INDIRECT METHOD TO CALCULATE THE OPERATING FLOW ON A KAPLAN TURBINE

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ABSTRACT

The paper presents an indirect method to calculate the operating flow in a hydraulic power station with derivation and free level or dam. The calculus algorithm is based on the polynomial representation of the working performance curve \( \eta = \eta(Q_{11}, n_{11}) \), model efficiency curve, electrical generator efficiency \( \eta_g = \eta_g(Z_{lac}, Q) \). Are well known kinematics of the runner blade and guide vane control mechanisms \( \varphi = \varphi(s_D) \) and \( a_0 = a_0(s_D) \). Software using the algorithm mentioned before was made to calculate the operating flow on each turbine in the power station having the levels upstream, \( Z_{am} \) and downstream, \( Z_{av} \) (or levels in the charge chamber and the downstream operating level), the produced power \( P \) and the servomotors stroke \( s_D, s_R \). It will be obtained a function \( Q = Q(P, Z_{am}, Z_{av}, s_D, s_R) \). The method could be adapted for a monitoring system of the hydropower development and to calculate on line the operating flow. The knowledge of the flow discharged allows us to appreciate the efficiency of the hydropower plant.

KEYWORDS

Kaplan turbine, working performance curve, efficiency, hydropower plant, runner, guide vane.

NOMENCLATURE

- \( \eta \) [-] efficiency
- \( Q_{11} \) [m\(^3\)/s] unit flow
- \( n_{11} \) [rot/min] unit speed
- \( g \) [m/s\(^2\)] gravity
- \( s_D \) [mm] stroke of the guide valve servomotor
- \( s_R \) [mm] stroke of the blade runner
- \( \varphi \) [grd.] rotation angle of the blade runner
- \( z \) [-] number of runner’s blade
- \( n \) [rot/min] speed runner

Subscripts and Superscripts

- \( am \) upstream
- \( av \) downstream

1. INTRODUCTION

The good working of a hydropower development means less hydraulic losses in the hydraulic circuit for all gross heads with high efficiency working. It could be obtained an economy of energy that is more important if the optimization is done on a cascade hydropower plants.

The paper proposed an algorithm to calculate the operating flow rate of a hydropower plant using an indirect method based on working characteristics of the hydraulic turbine.

It was used the measured performance curve of the K20/661 hydraulic turbine model of \( D_{1M} = 460 \) mm
and \( z = 4 \) tested at U.C.M. Resita. The measured performance curve was discreet and the working fields of turbines, which are working at Racaciuni hydropower plant, are drawing.

It was observed that the Racaciuni turbines have a small working zone in the curve representation, Fig. 1.

Using the Osterwalder’s relation the model measured performance curve was transposed for the turbine that is working at Racaciuni \( (D_1 = 5400 \text{ mm}, \quad n = 100 \text{ rot/min}) \). Then, for the turbine model, it was considered the curve of efficiency depending of the opening, \( a_0 \), of the adjustable guide vane and of the \( \varphi \) angle of the turbine’s runner releasing the came between them. This curve was transposed for the Racaciuni’s turbine. A program was made to calculate the operating flow of the turbine for an operating power if the heads upstream and downstream are known. The program is interactive and could be used in exploitation of Racaciuni hydropower.

2. ABOUT RACACIUNI HYDROPOWER STATION

The reservoir of Racaciuni is extend on the middle valley of Siret river having upstream the Galbeni hydropower plant and downstream, Beresti hydropower plant. The hydropower arrangement of Racaciuni has a mobile dam, a reservoir, a feeder canal of 930.47 m with a hydraulic slope of 0.0407‰ and the hydropower plant Racaciuni. The exit of the water is made in a escape canal that restores the water in Beresti reservoir.

Racaciuni hydropower plant has an installed power of 53 MW that is made with two vertical Kaplan turbines.

3. ANALYSIS OF THE HYDRO GENERATOR CHARACTERISTICS

3.1. Working performance curve of the turbine

The working of a hydraulic turbine could be described by a function depending on hydraulic parameters \((Q, \ E, \ NPSE)\), mechanical parameters \((P, \ \omega, \ \eta)\), geometrical parameters \((D, \ a_0, \ \varphi, \ k)\) and the fluid properties of \((\rho, \ \mu)\).

\[
f(Q, E, P, \omega, \eta, a_0, \varphi, k, \rho, \mu) = 0. \tag{1}
\]

This function is used in the case of model testing in the simple form of

\[
F(\pi_1, \pi_2, \ldots, \pi_{q-r}) = 0 \tag{2}
\]

were \(\pi_1, \pi_2, \ldots, \pi_{q-r}\) are dimensionless multipliers of the working parameters setting before; \(\rho\), the number of these parameters and \(r - 3\) is the number of fundamentals parameters. These \(\pi\) multipliers are formed in many ways depending of the goal of characteristic curve. It will be considered as initial values the density of water, \(\rho\), the specific energy changed, \(E\) and the characteristic diameter of the hydraulic machine, \(D\).

\[
\pi_i = \rho^{x_{i1}} E^{x_{i2}} D^{x_{i3}} A_i. \tag{3}
\]

Function \(F, (2)\), is the turbine characteristic and represents a surface in a space with more dimensions. It is unhandy to use it and for this reasons it is replace with characteristics that represent the link between two parameters.

Are selected the values that are important in the phenomena study and the others are considered as parameters. It is obtained a function of two variables and its graphical representation is named characteristic curve of the name’s independent variable.

3.2. Working performance curve of the model

The measured performance curve or the universal characteristic has unit flow in the abscissa and unit speed in the ordinate as in (4) and (5)

\[
Q_{11} = \frac{Q}{D^2 \sqrt{H}} \tag{4}
\]

\[
n_{11} = \frac{n \cdot D}{\sqrt{H}} \tag{5}
\]

where \(Q\) is the volume flow \([\text{m}^3/\text{s}]\), \(D\) is the characteristic diameter of the runner \([\text{m}]\), \(n\) is the runner speed \([\text{rot/min}]\), \(H\) is the net head \([\text{m}]\). To obtain the characteristic curve of the turbine it is used the model \(K \ 20/661\) measured performance curve, Figure 1.

3.3. The prototype passing through the model

To transpose the model efficiency curve to the turbine the Osterwalder’s relation is used

\[
\eta = 1 - (1 - \eta_M) \left( \frac{k \ D_M}{k_M \ D} \right)^{0.2} \tag{6}
\]

where \(\eta\) is the turbine efficiency and \(\eta_M\) is the model efficiency. The turbine diameter and model diameter is noted as \(D, \ D_M\) and the roughness surface of the turbine and model is \(k, \ k_M\).

The transposed measured performance curve of the model to the turbine is represented in Figure 2 where the interest zone of the working conditions to Racaciuni hydropower plant is marked. The domain of flow rates and heads of the turbine are obtained.

\[
H = \frac{n^2 \cdot D^2}{n_{11}^2}, \quad Q = Q_{11} \cdot D^2 \sqrt{H} \tag{7}
\]

In Figure 3 is presented the efficiency depending of the net head and of the turbine flow rate.
4. HYDRAULIC EFFICIENCY OF THE HYDROPOWER STATION

The hydraulic efficiency of the Racaciuni development depends of the hydraulic losses:

a) linear and local hydraulic losses at the entrance of the turbine as a function of the turbine discharge [9];

b) linear hydraulic losses on the feeder canal and escape canal.

The hydraulic efficiency is the ratio between the net head and the gross head.

$$\eta_h = \frac{H_{\text{net}}}{H_{\text{gross}}}$$  \hspace{1cm} (8)

where: $H_{\text{gross}}$ is the gross head of the Racaciuni hydraulic development, calculated as the difference between the level in Racaciuni reservoir and the level downstream of the plant; $H_{\text{net}}$ is the net head of the Racaciuni development as the difference of gross head and the hydraulic losses on the feeder and escape canal and the hydraulic losses in the charge chamber of the hydraulic plant.

5. EFFICIENCY CURVE OF THE ELECTRIC GENERATOR

It is estimated the efficiency of the generator by using the efficiency versus the power’s generator made by the constructor, U.C.M. Resita.

$$\eta_g = \frac{P}{P + \Delta P}$$  \hspace{1cm} (9)

where $P$ is the output power of the generator and $\Delta P$ is the losses power in the generator. The generator of the hydraulic turbine used at Racaciuni has the type of HVS 787/84-64 with the efficiency curve in Figure 5.

6. FLOW RATE DETERMINATION

Having the upstream level, the downstream level, the active produced power and the stroke of the two servomotors, the flow discharge (operating flow rate) could be determined, see (10).

$$Q = Q(P, Z_{am}, Z_{av}, s_D, s_R)$$  \hspace{1cm} (10)

The linking between the opening of the adjustable guide vane $a_0$ and the stroke of the hydraulic servomotor of adjustable guide vane $s_D$, $a_0 = a_0(s_D)$ in connection with the $\varphi$ rotation angle of runner blade and the stroke of hydraulic servomotor, $\varphi = \varphi(s_R)$, was considered from the kinematics of the mechanism.

The opening of adjustable guide vane $a_0$ or the rotation angles $\varphi$ of the runner blade were limited by working domain of the turbine read in the measured performance curve. So the limits for the opening of the adjustable guide vane are $a_0 \in [117, 315]$ mm and the limits for the rotation of the blade runner angle are $\varphi \in [-9^\circ, +10.5^\circ]$.

In the case of using those of the two levels in Racaciuni and Beresti reservoirs $Z_{am}$ is the free level in the upstream reservoir Racaciuni and $Z_{av}$ is the free level in the downstream reservoir Bereși. In this case, the hydraulic losses of feeder canal and escape canal are in accounting when the flow discharge is determined.

When are used the levels in the chamber of charge and in the escape canal of Racaciuni power plant, $Z_{am}$ is the free level in the chamber of charge and $Z_{av}$ is the free level in the escape canal. In this case the hydraulic losses are not considered.

Software is made to determine the flow discharge having the five values of (10) relation and the considerations above.

7. CONCLUSIONS

The indirect method offers the possibility to determine in each moment of the hydropower plant working the flow discharged if it is knowing the all five values used in the software. For this reason the method could be used on line by monitoring of the upstream level, the downstream level, the opening of the adjustable guide vane, the rotation angle of the blade runner and the stroke of the hydraulic servomotor. The flow discharged calculated could be displayed any time.

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Figure 1- Numerical representation of the model turbine measured performance curve.

Figure 2. 3-D measured performance curve representation of Racacuni turbine.
Figure 3 – The efficiency of Racaciuni turbine as a function of net head and flow discharged (working curve of the turbine)

Figure 4 – Example of hydraulic efficiency of Racaciuni development for the level of 131 mdM in the upstream reservoir and 110,7 mdM in the downstream reservoir
Figure 5 – Efficiency curve of HVS 787/84- generators