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Značilnosti radialnih malih vodnih turbin s prečnim tokom

Characteristics of Cross-Flow Radial Mini-Hydro Turbines

Krešimir Franjić

V prispevku je opisana turbina, ki jo običajno poznamo kot Bankijevo turbino. Opravljena je primerjava med dvema posebnima vrstama te turbine: Ossebergerjevo in Cinkovo turbino. Poleg teoretičnih osnov, ki so enake za obe vrsti turbine, so predstavljene najpomembnejše razlike. Na koncu prispevka so predstavljeni sklepi o osnovnih krmilnih značilnostih in učinkovitosti obeh vrst turbin.

(Ključne besede: turbine Banki, turbine radialne, krmiljenje turbin, učinkovitost turbin)

This paper describes a turbine that is usually known as Banki's turbine. A comparison was made between two specialized types of this turbine: Ossberger's and Cink's turbines. Besides the theoretical basis, which is the same for the two types of turbine, the principal differences are specified. At the end of the paper a conclusion is drawn about the basic control properties and effiency of both turbines.

(Keywords: Banki's turbine, radial turbine, turbine control, turbine efficiency)

1 ZGODOVINSKI POTEK

Teoretično podlago radialne turbine s prečnim tokom z dvojnim pretokom je v 19. stoletju objavil Poncelet. Njen temelj je bilo preprosto vodno kolo. V praksi je to rešitev prvi uresničil priznani avstralski inženir A. S. Michell, ki je svoj stroj patentiral leta 1903.

Po dolgotrajnih raziskavah v Nemčiji je za nadaljnji razvoj tega stroja poskrbel madžarski inženir D. Banki (v času od 1912 do 1919). Razviti stroj je bil patentiran leta 1917. Takrat se je turbina imenovala Michell-Bankijeva turbina.

Sodelovanje med Michellom in Fritzom Ossbergerjem, ki je bil lastnik tovarne v Thalmassingu blizu Nürnberga, se je začelo v zgodnjih dvajsetih letih 20. stoletja. Posledica tega razvoja je bil nov patent za turbino s prečnim tokom iz leta 1933. Turbina se od takrat v virih pojavlja kot Michell-Ossbergerjeva [1].

Po daljšem premoru pri razvoju turbine te vrste je pomenil naslednjo stopnjo razvoja radialne turbine s prečnim tokom patent češkega inženirja Miroslava Cinka [2]. Proizvodnja, usmerjena v tržišče, se je začela leta 1985 v sodelovanju s češkimi podjetji. Od leta 1992 za njihovo proizvodnjo skrbi tovarna Cink-MVE v Karlovih Varih. Do leta 2000 je bilo izdelanih že več ko 350 turbin.

1 HISTORICAL DEVELOPMENT

The theoretical basis of the cross-flow radial turbine was published by Poncelet in the 19th century. His idea was based on the simple water wheel. The practical outcome of his considerations was developed by an ingenious Australian engineer, A. S. Michell, who patented his machine in 1903.

Further development of this machine resulted from considerable research in Germany by a Hungarian engineer, D. Banki (in the period 1912 to 1919). The machine was patented in 1917. At this time the turbine was known as the Michell-Banki turbine.

A cooperation between Mitchell and Fritz Ossberger, who owned a factory in Thalmassing near Nürenberg, started in the early 1920s. The result was a patent for a cross-flow turbine which was issued in 1933. This turbine has been called the Michell-Ossberger turbine in the literature since this time [1].

After a long pause in the development of this type of turbine a patent by a Czech engineer, Miroslav Cink, introduced a further development of the cross-flow radial turbine [2]. Production began in cooperation with Czech firms in 1985 and since 1992 the turbine has been manufactured at the Cink-MVE factory in Carlsbad. More than 350 turbines had been manufactured and put into operation by 2000.

2 TEORETIČNA NAČELA

Teorijo radialne turbine s prečnim tokom, katere osnova je predelano vodno kolo, je oblikoval Poncelet. Teorija temelji na splošni Eulerjevi turbinski teoriji.

Primer prečnega toka skozi radialno kolo je predstavljen na sliki 1 [5]. Sprememba specifične energije v prvem delu prečnega toka je:

2 THEORETICAL PRINCIPLES

The theory of the cross-flow radial turbine based on a modified water wheel was formed by Poncelet from the general Euler turbine theory.

An example of cross-flow trough a radial wheel is presented in Fig. 1 [5]. The specific energy change in the first part of the cross-flow gives:

$$Y_{rt1} = u_{11} v_{11u} - u_{12} v_{12u} \quad (1)$$

in v drugem delu:

and in the second part:

$$Y_{rt2} = u_{21} v_{21u} - u_{22} v_{22u} \quad (2).$$

Celotna sprememba specifične energije v kolesu je:

The total change in the wheel being:

$$Y_{rt} = Y_{rt1} + Y_{rt2} \quad (3).$$

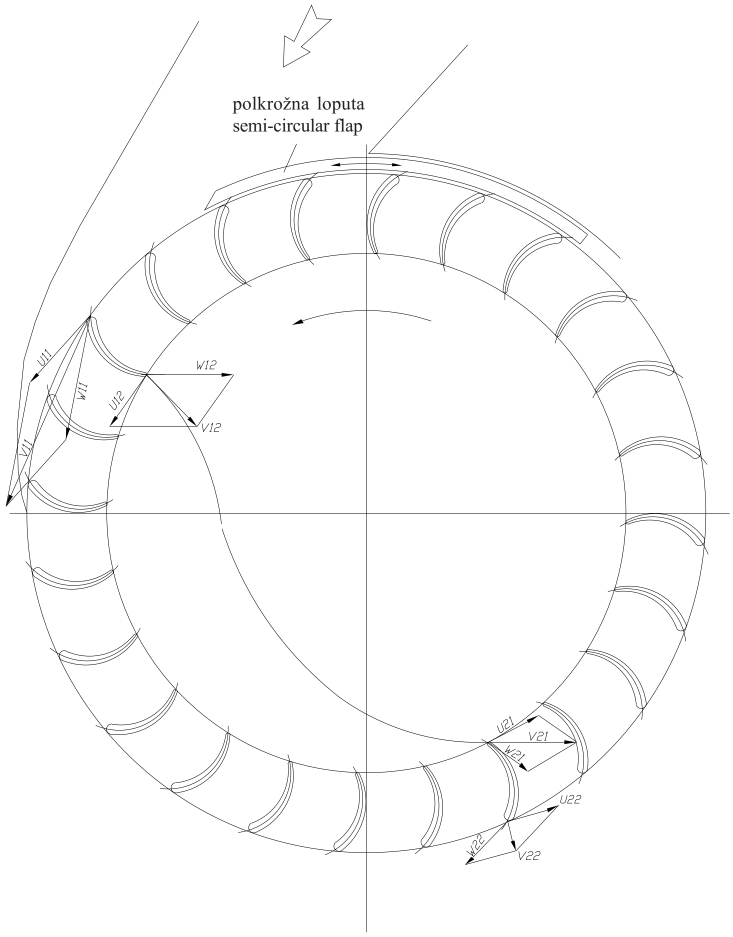
Največja sprememba energije je dosežena, ko je:

The maximum change of energy is reached when:

$$v_{12u} = v_{22u} = 0 \qquad (\alpha_{12} = \alpha_{22} = 90^o) \quad (4).$$

Ta točka se imenuje imenska delovna točka oziroma točka največje učinkovitosti.

This point is called the nominal working point or the point of maximum efficiency.



Sl. 1. *Primer prečnega toka skozi radialno kolo*
Fig. 1. *An example of cross-flow through a radial wheel*

V tem primeru je celotna sprememba energije v kolesu:

In this case the overall change of energy in the wheel is:

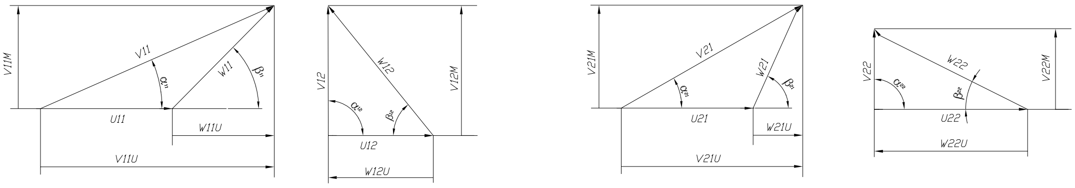
$$Y_{rt,\max} = u_{11} v_{11u} + u_{21} v_{21u} \quad (5).$$

Hitrostni vektorji pri pritoku in odtoku iz posameznih prečnih delov kolesa se ravnajo po zakonih vektorske algebre. V primeru toka skozi kanal lopatičja kolesa govorimo o absolutni hitrosti (v) kot vektorski vsoti obodne hitrosti (u) in relativne hitrosti (w).

Če vzamemo samo polovico vektorskega paralelograma, dobimo trikotnik hitrosti. Ti trikotniki so za imensko delovno točko prikazani na sliki 2.

The velocity vectors at inflow and outflow from the individual cross-sections of the wheel follow from the laws of vector algebra. In the case of flow through the impeller channel of the wheel this means that absolute velocity (v) is a vector sum of the circumferential velocity (u) and the relative velocity (w).

If we take one half of the vector parallelogram only, the so-called velocity vector triangle is formed. The velocity triangles for the nominal working point are shown in Fig. 2.



Trikotnika hitrosti - prvi prehod skozi rotor
Vector triangles - first cross-flow

Trikotnika hitrosti - drugi prehod skozi rotor
Vector triangles - second cross-flow

Sl. 2. *Vektorski trikotniki hitrosti*
Fig. 2. *Vector triangles*

Prej omenjena sprememba energije je ponazorjena s trikotniki hitrosti kot razlika produktov obodne hitrosti in projekcije vektorja absolutne hitrosti na smer obodne hitrosti med vstopnim in izstopnim robom rotorskega kanala. S pomočjo teh trikotnikov lahko sledimo tudi spremembam, ki jih povzročijo spremembe kinematike toka v turbini. S tem lahko predstavimo razlike med posameznimi turbinami. Če zanemarimo izgube turbine in izstopnega dela, je energija, ki jo daje turbina, enaka:

The previous considerations relating to the change of energy are illustrated by velocity triangles as a product of the lengths of the circumferential velocity vector and the projection of the absolute velocity vector onto the direction of the circumferential velocity during the two passages across the wheel cascade. The triangles also enable us to follow the changes caused by flow alterations in the turbine; this can be used to prove the differences between the individual turbines. If the turbine losses and the suction-bell or diffuser effects are neglected the power generated by the turbine is:

$$P \approx \rho Y_{rt} Q \quad (6)$$

in jo lahko pri nespremenljivi višini H_n spremenjamo samo s pretokom.

Prostorninski pretok Q v turbino lahko spreminjamo z različnimi metodami: s preprostim ventilom oziroma lokom (Banki), s hidrodinamično loputo (Ossberger) oziroma s profilno oblikovanim polkrožnim lokom (Cink).

V naslednjem delu bomo predstavili analizo turbine z vidika možnosti krmiljenja toka in posledic krmiljenja na karakteristike turbine.

and can be changed only by the rate of flow at the constant hight H_n.

The rate of flow Q into the turbine may be changed by various methods: a simple valve or segment (Banki), a hydrodynamic flap (Ossberger) or a profile-shaped semicircular segment (Cink).

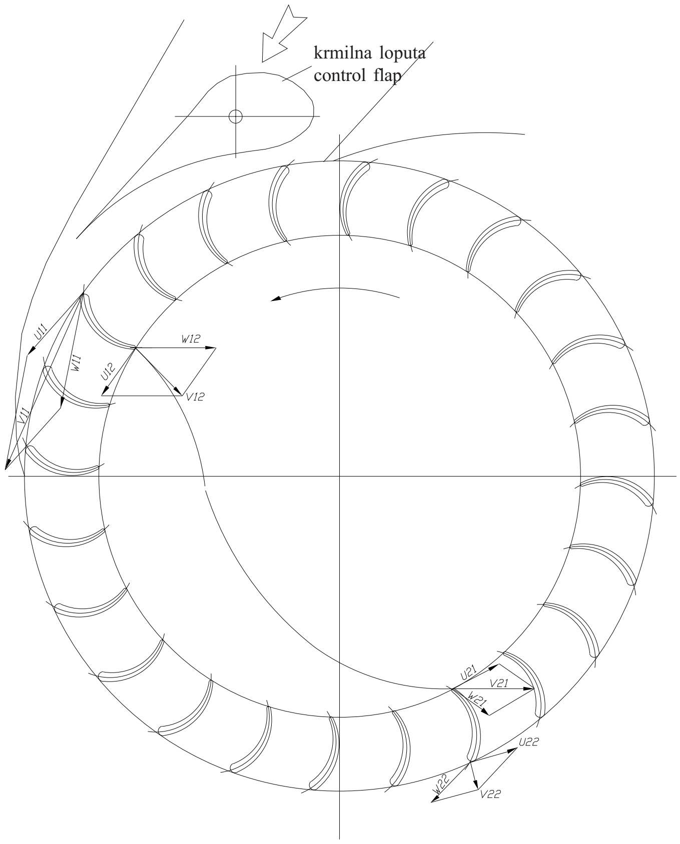
In the following part an analysis of the turbine will be made from the point of view of flow control possibilities and the consequences of this control as principal features of the turbine.

3 ANALIZA HIDRODINAMIČNIH ZMOŽNOSTI RADIALNE TURBINE S PREČNIM TOKOM

Natok na rotor Cinkove turbine je prikazan na sliki 1, natok na rotor Ossbergerjeve turbine pa na sliki 3. Sliki se v imenski delovni točki med seboj ne razlikujeta. Zaradi tega obe omenjeni turbini v tej točki dosegata enak izkoristek (če seveda zanemarimo posledice sesalnega zvona pri Ossbergerjevi turbini oziroma učinke difuzorja pri Cinkovi turbini).

3 AN ANALYSIS OF THE HYDRODYNAMIC POSSIBILITIES OF CROSS-FLOW RADIAL TURBINES

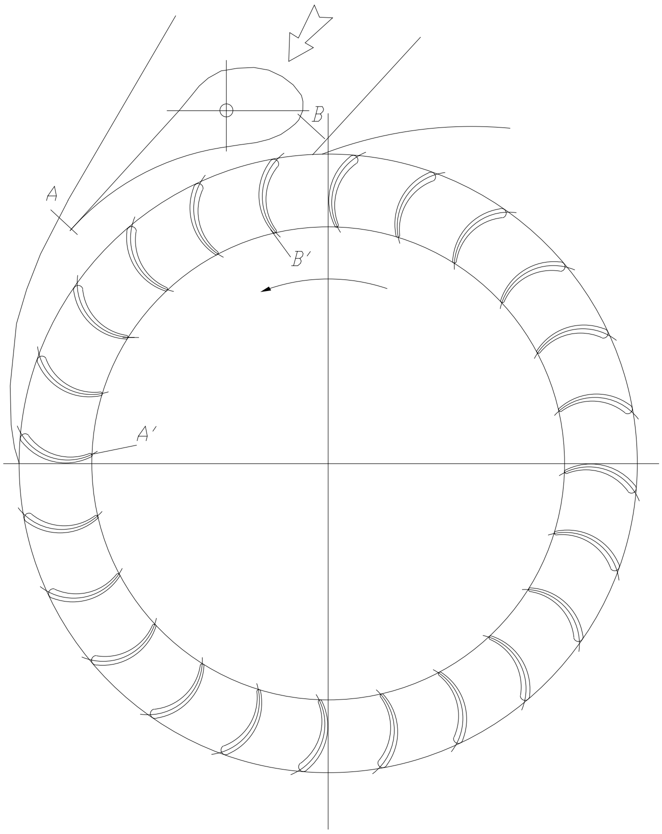
The flow into the Cink turbine wheel is shown in Fig. 1. Fig. 3 illustrates the flow into the Ossberger turbine wheel. Comparing these figures for the nominal point of operation indicates that there is no difference. This is the reason why both turbines reach the same efficiency at this point (when the effects of the suction bell for the Ossberger or the diffuser for the Cink are neglected).



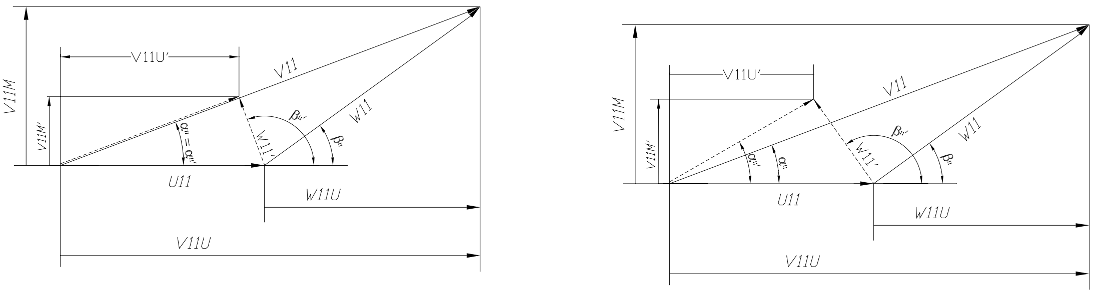
Sl. 3. *Tok skozi Ossbergerjevo turbino*
Fig. 3. *Flow through Ossberger turbine*

Če je treba pretok vode skozi turbino zmanjšati (zahteva električnega omrežja oziroma naravno zmanjšanje prostorninskega pretoka), moramo Cinkovi turbini postopno zapreti polkrožni lok. V tem primeru je površina vstopnega prereza zmanjšana, hitrostni trikotniki pa ostanejo nespremenjeni. Pri Ossbergerjevi turbini se kinematika natoka na rotor spremeni, ko zasukamo dinamično loputo (sl. 4). Smer vektorja absolutne hitrosti v_{11} določa oblika stene okrova turbine, kar ima za posledico, da sta kota enaka ($\alpha_{11} = \alpha'_{11}$). Zmanjšanje pretoka kot posledica spremembe položaja lopute neposredno vpliva na zmanjšanje meridianskih in obodnih komponent hitrosti v_{11}, kar je predstavljeno na sliki 5.

When it is necessary to diminish the flow (electric grid demand or natural flow decrease) the Cink turbine must have the semicircular segment gradually closed. In this case the inflow cross-sections is smaller but the triangle of velocities remains unchanged. For the case of the Ossberger turbine the inflow is changed by turning the flap (Fig. 4) to alter the inflow cross-sections (denominated A and B in Fig. 4). Turning the flap changes the flow conditions in the cascade in the zone limited by blades A' and B'. On the blades A' and B' the absolute velocity-vector direction remains unchanged as it is formed by the walls of the casing ($\alpha_{11} = \alpha'_{11}$). The consequences may be seen in the velocity-vector triangle in Fig. 5, left. The flow decrease leads to a decrease in both the meridional component



Sl. 4. *Sprememba pritoka Ossbergerjeve turbine*
Fig. 4. *Change of inflow of Ossberger turbine*



Sl. 5. *Vektorski trikotnik hitrosti*
Fig. 5. *Velocity-vector triangle*

Obodna hitrost u_{11} naj bi zaradi generatorjeve nespremenljive vrtilne frekvence ostala nespremenjena. Omeniti je treba, da sprememba toka povzroči spremembo kota β'_{11}, t.j. vstopnega kota na lopatice.

Vsaki lopatici, ki se nahaja med A' in B', se drugače ($\alpha_{11} \neq \alpha'_{11}$) spremeni smer vektorja absolutne hitrosti. To stanje lahko na splošno opišemo z vektorskim trikotnikom hitrosti, prikazanim na sliki 5, desno; sprememba β'_{11} je še vedno večja.

Na obeh omenjenih slikah so trikotniki, ki ustrezajo imenski točki, prikazani s polnimi črtami. Trikotniki, ki ustrezajo manjšemu pretoku, so prikazani s pikčastimi črtami. Očitne so spremembe vstopnega

v_{11M} and the circumferential component v_{11U}. The circumferential velocity u_{11} should remain unchanged because of the generator's uniform revolution. It should be noted that the flow change causes in change in the angle β'_{11}, i.e. the blade's angle of attack.

The blades remaining between A' and B' suffer from the change in the absolute velocity-vector direction being different ($\alpha_{11} \neq \alpha'_{11}$) for each of them. The state can be generally described by the velocity-vector triangle in Fig. 5, right; the change of β'_{11} is still greater.

In both figures the triangles corresponding to the nominal point are shown in full lines, and the triangles corresponding to a low rate of flow by dotkota β'_{11}, ki jih povzročijo spremembe sestavin absolutne hitrosti.

Če so lopatice narejene tako, da ustrezajo toku v imenski delovni točki, z ustreznim kotom β_{11}, je z vidika hidravlike vsako odstopanje iz te smeri neugodno. To povzroči hitro zmanjšanje učinkovitosti že pri majhni spremembi lege delovne točke iz imenske delovne točke.

Opisana dejstva pojasnijo vzrok za naglo spremembo učinkovitosti s pretokom pri aktivni celici Ossbergerjeve turbine, kakor prikazuje nepretrgana črta na sliki 6. Vsled pomembnega zmanjšanja učinkovitosti je moral Ossberger uvesti delni tok z dvema celicama (z razmerjem pretoka 1:2) z dvema neodvisnima krmilnima loputama, da bi dosegel delovanje v širokem razponu pretoka vode pri spremenljivih naravnih pretočnih razmerah. Učinek uporabe delnega toka in dveh neodvisnih loput prikazuje krivulja učinkovitosti. Prikazana je na sliki 6 kot črtkana črta.

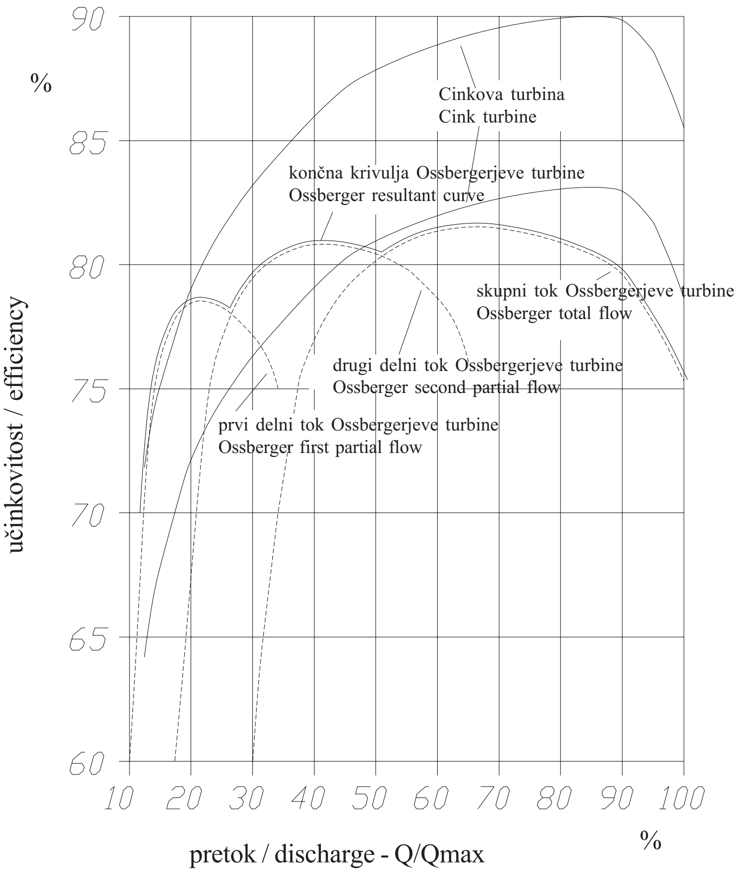
Če si ogledamo Cinkovo turbino, lahko opazimo razlog za uvedbo profilirane polkrožne lopute. Ker je prvi vstopni trikotnik hitrosti nespremenljiv (z izjemo zelo nizkih razmerij pretoka) in optimalen, se zaradi tega pojavi spremenljiva učinkovitost, ki je

ted lines. The changes in the angle of attack β'_{11} are evident, caused by the absolute velocity-component changes.

If the runner blades are designed and made to suit the flow at the nominal point with a corresponding angle of β_{11}, any deviation from this direction is unfavorable from the point of view of hydraulics. This causes a rapid decline in efficiency for very small rate-of-flow changes from the nominal point valve.

This explains the change in the efficiency with the inflow at the active cell for the Ossberger turbine, shown by the continuous line in Fig. 6. Ossberger was therefore forced to introduce a partial flow with two cells (with a flow rate ratio of 1:2) with two independent control flaps, in order to be able to work over the wide range of flow resulting from changeable natural conditions with an acceptable efficiency of the turbine. The effect of using partial flow and two independent flaps is illustrated in Fig. 6 by the resultant curve of the activity level, shown by the dashed line.

If we now take a look at the Cink turbine we can see the reason for the introduction of the profiled semi-circular flap. The first passage velocity triangle is constant (with the exception of extremely



Sl. 6. *Učinkovitost turbin*
Fig. 6. *Turbine efficiency*

odvisna od položaja lopute in prostorninskega pretoka, kar je razvidno iz črtkane površine na diagramu na sliki 6.

4 PREOSTALE RAZLIKE

Bankijeva turbina je turbina akcijskega tipa, tlak v okrovu je atmosferski. Nameščena mora biti precej visoko nad spodnjo vodno gladino, da se rotor ne dotika vodne gladine. Posledično je precejšnja izguba geodetske višine pomembna predvsem v primerih manjših višin, ki so tipične za večino izvedb.

Michell in Ossberger sta problem rešila z uvedbo cevi za podpritisk v okrovu turbine, kar turbini omogoča, da je neodvisna od sprememb spodnjega nivoja. Zato je treba na okrov turbine namestiti vzmetni ventil za omejevanje podtlaka.

Nespremenljivi premer sesalne cevi ne omogoča popolne pretvorbe hitrostne energije izstopne vode, označene kot v_{22} na sliki 2. Hitrost vode v sesalni cevi običajno znaša od 2,5 do 3,5 m/s. Če upoštevamo srednjo vrednost 3 m/s, je ustrezni dinamični tlak izražen s tlačno višino:

low rates of flow) and optimum the consequence is a tolerant surface of the change of the activity level with inflow, shown by the hatched area in Fig. 6.

4 THE REMAINING DIFFERENCES

The Banki turbine is an action-type turbine, i.e. the pressure in the casing is atmospheric. It has to be placed quite high above the lower water level to prevent the blades from touching the water. A significant loss of geodetic head results, significant in the case of low heads which are typical for most installations.

Michell and Ossberger solved the problem by introducing a tube for underpressure in the casing making the turbine independent of lower level variations. To achieve this an underpressure limiting spring operated air valve had to be installed in the casing.

A constant-section suction tube did not enable the full use of the outlet water velocity, shown as v_{22} in Fig. 2. This is approximately the velocity in the suction tube. Its value is usually between 2.5 and 3.5 m/s. If the mean value of 3 m/s is used the corresponding:

$$h_v = \frac{v^2}{2g} = 0,459\,\mathrm{m} \qquad (7).$$

To višino moramo odšteti od geodetske višine, ker ne prispeva k proizvodnji energije. Če je na primer geodetska višina 3 m, je izguba končne energije 15,3-odstotna, kar znaša 0,459 m. Zato je Ossbergerjeva turbina pri majhnih višinah zelo neučinkovita.

Cink je spremenil sesalno cev v obliko difuzorja s povečanjem prereza v smeri navzdol. Z uporabo difuznega efekta lahko izkoristimo večino izstopne energije. Če spremenimo zgoraj omenjeni primer v difuzor z izstopno hitrostjo 1 m/s, se izguba pri izstopu zmanjša na 0,051 m, kar je 1,7 odstotka geodetske višine. Na ta način je postala Cinkova turbina sprejemljiva celo za gradnje pri izjemno majhnih višinah, kar je velika prednost v primerjavi z Ossbergerjevo turbino.

5 SKLEPI

Cinkova turbina pomeni tretjo generacijo razvojnega postopka turbin s prečnim pretokom. Če jo primerjamo z Bankijevo in Ossbergerjevo turbino, pridemo do naslednjih sklepov:

Delovne karakteristike turbine

Delovno območje Cinkove in Ossbergerjeve turbine znaša 20 do 100 odstotkov največjega prostorninskega pretoka vode skozi turbino. Pri Bankijevi turbini je zaradi občutljivosti na tokovne spremembe delovno območje občutno manjše. Cinkova in Ossbergerjeva turbina sta skoraj

This head is taken away from the geodetic head, i.e. is not used for power generation. For instance in the case of a geodetic head equals to 3 m, a loss of 15,3 percent (i.e. 0,459 m) from the energy at hand results. This makes the Ossberger turbine very uneconomic at low heads.

Cink modified the suction tube into the shape of a diffuser there by increasing the section in the downward direction. By making use of the diffuser effect most of the runner outlet energy could be used. Modifying the above-mentioned example to a diffuser outlet speed of 1 m/s the outlet loss is reduced to 0.051 m making it 1.7 percent of the geodetic head. In this way the Cink turbine was acceptable even for extremly low head installations which is its great advantage over Ossberger turbine.

5 CONCLUSIONS

The Cink turbine is the third generation in the development of cross-flow turbines. By comparing it to the Banki and Ossberger turbines we can conclude:

Turbine working conditions

The working range of the Cink and Ossberger turbines is 20 to 100% of the flow through the turbine. For the Banki turbine (because of its sensitivity to flow changes) this range is considerably smaller. Cink and Ossberger turbines are nearly independent of low water level varianeobčutljivi za spremembe nizke gladine vode (difuzor oziroma sesalna cev), pri čemer je treba Bankijevo turbino dvigniti nad največjo višino spodnje vode.

Krmiljenje moči (nastavitev pri dejanskih pretočnih razmerah)

Pretočne razmere v manjših rekah se čez leto zelo spreminjajo, zato je potrebna velika prilagodljivost turbine, da bi lahko obratovala čim več ur v letu. Glede na druge vrste turbin za majhne hidroelektrarne sta Cinkova in Ossbergerjeva turbina najbolj prilagodljivi na tokovne spremembe. Pri Cinkovi turbini lahko to dosežemo z enim krmilno zanko, pri čemer sta zaradi delnega toka pri Ossbergerjevi turbini dve neodvisni krmilni zanki. V tem pogledu je Cinkova turbina preprostejša in sprejemljivejša rešitev. Najenostavnejša pa je Bankijeva turbina, ker se pretok krmili z zapornim ventilom. Vendar je pri tem treba upoštevati posledice, ki jih povzroča tovrstno krmiljenje.

Učinkovitost

Sklepe o učinkovitosti Ossbergerjeve in Cinkove turbine lahko razberemo s slike 6. Pri obeh turbinah sta največji učinkovitosti večji kakor pri drugih vrstah turbin za manjše hidroelektrarne. Če ti turbini primerjamo med seboj, opazimo razliko zaradi načina spreminjanja toka skozi turbino in zaradi uporabe difuzorja pri Cinkovi turbini. Cinkova turbina ima povprečno za nekaj odstotkov večjo učinkovitost. Tolerantno območje učinkovitosti Cinkove turbine je povezano z obstojem optimalne geometrijske oblike pretočnega trakta glede na razpoložljiv vodni potencial. Verjetno so pri Ossbergerjevi turbini razmere enake, vendar jih proizvajalec ne omenja. Zaradi preprostejšega krmiljenja toka Bankijeve turbine ne moremo primerjati z drugima dvema turbinama, saj je njeno področje delovanja veliko manjše.

Cena

Čeprav je cena odvisna od mnogih dejavnikov, je glavni dejavnik, ki določa ceno turbine, preprostost turbine. S tega vidika je Bankijeva turbina najpreprostejša in zato tudi najcenejša. Če pa bi k ceni prišteli učinke uporabe vodnega potenciala, je ta turbina s preostalima dvema neprimerljiva.

V primerjavi z Ossbergerjevo ima Cinkova turbina prednost povprečno boljše uporabe vodnega potenciala, poleg tega pa je z vidika krmiljenja preprostejša.

Omenjene prednosti turbine, ki jo je patentiral M. Cink, naredijo turbino izvirno in drugačno od njenih predhodnic (Michell-Banki in Michell-Ossberger). Zaželena je uporaba izraza “Cinkova turbina”, kajti ta izraz se uporablja tudi v tehnični zgodovini. Pomembno je namreč, da izumiteljevo ime ne bi šlo v pozabo, kakor se je zgodilo v primeru Michella.

tions (diffuser or suction tube) whereas the Banki turbine must be raised above the maximum low water level.

Power control (adjustment for natural flow conditions)

Small rivers have a very variable flow over the course of a year, which means that the maximum flexibility is required from the turbine in order that it can work as many hours in a year as possible. In comparison with other turbines, Cink and Ossberger types have the most adaptability to flow change. For the Cink turbine this can be achieved with one control laps, whereas for the Ossberger turbine there are two independent control laps (because of the partial flow). In this respect the Cink turbine is the simpler and more acceptable as a solution. The Banki turbine, with the flow controlled by a gate valve, is the simplest but with all the consequences of such control on the hydrodynamics through the turbine.

Efficiency

From Fig. 6 conclusions about the efficiency of the Ossberger and Cink turbines can be reached. For both turbines the maximum efficiencies are greater than for other types of turbines for small hydro power stations. The method of changing the flow through the turbines is different because of the use of a diffuser in Cink turbines. The Cink turbine has a higher efficiency (on average) of several percent. The area of efficiency for the Cink turbine is connected with the existence of the optimum geometry of the current apparatus according to the available hydropotential. There are probably similar conditions for the Ossberger turbine but the manufacturer does not specify them. The Banki turbine, because of the more primitive flow control, cannot be compared to be above-mentioned turbines, because it has a much lower activity level.

Price

Although the price depends on many factors, the simplicity of the turbine can be considered as the primary factor. On this basis the Banki turbine is the simplest and consequently the cheapest. However, if we build in the effects of the use of the hydropotential into the price, then this turbine, compared to the other two turbines, becomes uncompetitive.

Comparing Ossberger and Cink turbines we can conclude that the Cink turbine has the advantages of (on average) better hydropotential use, and simplicity in terms of control.

The advantages of the turbine patented by M. Cink make the turbine original and different from the previous types (Michell-Banki and Michell-Ossberger). The author feels it is right to use the term “Cink turbine” as it is clear that the turbine will be known by this name in technical history. There is also another reason. The name of the inventor should not get lost as happened with the name Michell.

6 SIMBOLI
6 SYMBOLS

specifična energija	Y	J/kg = m^2/s^2	specific energy
obodna hitrost	u	m/s	tangenential velocity
absolutna hitrost	v	m/s	absolute velocity
relativna hitrost	w	m/s	relative velocity
hitrostna višina	h	m	velocity head
težni pospešek	g	m/s^2	gravity
moč	P	W	power
prostorninski pretok	Q	m^3/s	volume flow rate
gostota	ρ	kg/m^3	density
absolutni kot	α	-	absolute angle
relativni kot	β	-	relative angle

Indeksi		**Subscripts**
število pretočnih poti	prva št. / first No.	number of flow path
vstopne (1) in iztopne (2) razmere rotorja	druga št. / second No.	rotor inlet (1) or outlet (2) condition
rotor - teoretično	rt	rotor - theoretical
projekcija na obodno hitrost	u	projection to circumferential velocity
največja vrednost	max	maximum value
hitrost	v	velocity

7 LITERATURA
7 REFERENCES

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