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HIDRAVLIČNA PRESOJA VODOSTANA HE PLAVE II
HYDRAULIC EVALUATION OF THE HPP PLAVE II SURGE TANK

Primož RODIČ

Prispevek prinaša opis in rezultate hidravlične presoje vodostana elektrarne HE Plave II na reki Soči, zaradi spremenjenih geometrijskih in hidravličnih lastnosti sistema glede na predhodno študijo. Opisane so različne možnosti obratovanja turbine: na konstantni pretok, na konstantno moč in na konstantno odprtje. Na podlagi študije so bile, ob upoštevanju dovoljenega najnižjega in najvišjega nivoja gladine v vodostanu, z matematičnim modelom določene nove, večje vrednosti koeficientov upora dušilke.
Ključne besede: *HE Plave, vodostan, dušilka, robni pogoji, masne oscilacije*

This paper describes and brings the results of the hydraulic evaluation of the HPP Plave II surge tank on the Soča River owing to the hydraulic and geometric characteristics changeover with regard to the preliminary study. Three different turbine operation possibilities are described: constant discharge operation; constant power operation and constant wicket gates opening operation. On the basis of this study considering the maximum and minimum permissible water levels in the surge tank with the mathematical model, the new, highest values of the throttle damping characteristics were evaluated.
Key words: *HPP Plave, surge tank, throttle, boundary conditions, mass oscillations*

1. UVOD

Na reki Soči obratujejo tri večje elektrarne: HE Plave I, HE Doblar I in HE Solkan. Vzporedno s starima elektrarnama HE Plave I in HE Doblar I gradijo novi tlačno-derivacijski elektrarni HE Plave II in HE Doblar II, ki bosta izkoristili zajem vode v obstoječih akumulacijah, vendar z lastnim zajetjem, s cevovodom, z vodostanom in s strojnico.

V prejšnjih študijah so bili določeni temeljni geometrijski parametri obeh vodostanov in vrednosti uporov dušilk. Ker je prišlo v obdobju projektiranja vodostana HE Plave II do nekaterih geometrijskih sprememb in ker se je pri graditvi dovodnega tunela pokazala verjetnost večje hrapavosti od predvidene, posledično, med drugim, večjega padca gladine v vodostanu pri zagonu turbine, je bila upravičena potreba po novi hidravlični presoji.

1. INTRODUCTION

Three large hydro power plants are already in operation on the Soča River: HPP Plave I; HPP Doblar I and HPP Solkan. Parallel with the old ones, HPP Plave I and HPP Doblar I, the new pressure-diversion hydro power plants HPP Plave II and HPP Doblar II, with water supplies in the existing storage reservoirs, but with their own intakes, tunnels, surge tanks and power stations, are under construction.

In the preliminary studies, the basic surge tank geometry parameters and throttles damping characteristics were defined. During the project time of the HPP Plave II surge tank, some geometric modifications were established, while during the pressure tunnel construction, a likelihood of increased roughness was proved, which means a greater water level fall in the surge tank. For these reasons, a new hydraulic evaluation was justified.

2. OPIS STARE IN NOVE ELEKTRARNE HE PLAVE I IN HE PLAVE II

Zajetje HE Plave I je postavljeno na desnem bregu reke Soče tik ob pregradi Ajba. V dovodnem tunelu, dolžine 6 km, teče voda s prosto gladino. Na začetku in na koncu je opremljen z bočnima prelivoma in šele tik pred strojnico preide v tlačni cevovod. Vodostana torej ni, saj se v primeru zapiranja turbine oblikuje povratni val, ki potuje nazaj po dovodnem tunelu oz. se voda preliva preko spodnjega bočnega preliva. V strojnici je vgrajena Kaplanova turbina z instaliranim pretokom 75 m^3/s in generator z instalirano močjo 15 MW.

V nasprotju s staro elektrarno teče voda v dovodnem tunelu HE Plave II (slika 1), ki ima premer 6.4 m in je dolg 5990 m, pod tlakom. Novo zajetje je postavljeno tik ob obstoječem. Na koncu dovodnega tunela je predviden spoj s spodnjo vodostansko komoro. Ta je podkvastega prereza, širok in visok v osi 5.0 m; na oddaljenosti 102 m od spoja se razcepi na dva kraka, dolga 20 m, do dveh vertikalnih cilindričnih jaškov s premerom 26.22 m in višine od dna komore ob jašku do pete kalote 20.04 m. Dovod se proti strojnici nadaljuje kot tlačni cevovod dolžine 183 m, od tega 92 m s premerom 6.4 m in 81 m s premerom 5.5 m. Tudi v novi strojnici je predvidena Kaplanova turbina. Instalirani pretok nove elektrarne HE Plave II je 105 m^3/s, bruto padec 26.92 m in največja moč agregata 20.5 MW.

3. VLOGA VODOSTANA V SISTEMU DERIVACIJSKE ELEKTRARNE

Vodostan je postavljen na mestu med običajno le rahlo nagnjenim daljšim dovodnim tunelom pod tlakom in strmo padajočim tlačnim cevovodom. Gre za objekt, ki lahko sprejme in odda relativno velike količine vode. Odvisno od parametrov, lastnih vsakemu sistemu posebej, obstajajo različne oblike vodostanov: od najbolj preprostih, cilindričnih, do zahtevnejših, s komorami, prelivi in z dušilkami.

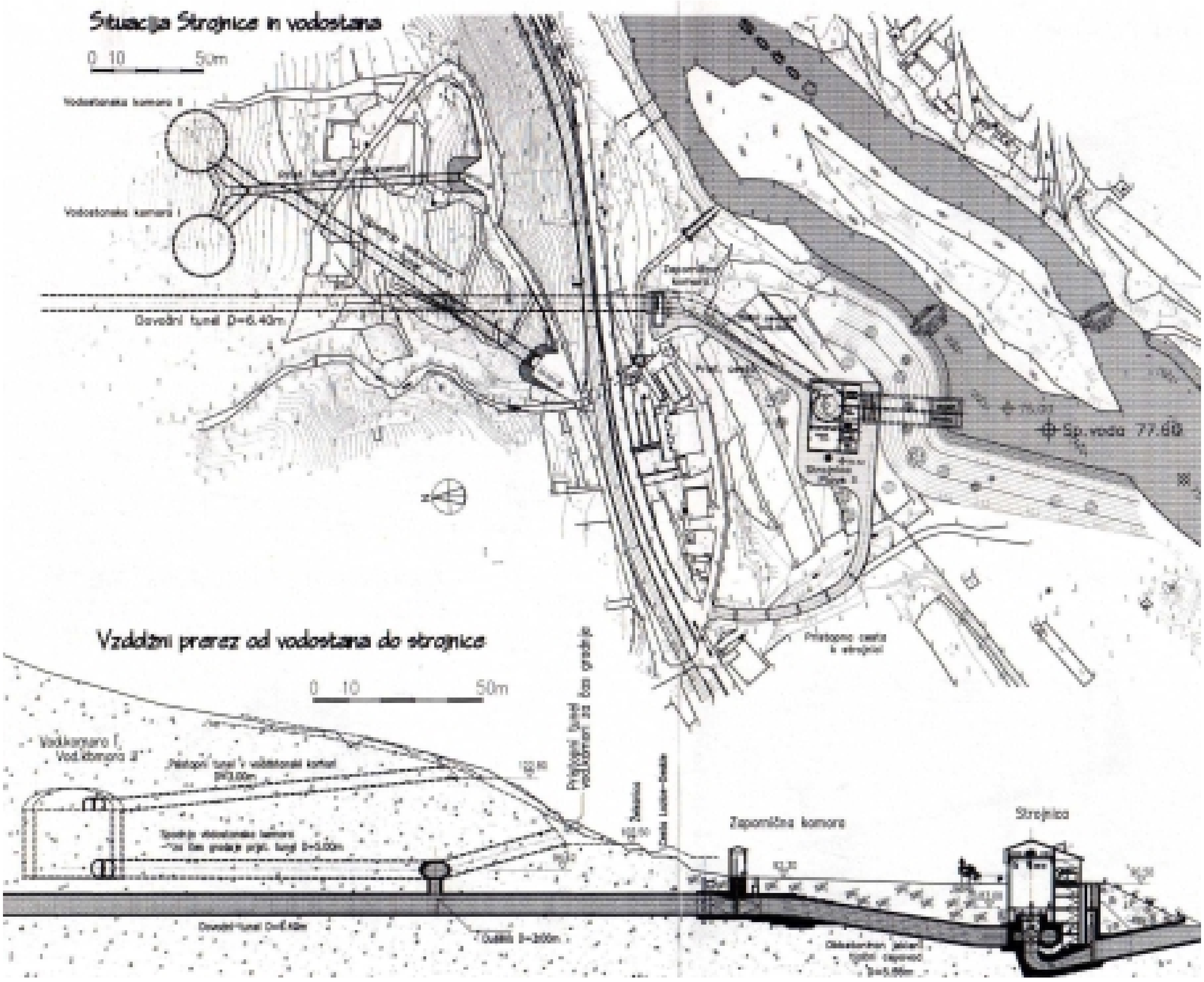
2. HPP PLAVE I AND HPP PLAVE II DESCRIPTION

The HPP Plave I intake is located on the right bank of the Soča River, close to the Ajba Dam. The free surface water diversion tunnel is of 6 km length, with side weirs at the beginning and at the ending, and only close to the power station does it convert into penstock. There is no surge tank, because in case of the turbine closing, the return positive wave forms and water spills over the lower side of the weir. In the power station, a vertical Kaplan turbine with a rated discharge of 75 m^3/s and a generator with a rated power of 15 MW are built in.

Unlike HPP Plave I, HPP Plave II (Figure 1) has a low pressure diversion tunnel of 5990 m length and 6.4 m diameter. The new intake is located close to the old one. At the end of the pressure tunnel, a connection with the lower expansion chamber is foreseen. It is horseshoe shaped, with a width and height of 5.0 m; 102 m from the connection point it divides into two legs of 20 m length, to the surge shafts with a 26.22 m diameter and a 20.04 m height. The diversion tunnel continues to the power station as a penstock with a 183 m length, and a 92 m by 6.4 m and 81 m by 5.5 m diameter. In the power station, a vertical Kaplan turbine is also foreseen. The rated discharge of the new HPP Plave II is 105 m^3/s, the gross head, 26.92 m and the maximum power, 20.5 MW.

3. SURGE TANK ROLE IN THE SYSTEM OF A DIVERSION TYPE HYDRO POWERPLANT

The surge tank is located between the slightly inclined pressure conduit and the steeply sloping penstock. It can intercept or give away a relatively large amount of water. Dependant on the system parameters, the surge tank could be very simple, cylindrical, or more complicated, with expansion chambers, weirs and restricted orifices, i.e., throttles.



Slika 1. Situacija in vzdolžni prerez od vodostana do strojnice HE Plave II.
Figure 1. Ground plan and cross section from surge tank to HPP Plave II Power Station.

V sistemu derivacijske elektrarne je vloga vodostana naslednja:

– pred vodnim udarom ščiti dovodni tunel in tlačni cevovod (zmanjšanje amplitud tlačnih valov v tlačnem cevovodu ugodno vpliva na stabilnost regulacije vodilnika in kontrolo hitrosti gonilnika),
– v primeru zapiranja turbine sprejme razliko dotoka vode iz dovodnega tunela in odtoka skozi tlačni cevovod,
– v primeru odpiranja hitro zagotavlja potrebo po večjem pretoku.

Vodostan mora biti projektiran tako, da so oscilacije nivoja gladine oz. piezometričnega tlaka pod dušilko tudi v primeru obratovanja na konstantno moč (pogl. 4.3.1) dušene (to je t.i. hidravlična stabilnost vodostana) in da so amplitude znotraj predpisanih meja.

The surge tank role in the system of the diversion type hydro power plant is:

– it protects the pressure tunnel and the penstock from pressure surges due to water hammering (the pressure surge reduction has a good influence on the wicket gate regulation stability and the turbine speed control),
– in the case of turbine closing, it intercepts the difference between the inflow through the pressure tunnel and the outflow through the penstock,
– in the case of turbine opening, it assures the need of a larger discharge.

The oscillations of water level and piezometric pressure under the throttle, respectively, are damped in the properly projected surge tank, even in he case of constant power operation (sect. 4.3.1) (this is so-called hydraulic stability) with amplitudes within the regulation area.

Da bi bile oscilacije zagotovo dušene, je potrebno izpolniti dva kriterija:

- Thomov kriterij, ki določa najmanjši potrebni horizontalni presek vodostana, ki se nato zaradi varnosti navadno poveča za 50 do 80 odstotkov:

In order that the oscillations should be damped, two conditions must be carry out:

- Thoma's criterion, which defines the least necessary surge tank horizontal cross section (which could be enlarged by 50 – 80% for safety's sake):

$$A_2 > \frac{L_1 \cdot Q_1^2}{2g \cdot A_1 \cdot H_{neto} \cdot R_1} \tag{1}$$

- kriterij hidravličnih izgub:

- hydraulic losses criterion:

$$R_1 < \frac{H_{br}}{3} \tag{2}$$

pri čemer pomeni:

A_2 horizontalni presek vodostana, [m^2]
A_1 presek dovodnega tunela, [m^2]
L_1 dolžina dovodnega tunela, [m]
Q_1 pretok v dovodnem tunelu, [m^3/s]
g zemeljski pospešek, [s/m^2]
H_{br} bruto padec, [m]
R_1 vsota hidravličnih izgub v dovodnem tunelu, [m]
H_{neto} neto padec (= $H_{br} – R_1$), [m].

where it means:

A_2 horizontal cross section, [m^2]
A_1 pressure tunnel cross section, [m^2]
L_1 pressure tunnel length, [m]
Q_1 pressure tunnel discharge, [m^3/s]
g gravitational acceleration, [s/m^2]
H_{br} gross head, [m]
R_1 pressure tunnel hydraulic losses sum, [m]
H_{neto} net head (= $H_{br} – R_1$), [m].

4. OSNOVNE ENAČBE IN ROBNI POGOJI ZA RAČUN MASNIH OSCILACIJ V VODOSTANU

4.1 DINAMIČNA ENAČBA

Dinamična enačba opisuje tok vode v dovodnem tunelu, pri čemer se vztrajnost vodne mase v vodostanu zaradi relativno majhnih hitrosti zanemari. Enačba, zapisana v obliki za numerično reševanje, je naslednja:

4. BASIC EQUATIONS AND BOUNDARY CONDITIONS FOR THE CALCULATION OF MASS OSCILLATIONS IN THE SURGE TANKS

4.1 DYNAMIC EQUATION

The dynamic equation describes the water flow in the pressure tunnel, where the water mass persistence in the surge tank is neglected due to relatively small velocities. The equation, arranged for numerical calculation, is:

$$\Delta Q_1 = -\frac{g \cdot A_1}{L_1} \cdot H_a \cdot \Delta t \tag{3}$$

$$H_a = z + r_1 Q_1 |Q_1| - r_2 Q_2 |Q_2| \tag{4}$$

pri čemer, poleg že zgoraj opisanih parametrov, pomeni še:

- ΔQ_1 sprememba pretoka v dovodnem tunelu, [m^3/s]
- H_a pospešna (akceleracijska) višina, ki je razlika med trenutnim nivojem gladine oz. piezometričneim tlakom pod dušilko in tistim nivojem gladine, ki bi se vzpostavil v vodostanu, če bi v dovodnem tunelu ves čas tekel trenutni pretok Q$_1$, [m]
- z odmik nivoja gladine v vodostanu od nivoja zgornje vode, [m]
- r_1 koeficient hidravličnega upora v dovodnem tunelu, [s^2/m^5]
- r_2 koeficient upora dušilke, [s^2/m^5]
- Q_2 pretok v vodostanu, [m^3/s]
- Δt časovni korak, [s].

where it means:

- ΔQ_1 change of discharge in the pressure tunnel, [m^3/s]
- H_a accelerating height as the difference between the momentary water level or piezometric pressure level under the throttle and that water level which would re-establish, if the discharge in the pressure tunnel would be the momentary disharge Q$_1$ all the time, [m]
- z water level deviation in the surge tank from the headwater level, [m]
- r_1 hydraulic resistance coefficient in the pressure tunnel, [s^2/m^5]
- r_2 throttle damping coefficient, [s^2/m^5]
- Q_2 surge tank discharge, [m^3/s]
- Δt time step, [s].

4.2 KONTINUITETNA ENAČBA

Kontinuitetna enačba opisuje dejstvo, da je algebraična vsota vseh pretokov na spoju dovodnega tunela, vodostana in tlačnega cevovoda enaka 0:

4.2 CONTINUITY EQUATION

The continuity equation describes the fact that the algebraic sum of all discharges at the junction of the pressure tunnel, surge tank and penstock are equal to zero:

$$Q_1 + Q_2 + Q_3 = 0 \tag{5}$$

$$Q_2 = -A_2 \frac{\Delta z}{\Delta t} \tag{6}$$

pri čemer pomeni še:

- Q_3 pretok v tlačnem cevovodu oz. skozi turbino, [m^3/s]
- Δz sprememba gladine v vodostanu, [m].

where also means:

- Q_3 penstock (turbine) discharge, [m^3/s]
- Δz change of water level in the surge tank, [m]

4.3 ROBNI POGOJI

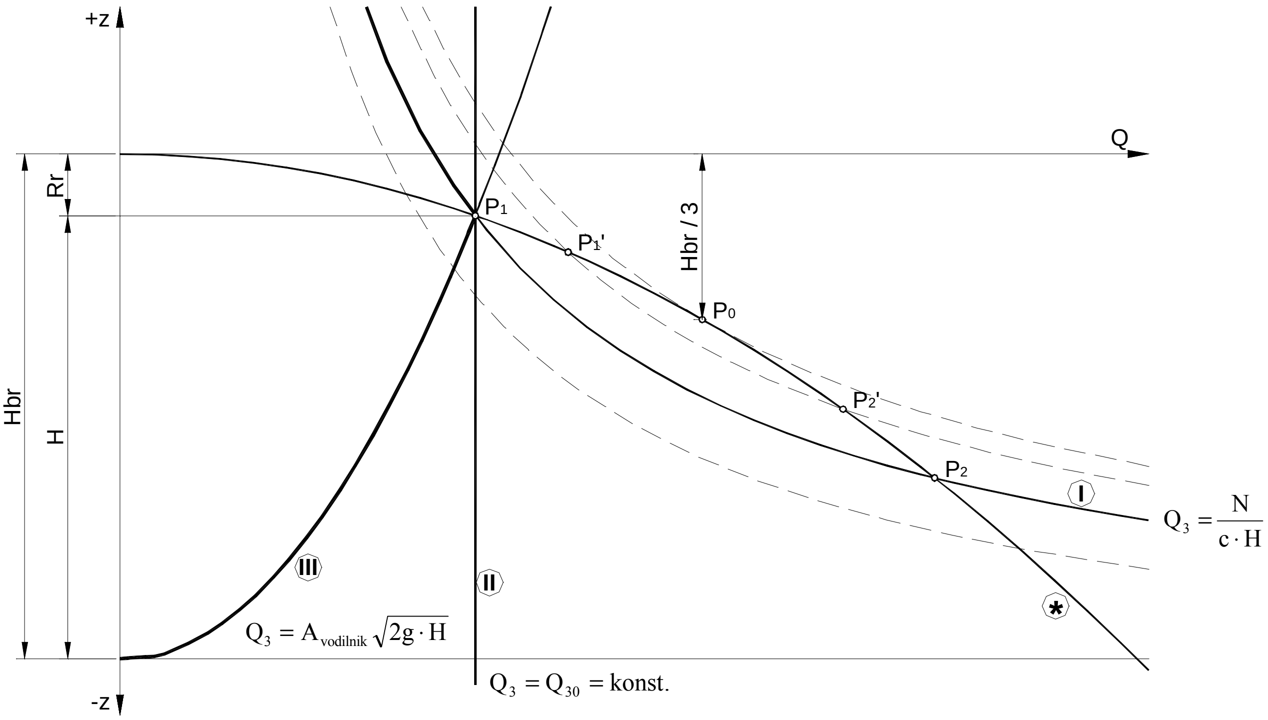
Levi (zgornji) robni pogoj predstavlja tako rekoč konstantna kota zajezbe. Desni (spodnji) robni pogoj pa predstavlja pretok Q_3 skozi turbino.

Na sliki 2 je predstavljen diagram, v katerem so poleg krivulje vseh hidravličnih izgub (*) na dovodnem tunelu in tlačnem cevovodu vrisane tri značilne krivulje, ki predstavljajo tri različne možnosti obratovanja turbine: na konstantno moč (I), na konstantni pretok (II) in na konstantno odprtje (III).

4.3 BOUNDARY CONDITIONS

The left (upper) boundary condition is the practically constant headwater level. The right (lower) boundary condition is the discharge Q_3 through the turbine.

Figure 2 presents the diagram, whereby the side of the resistance curve (*), three characteristic curves, which represent three different possibilities of the turbine operation, are drawn into: constant power operation (I), constant discharge operation (II) and constant wicket gate opening operation (III).



Slika 2.
Figure 2.

4.3.1 OBRATOVANJE NA KONSTANTNO MOČ

Prehod obratovanja elektrarne na novo moč, ki jo zahteva električno omrežje, pomeni tudi prehod iz starega v novo dinamično ravnovesje. Zaradi tega se v vodostanu sprožijo masne oscilacije oz. temu ustrezne oscilacije tlaka na turbini. Da bi elektrarna že takoj po začetnem izvedenem manevru spremembe položaja vodilnika konstantno obratovala z novo močjo, mora vodilnik ves čas povečevati oz. zmanjševati pretok skozi turbino po naslednji zakonitosti:

4.3.1 CONSTANT POWER OPERATION:

The transition of the power plant operation to the new power on the demand of the electric network, also means the transition from the old to the new dynamic equilibrium. The consequences are mass oscillations in the surge tank and pressure oscillations on the turbine. In order to operate on the constant new power immediately after the starting manoeuvre of changing the wicket gates position, the wicket gates must constantly magnify and reduce discharge through the turbine by the following equation.

$$Q_3 = \frac{N}{c \cdot H} \tag{7}$$

kjer pomeni:

N zahtevana konstantna moč, [MW]
H tlak na turbini, [m]
c spremenljivka, v kateri je vključen koeficient izkoristka agregata (v tej študiji upoštevan kot konstanten).

where it means:

N demanded constant power, [MW]
H pressure on the turbine, [m]
c parameter with included unit efficiency (here adopted as constant)

Manjši padec zahteva večji pretok in obratno, kot je razvidno iz krivulje moči (I) na sliki 2. Ta sicer seka krivuljo hidravličnih izgub v dveh točkah P_1 in P_2. Ti predstavljata mogoči kombinaciji pretoka in tlaka na turbini, ob zahtevani moči v stanju dinamičnega ravnovesja. S povečevanjem moči se točki P_1 in P_2 približujeta (na diagramu P_1' in P_2') in se v skrajnem primeru največje mogoče dosežene moči srečata v točki P_0, v kateri se krivulji hidravličnih izgub in moči le še dotakneta. V tem primeru je vsota hidravličnih izgub enaka eni tretjini bruto padca.

Čeprav pride v poštev samo dinamično ravnovesje, ki ga predstavlja točka P_1, pa v splošnem vedno obstaja tudi dinamično ravnovesje okoli točke P_2. V primeru, da sta si ti dve točki preblizu, lahko ob večjem padcu gladine v vodostanu vlogo novega dinamičnega ravnovesja prevzame prav točka P_2, kar vodi v izpraznitev vodostana oz. v t.i. hidravlični kolaps.

A lower head demands a higher discharge, and the opposite, as seen from the power curve (I) on Figure 2. It intersects the resistance curve at the two points P_1 in P_2. They represent possible combinations of discharge and pressure on the turbine in the state of dynamic equilibrium. With power magnifying, P_1 and P_2 come near each other (P_1' in P_2' on the diagram) to meet at the point P_0 in the case of necessity, when the power takes the peak value and both curves only touch each other. In that case, the hydraulic losses sum is equal to one third of a gross head.

Although only the dynamic equilibrium which represents the point P_1 is relevant, in the general case, there always exists, as well, the dynamic equilibrium with the point P_2. In case P_1 and P_2 are too close to each other, and if the water level in the surge tank drops too much, the point P_2 takes over the role of the new dynamic equilibrium, which can lead to the emptying of the surge tank, as called hydraulic collapse.

4.3.2 OBRATOVANJE NA KONSTANTNI PRETOK

4.3.2 CONSTANT DISCHARGE OPERATION

$$Q_3 = Q_{30} = konst. \tag{8}$$

Vzdrževanje konstantnega pretoka vsekakor zagotavlja stabilno obratovanje, saj premica (II) seka krivuljo hidravličnih izgub samo v eni točki P_1, v kateri se vzpostavi novo dinamično ravnotežje. Zaradi oscilacij gladin v vodostanu oz. piezometričnih tlakov pod dušilko v prehodnem obdobju oscilira tudi moč.

V praksi se takšno obratovanje ne izvaja; uporablja se ga zgolj kot preprostejši robni pogoj pri računih masnih oscilacij v vodostanih visokotlačnih hidroelektrarn. Ta pogoj je bil upoštevan pri določitvi prvotnih vrednosti upora dušilke.

The constan discharge operation, anyway, assures stabile operation, because the line (II) intersects the resistance curve only at one point P_1, which represents the new dynamic equilibrium. Owing to water level oscillations in the surge tank, as well as and piezometric pressure, oscillations under the throttle temporarily oscillate the power too.

This way of operation is completely inconvenient in the praxis. It is usable only as the simplest boundary condition at mass oscillations calculation for high head hydro power plants. In the preliminary study this condition was considered.

4.3.3 OBRATOVANJE NA KONSTANTNO ODPRTJE

4.3.3 CONSTANT WICKET GATES OPENING OPERATION

$$Q_3 = A_{vodi\ln ik}\sqrt{2g \cdot H} \tag{9}$$

kjer pomeni:
$A_{vodilnik}$ efektivna velikost odprtja vodilnika (t.j. ob upoštevanju koeficienta pretoka, [m^2].

Obratovanje na konstantno odprtje je prav tako stabilno obratovanje, saj tudi v tem primeru krivulja (III) seka krivuljo hidravličnih izgub v eni sami točki. Značilnost takšnega obratovanja je najhitrejša vzpostavitev novega dinamičnega ravnovesja, saj s padcem tlaka pade tudi pretok in obratno.

Obratovanje na konstantno odprtje je preprosto, saj se že na začetku nastavi položaj vodilnika na končno odprtje. Takšno obratovanje je nemenjeno elektrarnam, ki imajo manjši delež v sistemu proizvodnje električne energije, saj so oscilacije moči tu največje.

5. RAČUN IN REZULTATI HIDRAVLIČNE PRESOJE VODOSTANA HE PLAVE II

5.1 TEMELJNI PODATKI

instalirani pretok Q_{inst}: 105 m^3/s,
največja kota zgornje vode, upoštevana v hidravlični presoji: 106.00 m n.m.
najmanjša kota zgornje vode: 104.00 m n.m.,
najmanjša kota spodnje vode: 77.58 m n.m.
nominalni neto padec H_{nom}: 18.23 m.
nominalna moč N_{nom}: 17.4 MW,
največja moč N_{max}: 20.5 MW

5.2 MANEVRI IN REGULACIJA

Manever pomeni spremembo odprtja vodilnika in položaja lopatice gonilnika zaradi spremembe obremenitve. Na začetku se izvaja po predvideni odvisnosti od časa, v nadaljevanju pa v odvisnosti od trenutnega padca na turbini oz. pogoja vzdrževanja (nove) konstantne moči po enačbi, poenostavljeni z upoštevanim konstantnim izkoristkom agregata:

where it means:
$A_{vodilnik}$ effective wicket gates opening (with consideration of discharge coefficient), [m^2]

The constant wicket gates opening operation is a stabile operation because the curve (III) intersects the resistance curve at only one point. Its main characteristic is that it is the fastest way to take up the new dynamic equilibrium; namely, when the water level falls, the discharge falls too, and, to the contrary, they rise together.

The constant wicket gates opening operation is very simple because, just in the beginning, the wicket gates are setting up to the new position. This way of operation is usable for the power plant with a smaller share in the electric energy production, because power oscillations are the highest here.

5. CALCULATION AND RESULTS OF THE HYDRAULIC EVALUATION OF THE HPP PLAVE II SURGE TANK

5.1 BASIC DATA

rated discharge Q_{inst}: 105 m^3/s,
maximum headwater level, considered in hydraulic evaluation: 106.00 m n.m.
minimum headwater level: 104.00 m n.m.,
minimum tail water level: 77.58 m n.m.
rated net height H_{nom}: 18.23 m.
rated power N_{nom}: 17.4 MW,
maximum power N_{max}: 20.5 MW

5.2 MANOEUVRE AND REGULATION

Manoeuvre means the wicket gates open and the runner blade position changes because of the load change. It is dependant on time, at the beginning, and then dependant on the momentary turbine head by the equation with an adopted constant unit efficiency:

$$Q_3 = \frac{N}{c \cdot H} \tag{10}$$

Pri tem se upošteva največja mogoča nastavitev odprtja vodilnika $A_{100\%}$:

It takes into consideration the highest possibly wicket gate opening $A_{100\%}$:

$$A_{100\%} = \frac{Q_{inst}}{\sqrt{2g \cdot H_{nom}}} \tag{11}$$

V konkretnem izračunu je sicer za začetna manevra odpiranja oz. zapiranja, ki sta odvisna samo od časa, upoštevana naslednja dinamika:

– linearno odpiranje vodilnika od 0 do 100 odstotkov v 35s
– zapiranje vodilnika v dveh linearnih sekvencah od 100 do 30 odstotkov v 10.5s in od 30 do 0 odstotkov v 14.5s.

In the concrete calculation, the following starting manoeuvres dynamics were considered:

– linear wicket gates opening from 0% to 100% in 35s
– wicket gates closing in two linear sequences from 100% to 30% in 10.5s and 30% to 0% in 14.5s.

5.3 KRITERIJI ZA DOLOČITEV NAJVEČJE IN NAJMANJŠE GLADINE V VODOSTANU

Največja gladina v vodostanu je določena kot največja dosežena gladina za primer zaporednih manevrov odpiranja in zapiranja med 0 in 100 odstotki največje moči N_{max}, z upoštevanjem najmanj 15-minutnega čakalnega časa med zapiranjem in začetkom vnovičnega odpiranja. Pri tem je upoštevana kota zgornje vode 106.00 m n.m., kota spodnje vode 77.58 m n.m. in koeficient hrapavosti 0.012. Kota gladine v vodostanu ne sme preseči kote 113.0 m n.m., ki predstavlja najvišjo koto vodostanskega jaška, piezometrična kota pod dušilko pa ne sme preseči kote 118.0 m n.m.

Najmanjša gladina v vodostanu je določena kot najnižja dosežena gladina za primer zaporednih manevrov odpiranja in zapiranja med 0 in 100 odstotki največje moči N_{max} z upoštevanjem najmanj 15-minutnega čakalnega časa med zapiranjem in začetkom vnovičnega odpiranja. Pri tem je upoštevana kota zgornje vode 104.00 m n.m., kota spodnje vode 77.58 m n.m. in koeficient hrapavosti cevovodov 0.016. Kota gladine v vodostanu ne sme biti nižja od kote 93.1 m n.m., piezometrična kota pod dušilko pa ne sme biti nižja od kote temena dovodnega tunela na priključku vodostana 87.2 m n.m.

V primeru zaporednih manevrov je za začetek vsakega naslednjega manevra odločilen tisti trenutek, ki v naslednjem nihaju daje ekstremne vrednosti nivojev gladin.

5.3 MAXIMUM AND MINIMUM WATER LEVEL CRITERIONS IN THE SURGE TANK

The maximum water level in the surge tank is defined as the highest level in the case of a series of openings and closings between 0% and 100% maximal power N_{max}, with at least 15 minutes consideration of waiting time between the closing and the start of the renewed opening. The head level water of 106.00 m a.s.l., tail water level water of 77.58 m a.s.l. and Manning's resistance coefficient of 0.012 must be considered in its calculation. The water level must not exceed 113.0 m a.s.l., which represents the highest surge tank level, and the piezometric pressure level under the throttle must not exceed 118.0 m a.s.l.

The minimum water level in the surge tank is defined as the lowest level in the case of a series of openings and closings between 0% and 100% maximal power $N_{max,}$ with at least 15 minutes consideration of waiting time between the closing and the start of the renewed opening. The head level water of 104.00 m a.s.l., tail water level water of 77.58 m a.s.l. and Manning's resistance coefficient of 0.016 must be considered in its calculation. The water level must not be lower than 93.1 m a.s.l., and the piezometric pressure level under the throttle must not be lower than 87.2 m a.s.l., which represents the top of the pressure tunnel under the throttle.

The starting time for each following manoeuvre is the moment which gives the peak value in the next surge.

5.4 REZULTATI

Kljub temu, da naj bi se po vsebini iz točke 5.3 upošteval najmanj 15-minutni čakalni čas med zapiranjem in začetkom vnovičnega odpiranja, je izvedena hidravlična presoja s strožjim kriterijem, in sicer kadarkoli se začne vnovično odpiranje. Gre sicer za ekstremen in neobičajen, vendar v praksi izvedljiv primer, ki ga mora biti elektrarna zaradi varnosti sposobna prenesti.

Rezultat hidravlične presoje sta novi vrednosti upora dušilke, ki sta v skladu s pogoji iz točke 5.3. Njuni vrednosti sta:

- pri vtekanju v vodostan r_{vtok}: 0.00125 s^2/m^5
- pri iztekanju iz vodostana r_{iztok}: 0.00078 s^2/m^5.

Rezultati hidravlične presoje so prikazani tudi v obliki diagramov oscilacij gladin (poudarjena krivulja) in piezometričnih tlakov pod dušilko.

5.4.1 NAJVEČJI DVIG IN PADEC GLADINE PRI NEUPOŠTEVANJU NAJMANJ 15-MINUTNEGA ČAKALNEGA ČASA

Dvig gladine tako v drugem nihaju kot v tretjem nihaju znaša 112.98 m n.m., piezometričnega tlaka pa 116.22 m n.m. (v drugem nihaju) (slika 3). Največji padec gladine znaša v obeh nihajih 93.16 m n.m., piezometričnega tlaka pa 92.25 m n.m. (slika 4)

5.4.2 NAJVEČJI DVIG IN PADEC GLADINE PRI UPOŠTEVANJU NAJMANJ 15 MINUTNEGA ČAKALNEGA ČASA

Največji dvig gladine znaša 112.95 m n.m., piezometričnega tlaka pa 116.07 m n.m. (slika 5). Največji padec gladine znaša 93.60 m n.m., piezometričnega tlaka pa 93.50 m n.m. (slika 6).

5.4 RESULTS

In spite of the criterion in sect. 5.3, which defines 15 minutes waiting time between the closing and the start of renewed opening, the hydraulic evaluation was carried out with rigorous criterion, which permits the starting time anytime. Actually, this is extreme and unusual, but within the praxis, a completely realisable case which the power plant must stand for the sake of safety.

The results of the hydraulics evaluation are new values of the throttle damping characteristics. These are:

- when water flows into the surge tank r_{vtok}: 0.00125 s^2/m^5
- when water flows out of the surge tank r_{iztok}: 0.00078 s^2/m^5.

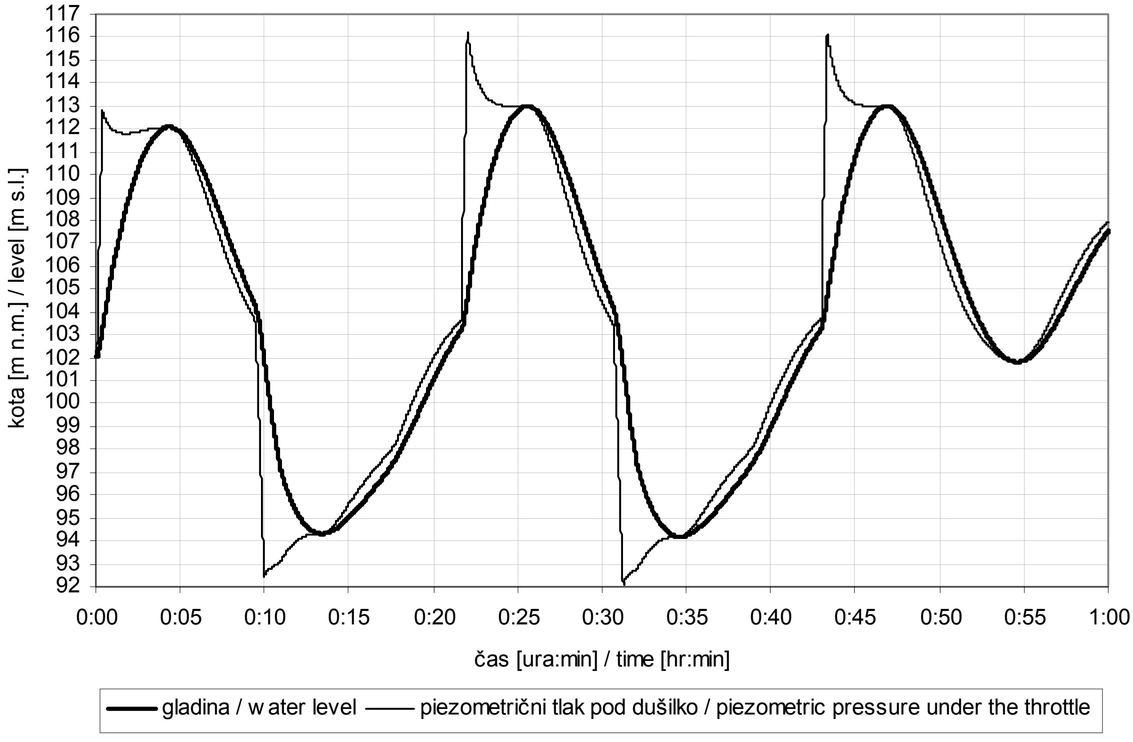
The result of the hydraulic evaluation are also shown in the diagrams of the water level oscillations bold curve) and the piezometric pressure oscillations.

5.4.1 MAXIMAL WATER LEVEL RISE AND FALL WITHOUT 15 MINUTES WAITING TIME.

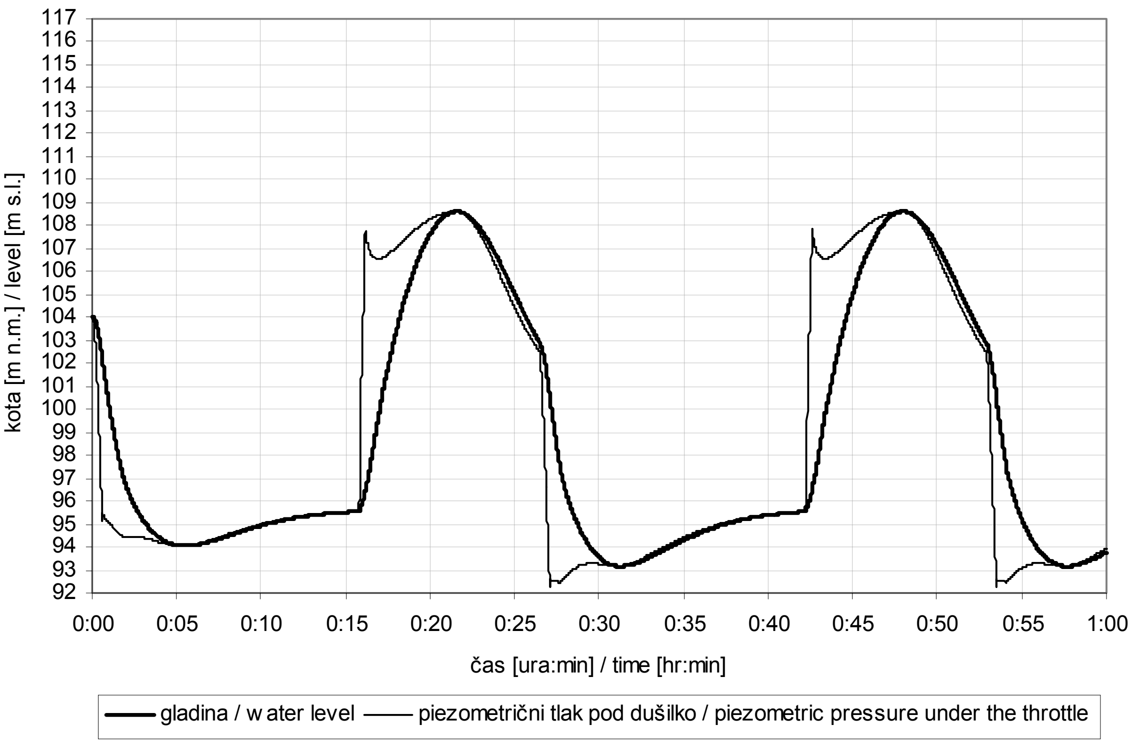
The maximal water level rise, equal in the second and third surge, is 112.98 m a.s.l.; the piezometric pressure rise is 116.22 m a.s.l. (in the second surge) (Figure 3). The maximal water level fall is 93.16 m a.s.l., and the maximal piezometric pressure fall is 92.25 m a.s.l. (Figure 4), both in the second and third surges.

5.4.2 MAXIMAL WATER LEVEL RISE AND FALL WITH 15 MINUTES WAITING TIME

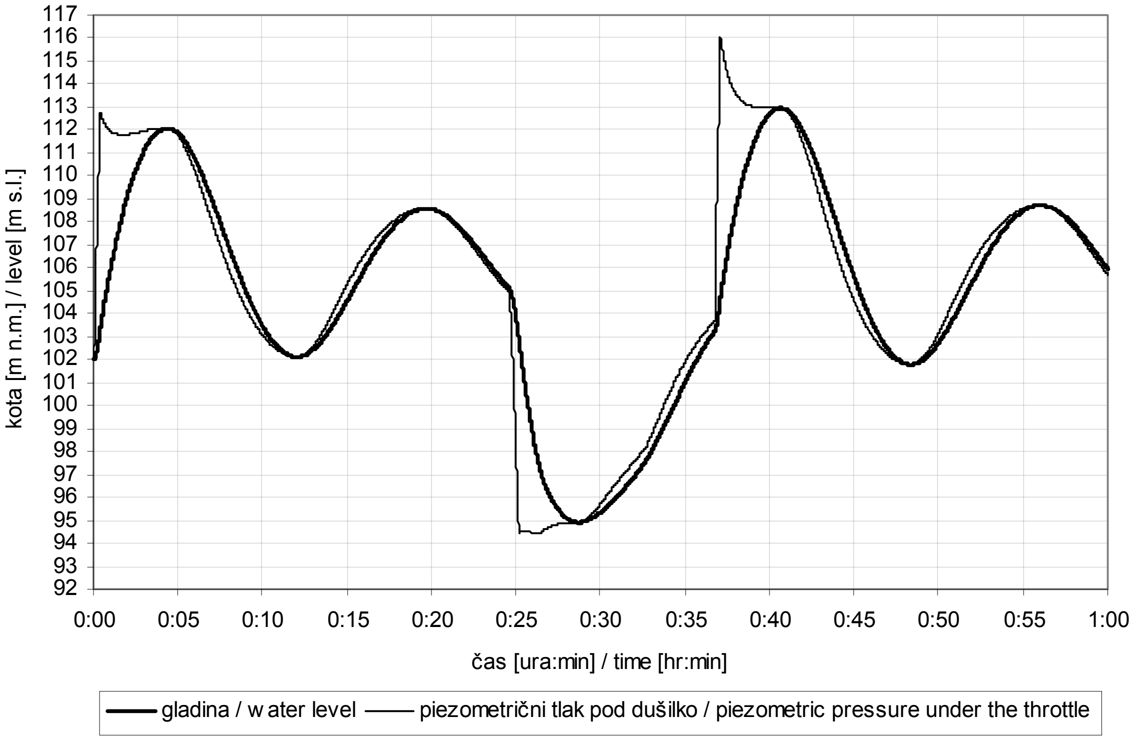
The maximal water level rise is 112.95 m a.s.l., and the maximal piezometric pressure rise is 116.07 m a.s.l. (Figure 5). The maximal water level fall is 93.60 m n.m., and the maximal piezometric pressure fall is 93.50 m a.s.l. (Figure 6).



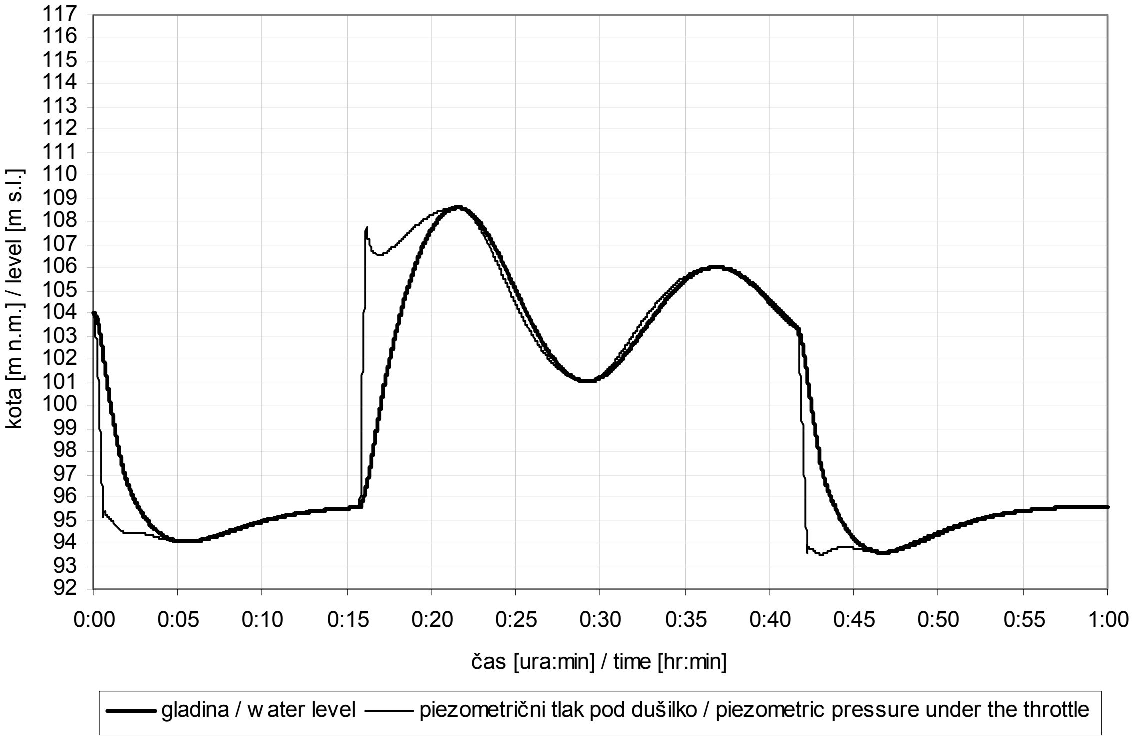
Slika 3. Maksimalni dvig gladine pri neupoštevanju najmanj 15 minutnega čakalnega časa.
Figure 3. Maximal water level rise without 15 minutes waiting time.



Slika 4. Maksimalni padec gladine pri neupoštevanju najmanj 15 minutnega čakalnega časa.
Figure 4. Maximal water level fall without 15 minutes waiting time.



Slika 5. Maksimalni dvig gladine pri upoštevanju najmanj 15 minutnega čakalnega časa.
Figure 5. Maximal water level rise with 15 minutes waiting time.



Slika 6. Maksimalni padec gladine pri upoštevanju najmanj 15 minutnega čakalnega časa.
Figure 6. Maximal water level fall with 15 minutes waiting time.

6. ZAKLJUČEK

S hidravlično presojo sta bili določeni novi vrednosti upora dušilke vodostana HE Plave II, ki sta za približno 10 odstotkov večji od prvotnih. Vzrok temu je že jasno koncipiran sistem nove elektrarne in posledično v računu upoštevan verodostojnejši desni robni pogoj – začetni manever v odvisnosti od časa, obratovanje na moč, z upoštevanjem največjega možnega odprtja vodilnika, ter upoštevano zaporedje manevrov odpiranja in zapiranja turbine. V predhodni študiji je bil račun izveden z upoštevanjem obratovanja na konstantni pretok ter preprostega zaporedja samo enega zapiranja turbine na predhodno odpiranje in obratno.

Rezultat hidravlične presoje pa je tudi ugotovitev, da upoštevanje 15-minutnega čakalnega časa bistveno ne vpliva na varnost obratovanja elektrarne, saj je pri največjem dvigu gladina v vodostanu nižja le za 3 cm, pri največjem padcu pa višja za 34 cm. Dejstvo, da elektrarna lahko vstopi v pogon v kateremkoli trenutku, pa ji daje glede na možnost hitrega prilagajanja trenutni potrebi po električni energiji vsekakor večjo vrednost.

6. CONCLUSION

New values of the HPP Plave II throttle damping characteristics were evaluated. They are approximately 10 % higher than the preliminary ones. The reason is the more defined concept of the new hydro power plant and the consecutive consideration of a reliable right boundary condition – starting manoeuvre dependant on time, constant power operation with the highest possible wicket gate opening and the sequence of opening and closing the turbine. In the preliminary study, the calculation was executed by considering the constant discharge operation and by the simple sequence opening after starting the closing, and, vice versa, closing after starting the opening.

The result of the hydraulic evaluation is also to the fact, that the 15 minutes waiting time doesn’t essentially influence operational safety. The difference between the maximal water level rise with and withou the consideration of waiting time is only 3 cm, and the difference between the maximal fall is 34 cm. But starting to run anytime to assure the momentary need for electrical energy is an advantage which gives higher value to the hydro power plant.

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Naslov avtorja - Author's Address

Primož RODIČ
Inštitut za hidravlične raziskave – Institute for Hydraulic Research
Hajdrihova 28, SI – 1000 Ljubljana