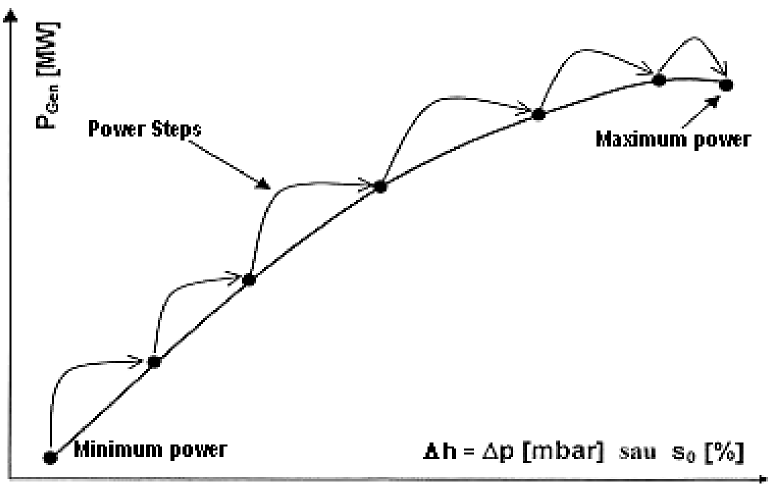

Figure 1. $P_{Gen} = f(\Delta p, s_0\ (a_0))$ for a head on cam operation

- Measuring off cam operation (Propeller characteristics). The measurement procedure is given in figure 2 an it is the following: the runner blades will be fixed, the wicket gates will be adjusted by increasing and decreasing, starting at the on cam position. The steps will be around 5% of opening. 5 – 10 wicket gate openings a_0 will be measured for exactly defined of Propeller curves. After finishing the Propeller curve (measurements), the wicket gates opening will be adjusted on cam position and then the power will be decreased to a new position.

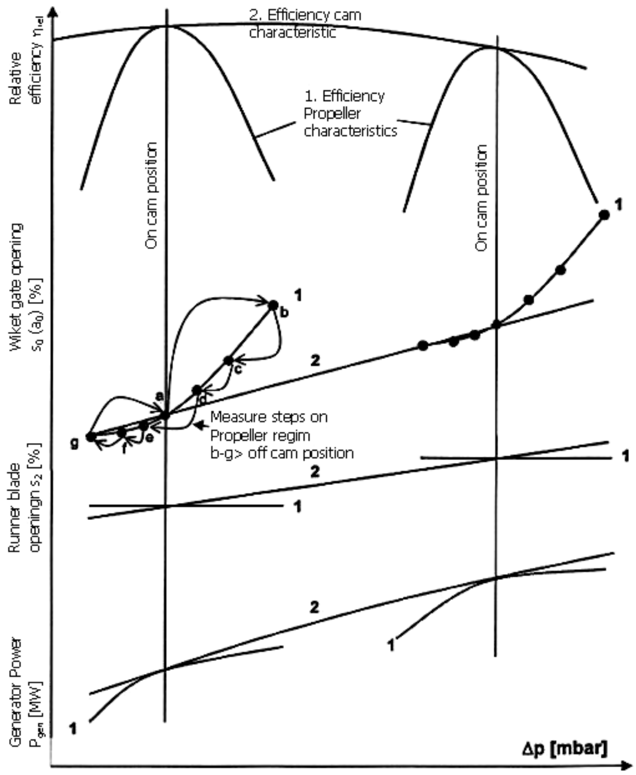

Figure 2. Measuring procedure

Evaluation of results

The index tests give the relative values for discharge and efficiency. In this paper we present a method for discharge calculation as an absolute value. With these discharge will be computed the efficiency as an absolute value. The efficiencies obtained on this way can be compared with the efficiencies scaled up from model measurements.
The method for discharge calculation assumes the Winter – Kennedy measurements performed and known and is developed in [2].
The scale up relation of discharge measurement from the model to the prototype assumes Euler criteria valid.

$$\frac{\delta_{p_p}}{\rho_p \cdot V_p^{\;2}} = \frac{\delta_{p_m}}{\rho_m \cdot V_m^{\;2}} \tag{4}$$

$$\frac{V_p}{V_m} = \frac{\sqrt{\rho_m \cdot \delta_{p_p}}}{\sqrt{\rho_p \cdot \delta_{p_m}}}$$

$$\frac{Q_p}{Q_m} = \frac{V_p \cdot D_p^{\ 2}}{V_m \cdot D_m^{\ 2}} = \frac{D_p^{\ 2}}{D_m^{\ 2}} \frac{\sqrt{\rho_m \cdot \delta_{P_p}}}{\sqrt{\rho_p \cdot \delta_{P_m}}}$$

$$\delta_{P_p} = \gamma_P \cdot \Delta h_p = \rho_p \cdot g_p \cdot \Delta h_p$$

$$\delta_{P_m} = \gamma_m \cdot \Delta h_m = \rho_m \cdot g_m \cdot \Delta h_m$$

where Δh_p and Δh_m are the pressure differences for prototype and model.

$$\frac{Q_p}{Q_m} = \frac{D_p^{\ 2}}{D_m^{\ 2}} \frac{\sqrt{\rho_m \cdot \rho_p \cdot g_p \cdot \Delta h_p}}{\sqrt{\rho_p \cdot \rho_m \cdot g_m \cdot \Delta h_m}} = \frac{D_p^{\ 2}}{D_m^{\ 2}} \frac{\sqrt{g_p \cdot \Delta h_p}}{\sqrt{g_m \cdot \Delta h_m}}$$

so:

$$\frac{Q_p}{D_p^{\ 2}\sqrt{g_p \cdot \Delta h_p}} = \frac{Q_m}{D_m^{\ 2}\sqrt{g_m \cdot \Delta h_m}} = k \qquad (5)$$

$$\begin{cases} Q_p = k \cdot D_p^{\ 2}\sqrt{g_p \cdot \Delta h_p} \\ Q_m = k \cdot D_m^{\ 2}\sqrt{g_m \cdot \Delta h_m} \end{cases} \qquad (6)$$

$$Q_p = Q_m \cdot \frac{D_p^{\ 2}}{D_m^{\ 2}} \frac{\sqrt{g_p \cdot \Delta h_p}}{\sqrt{g_m \cdot \Delta h_m}} \qquad (7)$$

$$Q_p = k \cdot D_p^{\ 2}\sqrt{g_p \cdot \Delta h_p} \qquad (8)$$

The Reynolds and Euler criteria can not respected. Then the relation (7) and (8) will be corrected with scale up effect for efficiencies:

$$Q_p \cdot \eta_{Q_p} = Q_m \cdot \eta_{Q_m} \frac{D_p^{\ 2}}{D_m^{\ 2}} \frac{\sqrt{g_p \cdot \eta_{h\,p} \cdot \Delta h_p}}{\sqrt{g_m \cdot \eta_{h\,m} \cdot \Delta h_m}}$$

$$Q_p = Q_m \frac{D_p{}^2}{D_m{}^2} \frac{\sqrt{g_p \cdot \Delta h_p}}{\sqrt{g_m \cdot \Delta h_m}} \frac{\sqrt{\eta_{hp}}}{\sqrt{\eta_{hm}}} \frac{\eta_{Qm}}{\eta_{Qp}}$$

$$Q_p = k \cdot D_p{}^2 \sqrt{g_p \cdot \Delta h_p} \frac{\sqrt{\eta_{hp}}}{\sqrt{\eta_{hm}}} \frac{\eta_{Qm}}{\eta_{Qp}} \tag{9}$$

With assumption $\eta_{Qp} = \eta_{Qm}$ the relation (5) is:

$$Q_p = k \cdot D_p{}^2 \sqrt{g_p \cdot \Delta h_p} \sqrt{\frac{\eta_{hp}}{\eta_{hm}}} \tag{10}$$

The efficiencies η_{hp} , η_{hm} will be computed in accordance with [3]. The unit discharges result from:

$$Q_p = Q_m \frac{D_p{}^2}{D_m{}^2} \frac{\sqrt{g_p \cdot \Delta h_p}}{\sqrt{g_m \cdot \Delta h_m}} \frac{\sqrt{\eta_{hp}}}{\sqrt{\eta_{hm}}}$$

$$\frac{Q_p}{D_p{}^2 \sqrt{H_p}} = \frac{Q_m}{D_m{}^2 \sqrt{H_m}} \frac{\sqrt{g_p \cdot \Delta h_p}}{\sqrt{g_m \cdot \Delta h_m}} \frac{\sqrt{H_m}}{\sqrt{H_p}} \frac{\sqrt{\eta_{hp}}}{\sqrt{\eta_{hm}}} \tag{11}$$

$$Q_{11p} = Q_{11m} \cdot \sqrt{\frac{g_p}{g_m}} \cdot \sqrt{\frac{\frac{\Delta h_p}{H_p}}{\frac{\Delta h_m}{H_m}}} \cdot \sqrt{\frac{\eta_{hp}}{\eta_{hm}}}$$

The index tests results performed on the Kaplan turbines from HPP Turnu and HPP Portile de Fier I

In the HPP Turnu on a Kaplan turbine with D = 5500 mm and P = 33,5 MW index tests was performed by CCHAPT Resita, in 2001 year. In this paper we present a few results from this tests, figure 4. In figure 4 η_a is the efficiency of the hydro unit and Q is the discharge of the turbine.

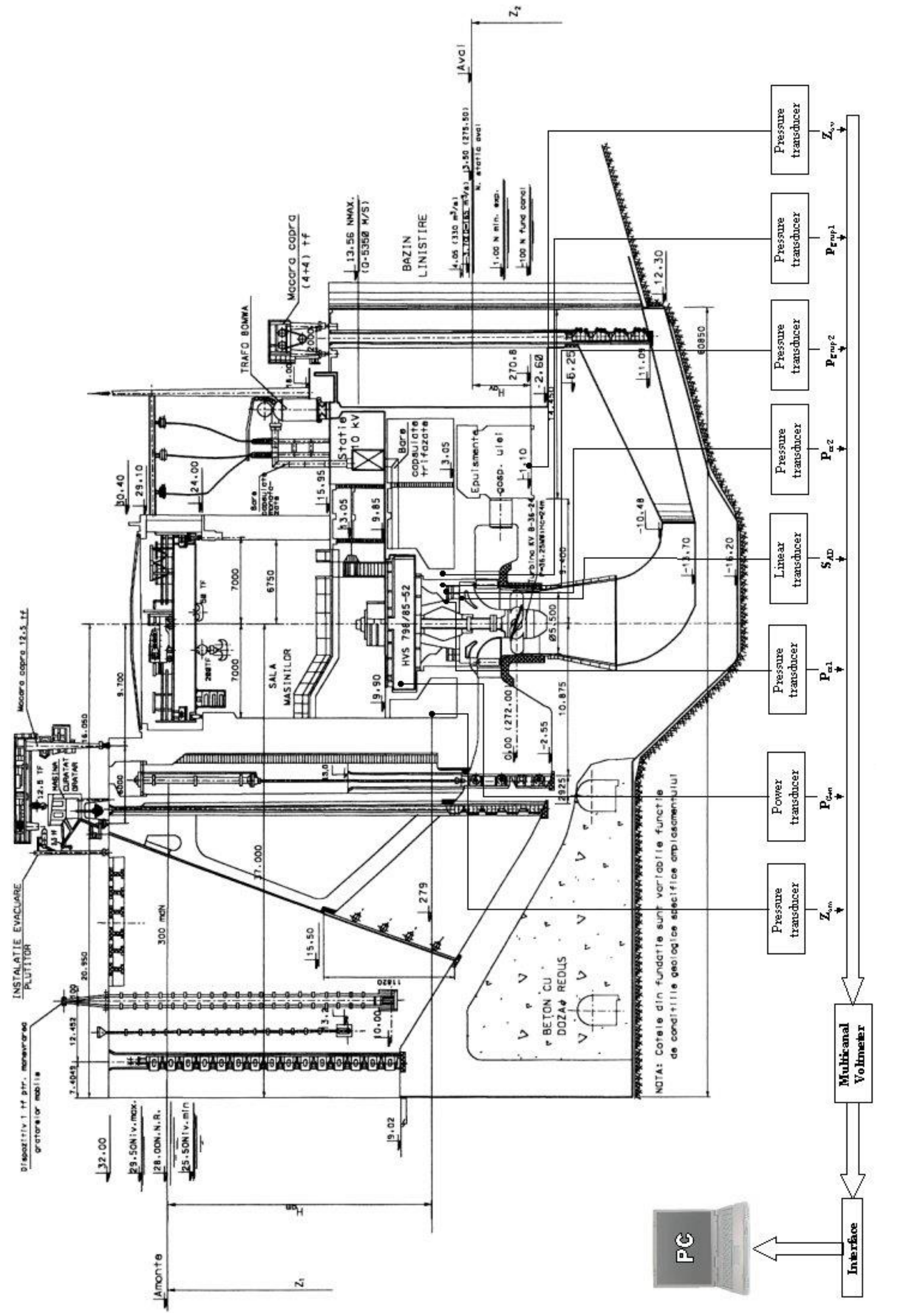

Figure 3. Arrangement of the measuring instruments

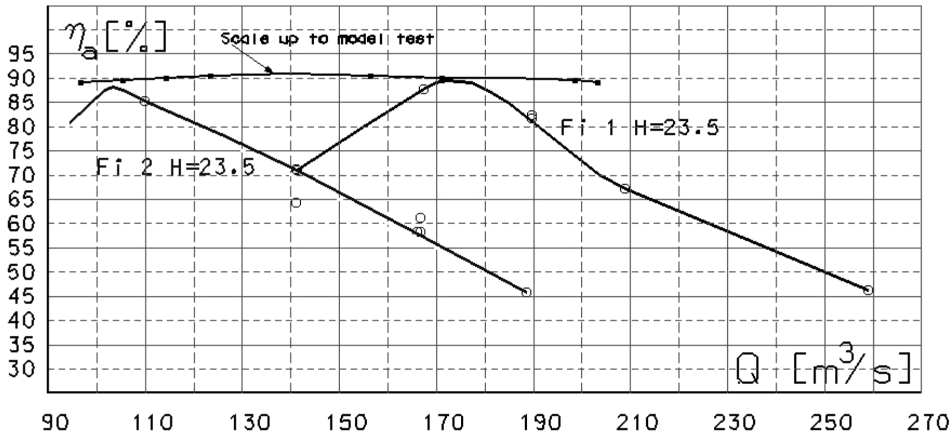

Figure 4. Propeller and Kaplan characteristics for turbine and hydro unit HPP Turnu before rehablitation

In the time of September 1998 at unit 6 from HPP Portile de Fier I, the first index tests before the rehabilitation was executed by VA TECH. CCHAPT has participated at this measurements. In figure 5 are presented the results computed by CCHAPT.

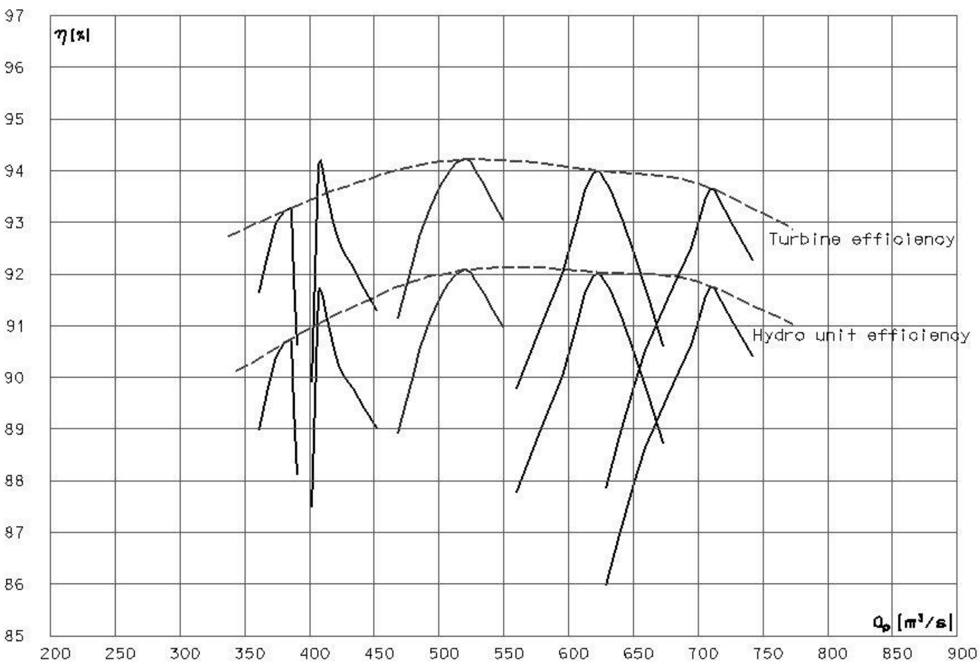

Figure 5. Propeller and Kaplan characteristics for turbine and hydro unit n^o 6 HPP Portile de Fier I before rehablitation

References

[1] ***. Field acceptance tests to determine the hydraulic performance of hydraulic turbines, storage pumps and bulb turbines. International Standard IEC 41/1991 - 11

[2] Campian CV, Zembinschi St. Hydrodinamic turbines discharge measurement by Winter – Kennedy method. Proceedings "Conerinta Nationala de Energetica" Neptun, 19 – 18 iunie 1992, Romania.

[3] ***. Determination of the prototype performance from model acceptance tests of hydraulic machines with consideration of scale effects. International Standard IEC 995. First edition 1991 – 08.

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