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Nekateri vidiki terenskih preskusov peltonovih turbin v HE “Perućica”

Some Aspects of the Research Carried out on the Power Generation Units at the Perućica Hydroelectric Power Plant

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V delu so predstavljeni osnovni delovni parametri HE “Perućica”, prikazana je analiza delovnega procesa v Peltonovi turbini in eksperimentalno-analitična metoda za določitev pretočne karakteristike šob vgrajenih v HE “Perućica” pri obratovalnih pogojih.

(Ključne besede: turbine Peltonove, parametri energetski, karakteristike procesov, metode eksperimentalne)

This paper describes the basic power parameters of the “Perućica” HEPP. Also included is an analysis of the work process in the Pelton turbine and an experimental-analytical method for determining the nozzle-flow characteristics under real working conditions.

(Keywords: Pelton turbines, power parameters, process characteristics, experimental methods)

0 UVOD

Hidroelektrarna “Perućica” ima moč 307 MW. Zgrajena je bila v treh fazah, prva faza se je začela leta 1960. Hidroelektrarna je derivacijskega tipa in ima skupaj sedem agregatov vodoravne izvedbe s Peltonovimi turbinami.

Prvi avtor prispevka je delo začel kot hidroinženir v tej elektrarni leta 1964, zaposlen z reševanjem obratovalnih problemov. V dolgem času delovanja elektrarne so bila opravljena raziskovanja mnogih pojavov v dejanskih razmerah, da bi zagotovili pogonske stabilnosti. Pri neposrednem učenju pogonskega osebja so bila v raziskovanja vključene domače strokovne institucije. Avtor je pri vseh raziskovanjih sodeloval neposredno ali kot svetovalec.

Glede na bogato znanje in izkušnje, pridobljene v času delovanja hidroelektrarne, je avtor v svojem delu podal vidike, pridobljene pri eksperimentalnih raziskovanjih v dejanskih razmerah in iz tega izhajajoče metode analitičnega določanja pretočnih karakteristik Peltonovih turbin, vgrajenih v obravnavani hidroelektrarni.

0 INTRODUCTION

The Perućica hydroelectric power plant (HEPP) has an installation power of 307 *MW*. It was built in three phases, and the first phase began operating in 1960. It was built as a derivative type, and it has seven power-generation units of the horizontal type with Pelton turbines.

One of the authors of this paper started work as a hydro engineer at this HEPP in 1964, when he was working on some problems concerning exploitation. During the long exploitation period of this HEPP a lot of research was conducted on many occurrences in stationary and non-stationary regimes under real conditions. In order to acquire operational staff, other qualified domestic and scientific institutions were engaged. In all this research the author participated directly or as a consultant.

Having gained much experience during the exploitation period of this HEPP, from the very beginning to the present day, the author presents some aspects of the completed experimental research under real conditions, and the method of analytically determining the flowing exploitation characteristic of the Pelton turbines mounted in this HEPP.

1 OSNOVNI ENERGETSKI PARAMETRI TURBIN V PRIMERU HE PERUĆICA

Za vsak hidroenergetski sistem so karakteristični osnovni delovni parametri bruto in čisti padec ter instalirani pretok. V že zgrajenih hidroelektrarnah obratujejo turbine pod določenimi energetskimi parametri, od katerih so nekateri lahko stalni, večina pa se jih spreminja glede na funkcijo delovnega režima. Med osnovne parametre vodnih turbin spadajo: moč (P), pretok (Q), specifična energija (Y), izkoristek (η) in število vrtljajev turbine (n).

Specifični energiji vodnega toka (Y_g, Y_d) na gladini vode zgornje akumulacije $\dot{\nabla}$ GNV (indeks g) in na gladini vode spodnje akumulacije $\dot{\nabla}$ DNV (indeks d) sta za splošni primer hidroenergetskega sistema izraženi z enačbama:

1 BASIC POWER PARAMETERS OF THE PELTON TURBINES ON THE PERUĆICA HEPP

The basic characteristic working parameters of any hydroelectric power plant are the gross and the net fall and the installed flow. On the hydroelectric power plants that are already built the turbines operate with certain power parameters, some of which can be permanent, whereas most of them change depending on the function of the working mode. The basic parameters of water turbines include the following: power (P), flow (Q), specific energy (Y), degree of efficiency (η) and the number of revolutions (n).

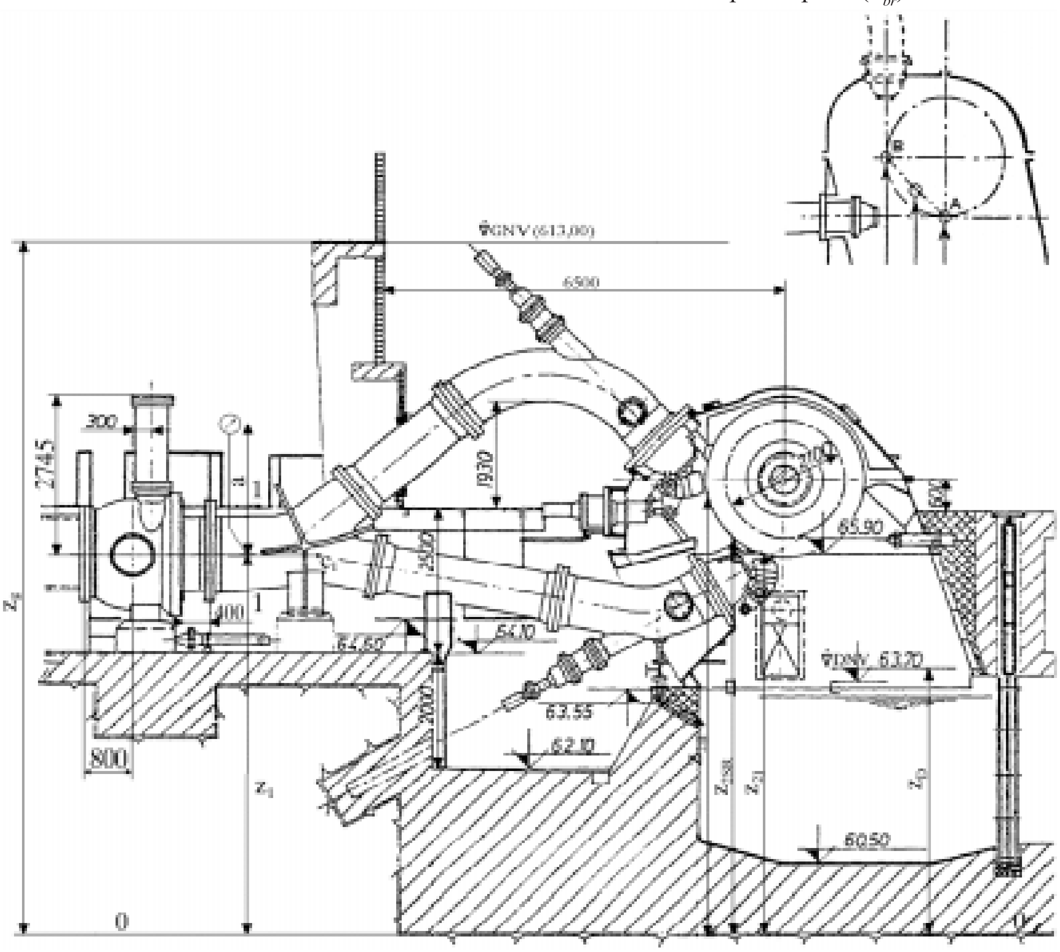
The specific energies of the water flow (Y_g, Y_d) on the surface of the upstream reservoir $\dot{\nabla}$ GNV (index g) and on the surface of the downstream reservoir $\dot{\nabla}$ DNV (index d) on the Perućica hydroelectric power plant with Pelton turbine are:

$$Y_g = \frac{p_g}{\rho} + g \cdot z_g + \frac{c_g^2}{2} \qquad (1),$$

$$Y_d = \frac{p_d}{\rho} + g \cdot z_d + \frac{c_d^2}{2} \qquad (2).$$

Razlika energij Y_g in Y_d pomeni bruto specifično energijo hidroelektrarne (Y_{br}).

The difference between the specific energies Y_g and Y_d represents the gross specific fall in the flow of the electrical power plant (Y_{br}).



Sl. 1. *Razporeditev hidroagregata s Peltonovo turbino, vgrajenega v HE "Perućica"*
Fig. 1. *General arrangement of power generation unit with Pelton turbine in the Perućica HEPP*

V (1) in (2) so: p_g in p_d tlaka na nivojih *(g - g)* in *(d - d)*, c_g in c_d srednji hitrosti v prerezih, z_g in z_d koti zgornjega in spodnjega nivoja vode hidroelektrarne, *g* je zemeljski pospešek.

Za Peltonove (akcijske) turbine z eno šobo (agregati I do V v HE "Perućica") je razpoložljiva specifična energija:

The designations in (1) and (2) are as follows: p_g and p_d - absolute pressure at levels (*g- g*) and (*d - d*), c_g and c_d - mean velocities in the cross-sections, z_g and z_d - elevations of upstream and downstream water surface, *g* - acceleration due to gravity.

For the Pelton (action) turbines with one nozzle (power generation units I–V) the available specific energy:

$$Y = g \cdot H = \frac{p_m}{\rho} + \frac{c_1^2}{2} + g \cdot (z_1 + a - z_2) \quad (3),$$

kjer so: z_1 - kota vstopnega prereza turbine, *a* - oddaljenost kote težišča vstopnega prereza do kote vgradnje manometra, z_2 - kota točke, kjer os šobe tangira osnovni krog turbinskega kolesa, p_m- manometrični tlak, *H* - neto padec.

Hitrost c_2 na izstopnem prerezu turbine (izhodni rob Peltonove turbine) je zanemarljiva ($c_2 << c_1$).

V primeru, ko ima turbina dve šobi z enakim pretokom (agregati VI in VII v HE "Perućica"), se kota $z_{2\ sr}$ določa kot srednja vrednost kot točk A in B (sl. 1). Vse hitrosti, podane v prejšnjih enačbah, so srednje hitrosti, ki se določajo s pretokom Q in pretočnim prerezom A, tj. po enačbi $c_i = Q_i/A_i$.

Moč vodnega toka se določa z enačbo:

where: z_1 - the elevation of the turbine inlet cross section, *a* - the distance between the elevation of the centre of gravity of the inlet cross section and the elevation of the installation of the pressure gauge, z_2 - the elevation of the point where the nozzle axis touches the basic circle of the turbine wheel, p_m - the overpressure indicated by the pressure gauge, *H* - the net turbine fall.

The velocity c_2 at the turbine outlet cross section (outlet edge of the Pelton turbine) is low ($c_2 << c_1$).

In the event that the turbine has two nozzles with the same flow rate (units VI–VII) the elevation $z_{2\ mean}$ is determined as the mean value of the elevation of points A and B (Figure 1.). All velocities given in the preceding equation are the mean velocities determined by means of the flow (Q) and the flow cross section A, i.e. according to the equation $c_i = Q_i/A_i$.

The power of the water flow is determined with the following equation :

$$P_s = \rho \cdot g \cdot Q \cdot H \quad (4),$$

na gredi turbine pa z enačbo:

and the mechanical power of the turbine:

$$P_s = \rho \cdot g \cdot Q \cdot H \cdot \eta \quad (4'),$$

pri čemer je ρ gostota vode

where ρ is water density.

2 KARAKTERISTIKE DELOVNEGA POSTOPKA V PELTONOVI TURBINI

Slika 2 prikazuje karakteristike moči in izkoristka dvojne Peltonove turbine 2 · P_2 · 2,1 / 255 (pri čemer so: 2 - število delovnih koles hidroagregata; P_2 - Peltonova turbina z dvema delovnima kolesoma; 2,1 – premer delovnega kolesa v m; 255 – premer vstopa v mm),

Karakteristike so dobljene pri preskusu garantiranih parametrov III faze HE "Perućica" pri padcu *H* = 526 m in pretoku *Q* = 12,75 m^3/s.

Gonilnik Peltonove turbine izkorišča samo kinetično energijo vodnega toka. Zaradi tega mora spremeniti pretočni aparat turbine (šob) ustrezno rezervo energije vodnega toka v kinetično energijo.

Razpoložljivi padec (višina) na izstopu iz šobe je:

2 CHARACTERISTICS OF THE WORK PROCESS IN A PELTON TURBINE

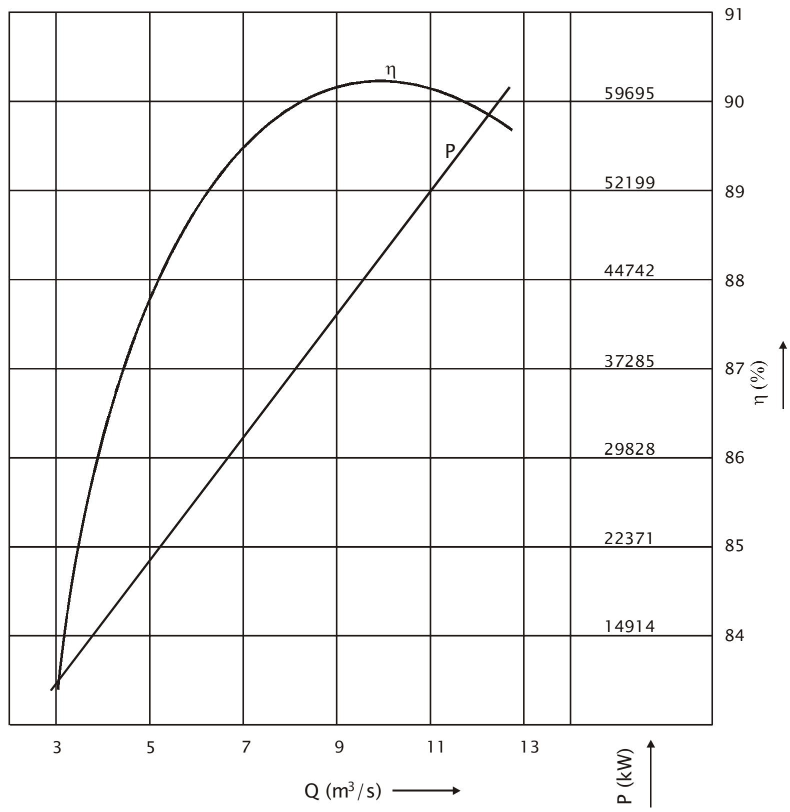
Figure 2 shows the characteristics of the power and the degree of efficiency of the double Pelton turbine 2 · P_2 · 2.1 / 255 (where: 2 is the number of working wheels of the power generation unit, P_2 is the Pelton turbine with two nozzles, 2.1 is the diameter of working wheel [m], and 255 is the nozzle diameter [mm]).

The characteristics are obtained experimentally when testing the guaranteed parameters of the stage III of the Perućica HEPP at the fall *H* = 526 m and the flow *Q* = 12.75 m^3/s.

The runner of the Pelton turbine only uses the kinetic energy of the water flow. Therefore, the flow device of the turbine (nozzle) must convert the relevant reserve of the water flow energy into kinetic energy.

The kinetic energy at the nozzle outlet is:

$$\frac{c^2}{2 \cdot g} = H \cdot \eta_m \quad (5),$$



Sl. 2 *Diagram izkoristka in moči Peltonove turbine 2 · P_2 · 2,1/255 (padec H=526 m , pretok Q=12,75 m³/s)*
Fig. 2 *Diagram of degree of efficiency and power of the Pelton turbine 2 · P_2 · 2.1/255 in case of fall H = 526 m and Q = 12.75 m³/s*

pri čemer so: H - razpoložljiva višina pred šobo; c - pretočna hitrost; η_m - izkoristek šobe.

Torricellijeva enačba za hitrost iztekanja tekočine skozi odprtino pri nespremenljivi višini je:

where: H - the available height at the nozzle, c - the flow velocity, η_m - the degree of efficiency of the nozzle.

The well-known Torricellian formula for the velocity of a liquid flow from an opening at constant water level is:

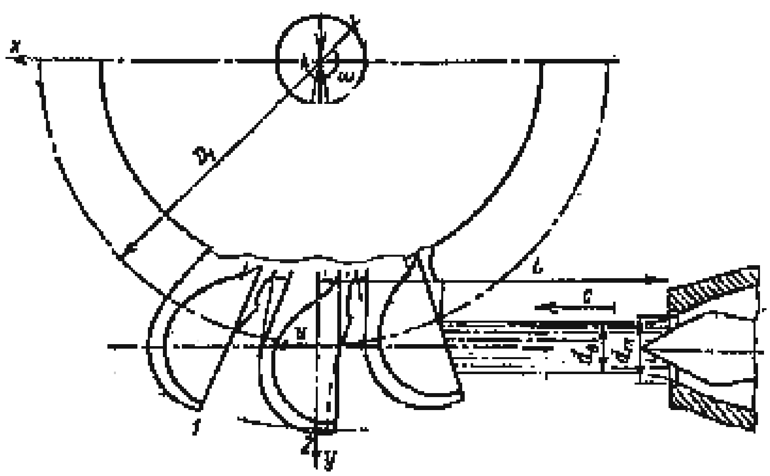
$$c = \sqrt{2g \cdot H \cdot \eta_m} = \varphi\sqrt{2g \cdot H} \quad (6),$$

pri čemer je: $\varphi = \sqrt{\eta_m}$ - koeficient hitrosti iztekanja.

Šoba Peltonove turbine ima krožno izhodno odprtino in osnosimetrični natok, kar zagotavlja

where: $\varphi = \sqrt{\eta_m}$ - the coefficient of the discharge velocity.

The nozzle of the Pelton turbine has a circular outlet opening and axially symmetrical in flow



Sl. 3. *Lega delovnega kolesa in šobe Peltonove turbine*
Fig. 3 *Position of mounting of the runner and nozzle of the Pelton turbine*

stabilne, praktično valjne tokove na izhodu (slika 3).

Specifičnost delovnega postopka v Peltonovi turbini je v tem, da sprememba hitrosti vrtljajev gonilnika ne vpliva na pretočno moč turbine, tj. med momentom na osi turbine in parametri vodnega toka ni povratnega vpliva. Pretočna karakteristika šobe ni odvisna od obratovalnega režima, profila in izmer gonilnika. Odprtja šobe so v karakterističnem diagramu Q_{11} - n_{11} (Q_{11} je enotski pretok, n_{11} je enotska vrtilna frekvenca) predstavljena s premicami, ki so vzporedne z absciso (n_{11}). Zaradi tega pri Peltonovih turbinah odprtino pretočnega aparata, gib igle šobe (s) ne definiramo glede na premer delovnega kolesa. Relativni gib igle s' se izraža glede na premer izhodne odprtine šobe d_m po enačbi (sl. 3):

ensuring stable, practically cylindrical flow at the outlet (Figure 3).

It is a specific feature of the working process in the Pelton turbine that the change of rotating speed of the runner does not affect the flow rate of the turbine, i.e. there is no return influence between the turbine shaft torque and the water flow parameters. The flow characteristic of the nozzle does not depend on the mode of working, the runner contours and the dimensions. The nozzle openings in the characteristic diagram Q_{11} – n_{11} (Q_{11} is the unit pressure, n_{11} is the unit rotating speed) are given with straight lines parallel to the abscissa (n_{11}). Therefore, for these turbines it is not rational to express the flow device opening, nozzle needle motion (s), with regard to the working wheel diameter. The relative needle motion (s') is expressed with regard to the diameter of the nozzle outlet opening (d_m) (Figure 3), i.e.:

$$s' = s/d_m \qquad (7).$$

Pri Peltonovih turbinah izrazimo karakteristično površino A_{xm} in pretok šobe Q_{xm} z enačbami ($c_x = \sqrt{2 \cdot g \cdot H}$):

It is appropriate in the case of the Pelton turbine to express the characteristic surface and nozzle flow (A_{xm}; Q_{xm}) by means of equations ($c_x = \sqrt{2 \cdot g \cdot H}$):

$$A_{xm} = d_m^2 \cdot \pi/4 \quad \text{in / and} \quad Q_{xm} = c_x \cdot A_{xm} \qquad (8),$$

pri čemer indeks “x” označuje poljuben delovni režim, D_1 – osnovni premer gonilnika.

Z uporabo karakterističnih veličin (8) definiramo brezdimenzijski pretočni koeficient šobe Peltonove turbine k_g:

where the index “x” designates the characteristic mode of working, D_1 is the basic diameter of the working wheel.

By means of these characteristic values (8) the unit flow of the nozzle of the Pelton turbine (k_g) is defined :

$$k_g = \frac{Q_m}{Q_{xm}} = \frac{4\,Q_m}{\sqrt{2}\,\pi\, d_m^2 \sqrt{g\,H}} = 0{,}901 \frac{Q_m}{d_m^2 \sqrt{g\,H}} \qquad (9).$$

Glede na enačbo (6) lahko pretok šobe izrazimo takole:

On the basis of equation (6) it is possible to express the nozzle flow as follows:

$$Q_m = \frac{d_o^2\,\pi}{4} \varphi \sqrt{2g\,H} \qquad (10),$$

pri čemer je d_0 premer vodnega curka, d_m pa premer šobe (sl. 3).

Nadalje lahko enotni pretok šobe izrazimo tudi z enačbo:

where d_o is the diameter of the water jet, d_m is the diameter of the nozzle (Figure 3.).

Further, the unit nozzle flow can be expressed by the equation:

$$k_g = \varphi \left(d_o / d_m \right)^2 \qquad (11).$$

3 GEOMETRIJSKI PARAMETRI ŠOB, VGRAJENIH V HE “PERUĆICA”

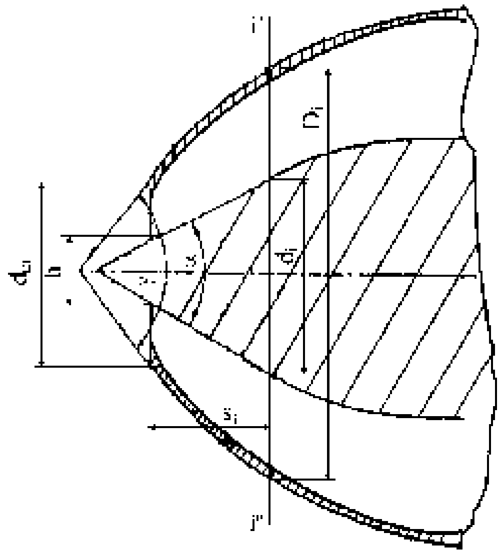
V HE “Perućica” je vgrajenih 7 agregatov z dvojno Peltonovo turbino vodoravne izvedbe. Na petih agregatih so turbinska kolesa izvedena z eno šobo tipa $2 \cdot P_1 \cdot 2{,}4 / 300$, na dveh agregatih pa kolesa z dvema šobama tipa $2 \cdot P_2 \cdot 2{,}1 / 255$.

Na sliki 4 je prikazan profil izstopnega dela šobe na agregatih HE “Perućica”. Osnovni geometrijski parametri šobe so: d_m - premer izhodne odprtine (d_m = 300 mm), $A_m = d_m^2 \cdot \pi / 4$ - površina

3 GEOMETRIC PARAMETERS OF NOZZLES INSTALLED ON THE PERUĆICA HEPP

On the Perućica HEPP seven power-generation units with double Pelton turbines in the horizontal position are installed. On five units the turbine wheels are equipped with one nozzle of type $2 \cdot P_1 \cdot 2.4 / 300$, and on two units the wheels are equipped with two nozzles of type $2 \cdot P_2 \cdot 2.1 / 255$.

Figure 4 shows the contour of the outlet part of the nozzle on the Perućica HEPP. The basic geometrical parameters of the nozzle are: d_m is the diameter of outlet opening (d_m = 300 mm), $A_m = d_m^2 \cdot \pi / 4$ is the surface of



Sl. 4 *Profil izstopnega dela šobe, vgrajene v HE "Perućica" v poljubni legi "i-i"*
Fig.4. *Contour of outlet part of the nozzle installed on the Perućica HEPP in arbitrary position "i-i"*

izhodnega pretočnega prereza (A_m = 70650 mm^2), s - gib igle šobe, s_{maks} - največji gib šobe (s_{maks} = 195 *mm*), α - kot igle šobe (α=57,2^o), h - višina odprtine šobe, h_{imax} - največja višina odprtine šobe, (h_{imax} = 90 mm), D_i - premer okrova na "i - i", d_i - premer igle v prerezu (i - i), γ - izstopni kot šobe.

the outlet flow cross section (A_m = 70650 mm^2), s is the nozzle needle motion, s_{max} is the maximum nozzle motion (s_{max}=195 *mm*), α is the nozzle needle angle (α=57,2^o), h is the height of nozzle opening, h_{imax} is the maximum height of the nozzle opening (h_{max}=90 mm), D_i is the diameter of housing "i-i", d_i is the diameter of the needle in cross section (i-i), γ is the outlet angle of the nozzle.

4 DOLOČITEV PRETOČNE KARAKTERISTIKE ŠOBE NA IZVEDBI

4 DETERMINATION OF NOZZLE FLOW CHARACTERISTICS UNDER REAL CONDITIONS

Pretok šobe se lahko glede na enačbi (10) in (11) izrazi kot:

With respect to equations (10) and (11) the nozzle flow can be expressed as:

$$Q_m = k_g\, A_m \sqrt{2g\,H} \qquad (12).$$

Razpoložljiva višina šobe (H) je definirana z enačbo:

The available height of the nozzle (H_m) is defined by the equation:

$$H = H_b - \Delta H_1 - \Delta H_2 \qquad (13),$$

pri čemer sta: H_b - bruto višina HE "Perućica" ($H_b \cong$ 550 m), ΔH_1 - hidravlične izgube v dovodnem sistemu od vtočne zgradbe do izhoda iz razvejanja (sl. 1).

Izgube v dovodnem sistemu HE "Perućica" (ΔH_1) so izmerjene po delih na vstopni rešetki, v predoru, na razvejanju v izravnalniku in v dovodnih cevovodih (slika 5).

Rezultati meritev izgub po posameznih cevovodih (leta 1998) so:

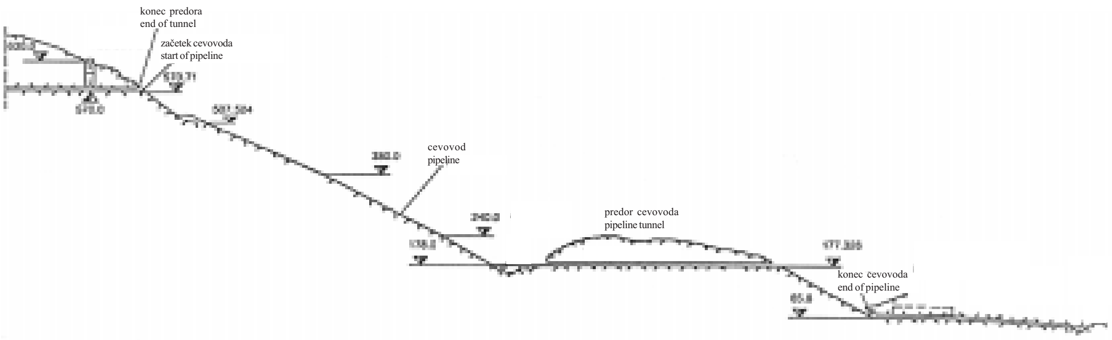
- cevovod 1 (agregati 1, 2; dolžina L = 1851 m; premer D = 2,2 m - 1,8 m): $\Delta H_{c1} \cong 0{,}0563 \cdot Q^2_{c1}$,
- cevovod 2 (agregati 3, 4, 5; dolžina L = 1883 m; premer D = 2,2 m - 2,1 m): $\Delta H_{c2} \cong 0{,}0407 \cdot Q^2_{c2}$,
- cevovod 3 (agregati 6, 7; dolžina L = 1931 m; premer D = 2,5 m - 2,2 m): $\Delta H_{c3} \cong 0{,}02297 \cdot Q^2_{c3}$.

where: H_b is the gross water level of the Perućica HEPP ($H_b \cong$ 550 m), ΔH_1 is the hydraulic loss in the supplying system from the intake structure to the bifurcation outlet (Figure 1).

The losses in the supply system of the Perućica HEPP (ΔH_1) are measured according to the sections in entering the trash rack, in the tunnel, in the surge tank and in the supply pipelines. (Figure 5).

The measured results of the losses according to the branches of the pipeline (in 1998) are:

- pipeline 1 (units 1, 2; length L = 1851 m; diameter D = 2.2 m - 1.8 m): $\Delta H_{c1} \cong 0.0563 \cdot Q^2_{c1}$,
- pipeline 2 (units 3, 4, 5; length L = 1883 m; diameter D = 2.2 m - 2.1 m): $\Delta H_{c2} \cong 0.0407 \cdot Q^2_{c2}$,
- pipeline 3 (units 6, 7; length L = 1931 m; diameter D = 2.5 m - 2.2 m): $\Delta H_{c3} \cong .0.02297 \cdot Q^2_{c3}$.



Sl. 5 *Pretočni sistem HE "Perućica"*
Fig. 5 *Flow system of Peručica HEPP*

Srednja vrednost koeficienta izgub je:
a) rešetka: $k_r = 0{,}749.10^{-3}$
b) predor: $k_t = 1{,}261.10^{-3}$
c) izravnalnik: $k_1 = 6{,}50.10^{-3}$
$k_2 = 4{,}66.10^{-3}$
$k_3 = 5{,}31.10^{-3}$

Pretok šobe oziroma koeficient pretoka sta odvisna od giba igle šobe *s*:

The average value of the loss coefficient is :
a) in trashrack: $k_r = 0.749.10^{-3}$
b) in tunnel: $k_t = 1.261.10^{-3}$
c) in surge tank: $k_1 = 6.50.10^{-3}$
$k_2 = 4.66.10^{-3}$
$k_3 = 5.31.10^{-3}$

The nozzle flow and/or the flow coefficient depend on the nozzle needle motion (*s*), therefore:

$$k_{g(s)} = \frac{Q_{m(s)}}{A_m \sqrt{2g \cdot H}} \qquad (14).$$

V primeru hidroelektrarne "Perućica" lahko predpostavimo nespremenljivo vrednost višine *H* pri vseh delovnih režimih elektrarne (glede na veliko bruto višino ($H_b \approx 550$ m) in s tem tudi relativno zanemarljiv vpliv izgub višine v dovodnem sistemu pri spremembah pretokov v delovnem področju turbine).

Z merjenjem pretoka $Q_{m(s)}$ za znane vrednosti A_m in H_m lahko s preskusi določimo odvisnost koeficienta pretoka $k_{q(s)}$ od relativnega giba igle šobe *s'* (enačba 7).

V obsegu raziskav nestalnih režimov obratovanja v sistemu HE "Perućica", je bila določena karakteristika šobe $k_q = f(s/d_m)$ agregatov I-V. Karakteristika je grafično prikazana na sliki 6. Delovno področje agregatov VI - VII je:

In the case of the Perućica HEPP the constant value of height *H* for all working modes of the power plant (with respect to the great gross water level (H_b ≈ 550 m) and, consequently, a relatively unimportant influence of height losses in the adduction system in the case of changes to the flow in the turbine working area is assumed.

Thus, by measuring the flow $Q_{m(s)}$ for the known values A_m and H_m the dependence of the flow coefficient $k_{q(s)}$ on the flow $Q_{(s)}$ and/or on the relative nozzle needle motion (equation 7) is experimentally determined.

Within the scope of research on the unstable working modes of the Perućica HEPP the nozzle characteristic $k_q = f(s/d_m)$ of units I–V graphically shown in Figure 6 was determined. The working range for the Peručica III power generation units is :

$$H_{max} = 526 \text{ m}; \; H_{min} = 520 \text{ m}; \; n = 428{,}5 \text{ min}^{-1};$$
$$Q_{11} = 63{,}0 \text{ l/s}; \; n_{11} = 39{,}2 \text{ min}^{-1}; \; P = 59 \text{ MW};$$
$$(D_1 = 2100 \text{ mm}, \; d_0 = 225 \text{ mm}, \; \varphi = 0{,}614)$$

Parametri agregatov I - V so:

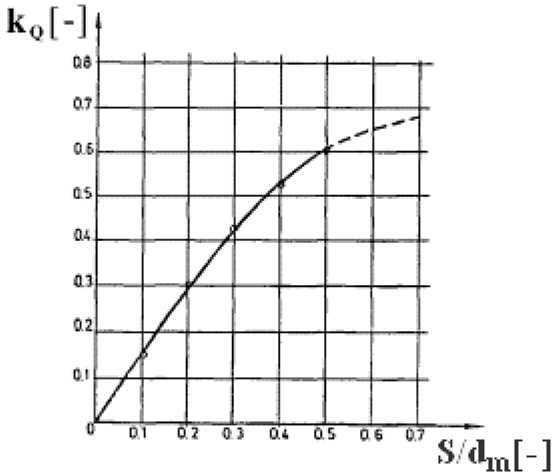
The parameters of the units I–V are :

$$n = 375 \text{ min}^{-1}, P = 39 \text{ MW}, Q = 8{,}5 \text{ m}^3/\text{s}, D_1 = 2400 \text{ mm}, d_0 = 300 \text{ mm}$$

Ker se pretok Q_m na izhodu iz šobe s spremembo giba igle *s* spreminja zaradi spremembe površine dejanskega pretočnega prereza, skozi katerega prehaja voda in spremembe polja hitrosti vode v šobi, lahko enačbo za pretok napišemo v obliki:

As the flow Q_m at the nozzle outlet changes with the needle motions due to the change of surface of the effective flow cross section through which the water passes and the change of the water speed in the nozzle, the equation for the flow can be written in the following form:

$$Q\left(s/d_m\right) = c\left(s/d_m\right) A\left(s/d_m\right) \qquad (15).$$



Sl. 6. *Karakteristika šobe $k_Q = f\ (s/d_m)$ agregatov I-IV*
Fig. 6. *Nozzle characteristic $k_Q = f\ (s/d_m)$ of units I-IV*

Glede na (12) velja:

Taking into account (12), the following applies:

$$k_Q\, A_m \sqrt{2g\, H} = c\, A(s\, /\, d_m) \tag{16}$$

5 SKLEP

Prvo vprašanje, na katerega mora odgovoriti projektant Peltonove turbine, je izbira njenih osnovnih parametrov; konstrukcijske skice same turbine, hitrosti vrtenja, število šob, premer delovnega kolesa, premer šobe itn. Pri tem se razume, da so meje sprememb vodnega padca in mejna moč po navadi podane s projektno nalogo.

Rešitev te naloge ni enolična. Praktično je treba analizirati več možnih variant. Za končno rešitev se odločimo po vsestranski tehnično-gospodarni analizi.

Svetovne izkušnje potrjujejo, da so v 60. letih v gradili Peltonove turbine z vodoravno gredjo z eno ali največ dvema šobama na en gonilnik. Po tem obdobju pa so prišli iz vodoravne v navpično izvedbo. Namen projektantov je bil, da se poveča število šob na gonilnik. Tako so sodobne velike Peltonove turbine najpogosteje izvedene z navpično gredjo in šestimi šobami na en gonilnik.

Peltonove turbine v HE “Perućica” imajo vodoravno gred z dvema gonilnikoma na enoto (I do V) oziroma dvema šobama na enoto (VI in VII) za en gonilnik.

Rezultat raziskav nestalnih režimov obratovanja je pretočna karakteristika šobe $2 \cdot P_1 \cdot 2.4 / 300$ Peltonove turbine $2 \cdot P_1 \cdot 2.4 / 300$ (enote I do V) (slika 6).

5 CONCLUSION

The first question that should be answered by the design engineer of the Pelton turbine is the selection of its basic parameters: the design sketch of the turbine alone, the number of revolutions, the nozzle number, the diameter of the runner, the diameter of the nozzle, etc. It goes without saying that the limits of the changing fall and the limited power are usually set in the design assignment.

The solution of this assignment is not uniform. It is necessary to analyze practically several possible variants. The final solution to the problem is adopted after the comprehensive tech-eco analysis.

General practice around the world showed that in the 1960s Pelton horizontally mounted turbines with one or a maximum of two nozzles for one runner were built. After that period they moved from horizontal to vertical mounting. That is, in the first place, the result of the designer’s desire to increase the nozzle number for the runner. The modern Pelton turbines are usually built with a vertical shaft and with six nozzles in one working circle.

Pelton turbines’ HEPPs have a horizontal shaft with two runners and with one (I–V) or two nozzles for one runner (VI and VII).

A result of the research into unstable operating modes is the nozzle flow characteristic $k_g = f(s/d_m)$ of the Pelton turbine $2 \cdot P_1 \cdot 2.4 / 300$ (units I–V) (Fig. 6) .

6 OZNAKE
6 SYMBOLS

oddaljenost kote težišča vstopnega prereza do kote vgradnje manometra	a	distance between the elevation of the centre of gravity of the inlet cross section and the elevation of the pressure gauge fastening
površina izhodnega pretočnega prereza	A_m	surface of outlet flow cross section
pretočna hitrost	c	flow velocity
srednja hitrost v prerezu (g - g)	c_g	average velocity in cross section (g – g)
srednja hitrost v prerezu (d - d)	c_d	average velocity in cross section (d – d)
osnovni premer gonilnika	D_1	basic diameters of runner
premer okrova na "i - i"	D_i	diameters of housing on "i - i"
premer igle v prerezu (i - i)	d_i	diameter of needle in cross section (i – i)
premer vodnega curka	d_o	diameter of water jet
premer izhodne odprtine šobe	d_m	diameter of nozzle outlet opening
čisti padec	H	net fall
bruto padec hidroelektrarne	H_{br}	gross fall of HEPP
višina odprtine šobe	h	height of nozzle opening
največja višina odprtine šobe	h_{imax}	maximum height of nozzle opening
koeficient izgub	k	loss coefficient
brezdimenzijski pretočni koeficient šobe Peltonove turbine	k_q	non–dimensional flow coefficient of Pelton turbine nozzle
število vrtljajev turbine	n	number of turbine revolutions
moč	P	power
tlak na ravni (g - g)	p_g	pressure at level (g – g)
tlak na ravni (d - d)	p_d	pressure at level (d – d)
manometrični tlak	p_m	gauge pressure
pretok	Q	flow
pretok šobe	Q_m	nozzle flow
gib igle šobe	s	nozzle needle movement
relativni gib igle	s'	relative needle movement
največji gib šobe	s_{max}	maximum nozzle movement
specifična energija	Y	specific energy
specifična energija vodnega toka na gladini vode zgornje akumulacije	Y_g	specific energy of water flow on water surface of upstream reservoir
specifična energija vodnega toka na gladini vode spodnje akumulacije	Y_d	specific energy of water flow on water surface of downstream reservoir
bruto specifična energija hidroelektrarne	Y_{br}	gross specific energy of HEPP
kota vstopnega prereza turbine	z_1	elevation of turbine inlet cross section
kota točke, kjer os šobe dotika osnovni krog turbinskega kolesa	z_2	elevation of point where the nozzle are s touches the basic circle of the turbine wheel
kot igle šobe	α	nozzle needle angle
koeficient hitrosti iztekanja	φ	coefficient of discharge velocity
gostota vode	ρ	water density
izstopni kot šobe	γ	nozzle outlet angle
izkoristek	η	efficiency
izkoristek šobe	η_m	nozzle efficiency
hidravlične izgube v dovodnem sistemu	ΔH_1	hydraulic losses in supplying system

7 LITERATURA
7 REFERENCE

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