Tidal Power as Basis for Hydrogen Energetic.

Victor M. Lyatkher, Doctor of Science, Professor
New Energetic LLC, Elegazservice LLC, Russia, Clean Energy Co., Inc., USA.
E-mail: anlyatkh@megsinet.net (USA), anlyatkh@online.ru (Russia)

ABSTRACT:

It is shown the relations to estimate maximum of capacity and power that may be transformed from the tidal in closed basin. Using these relations is estimated the word power from tidal and volume of the annual producing hydrogen liquid or gas. It is enough to change the power situation in the Word. The new technology of the tidal power and hydrogen manufactures construction, produced liquid hydrogen with low cost and low initial investment, is described. To converse the power from tidal flow may be used the new floating orthogonal turbine. The tidal power station with these power units will not be so expensive as other modern kinds because we do not need to cross the entrance of a gulf – the power unit converses flow power without a dam. We do not need to invest too much money, because the power out put and hydrogen manufacturing may be go up step by step – from one block to another, but we will refund the investment very fast – immediately after the first block will go on. The produced hydrogen will keep in storage and delivery to the industrial centers by the ships or by the refrigerated glass pipe lines. Tidal power stations with these units have no environmental problems.

KEYWORDS: tidal power, hydrogen production

To produce the hydrogen as fuel for cars and electric power plants the best source may be the tidal power plants (TPP) with new technology and equipment. The traditional tidal power plants, which provide for the building of dams, complete cutting from the sea of the bay being used and creation of one or several energy basins, have four fundamental drawbacks restraining until now the development of this branch of power engineering.

1. All projects provide for the building of the closed head front of TPP, the dams and other hydraulic structures which cut off the TPP basin from the sea. The existence of such front noticeably changes the ecological situation in the basin.
2. The maximum power, which can be issued by TPP, is determined by the flow regime, the basin configuration and the TPP design. In any event it varies in the time from maximum to zero attainable twice in 24 hour period.
3. The heads at TPP are not large, the traditional hydropower equipment is expensive and production is relatively small. The cost of TPP building and head front constructions designed for gale oceanic wave and heavy ice load is great. This determines large building terms, high capital investments per unit of the installed capacity and relatively high prime cost of energy.
4. The existence of head front determines the unfavorable regime of object financing – it is necessary to completely finish the building (completely pay for all the works) and only after this the station begins to generate the energy and return capital investments.

Another approach to TPP designing, which is free from mentioned drawbacks, is proposed [1]. The main distinctive feature of the proposed approach consists in the use of free tidal flows in those parts of the water area, where the absolute values of these flows speeds are maximum. TPP in our proposal consists of the stationary or floating, fixed at the bottom, underwater (in the regions with heavy ices) hydropower units, which convert tidal flow energy into the electric power and further into gaseous or liquid hydrogen, in the case if the direct issuing of electric power is impossible or economically inexpedient**.** *There is no need to completely cut off the estuary of the basin and create the head front for complete utilization of tidal flows energy*. **The highest possible power and power production is obtained in the case of well-defined hydraulic resistance brought in by the turbines which are installed at the entrance into the TPP basin (in its narrowest part) [2]. The selection of the installed capacity of TPP is a technical and economic task.** *The distinctive feature of our proposal consists in the fact that TPP power can have any value, that corresponds to the financial possibilities of investor but is smaller than the limiting maximum value determined by hydrological and topographic conditions.*

Hydropower units can have various construction. They can be located freely in the form of the simplest complex “hydroturbine+generator” or as a part of power unit. It is important that there is no need to completely cut off the estuary of the basin for complete utilization of tidal flows energy.

In the general case the energy efficiency of tidal basin of the area Ω at the rise of tide A and period T is determined from the formula

$$P = C\,\Omega A^2/T \qquad (1).$$

Here by symbol P the installed capacity of TPP or its average annual value, which determines the production of the station, can be denoted. In [2] it is shown that maximum power and maximum power production in the case of the fixed basin area Ω and fixed height of tidal wave A at the approach to the basin has place in the presence of particular value of dimensionless parameter

$$X \equiv \alpha = [\Omega/\Omega_p]^2 \xi A/4gT^2 \qquad (2).$$

Here Ωp is the cross-sectional area of the channel or the strait, where power units are installed (or the summary cross-sectional area of turbine paths in case of traditional TPP composition), ξ is the coefficient of the hydraulic resistance of turbine path,

$g = 9.8$ m/s^2 is the acceleration of gravity, T is the period of tidal wave.

The maximum power and power production of tidal power station (fig.1) is obtained with

$$\alpha = 0.03 \div 0.04 \qquad (3).$$

In this case the coefficient C in (1) for the limiting maximum power is equal to

$$C = C_{max} = 7.27 \qquad (4).$$

For the average power, which determines maximum production,

$$C = C_{average} = 2.82 \qquad (5).$$

The relative time of usage of the installed capacity $\tau = 0.388$.

At that the amplitude of the water level fluctuations in the basin amounts approximately 78% of the amplitude of the sea level fluctuations and phase shift φ is determined by the equality

$$\mathrm{Cos}\ \varphi = 0.67 \qquad (6).$$

The tidal regimes in the sea $z_0(t)$ and in TPP basin $z(t)$ are periodical:

$$Z_0(t) = A\ \mathrm{Cos}\ (2\pi t/T)\ /2\ , \qquad z(t) = A\ z_m\ \mathrm{Cos}\ (2\pi t/T - \varphi)\ /2$$

Here: A – tidal range, T- tidal period.

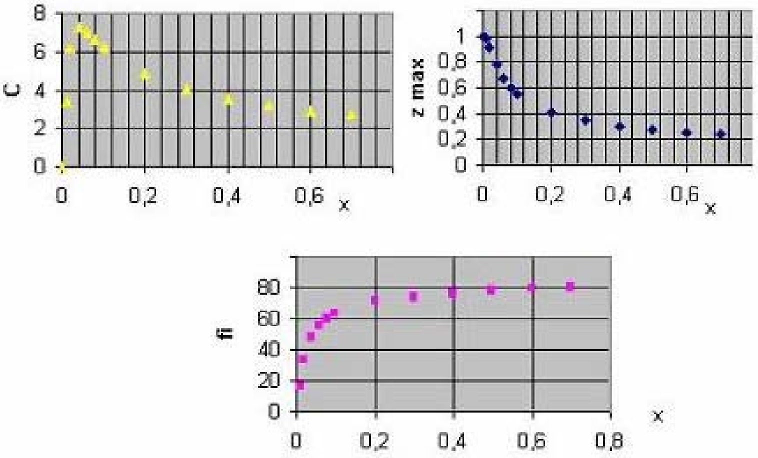


Fig.1. The tidal parameters in the basin of TPP

Depending on the adopted lay-out diagram of TPP and the selected type of hydropower units the parameters, which are included in the formula (2), can change, however, for ensuring the maximum power and power production their combination must give the value defined by the relation (3). If the area of the basin is measured in km^2 and the period of the flow is taken such that in the course of twenty-four hours there would be 3.87 half cycles (tidal period T=12.4 hours), then in case of measurement of rise of tide A in meters the formula (1) takes the following form.

The maximum (installed) capacity of TPP

$$P_{max}\ (kW) = 163\ \Omega(km^2)\ A^2(m^2) \qquad (7).$$

The maximum average power of TPP

$$P_{average}\ (kW) = 63\ \Omega(km^2)\ A^2(m^2) \qquad (8).$$

The maximally possible average annual power production

$$E\ (MWh) = 552\ \Omega(km^2)\ A^2(m^2) \qquad (9).$$

The maximum value of rise of tide should be inserted in the formula (7) and in the formulas (8) and (9) – the average root-mean-square value.

The tidal is irregular process, but approximately it may be presented as the sum of the moon and sun influential. The relation of the amplitudes of these two components is 2.17 about. Because maximum and minimum of the tidal amplitudes may be estimate as follow

$$A_{max} = A_0(1 + 1\ /2.17) = 1.46\ A_0 \qquad (10)$$

$$A_{min} = A_0(1 - 1\ /2.17) = 0.54\ A_0 \qquad (11),$$

Here $A_0 = 0.685\ A_{max}$ – the tidal height acted by the moon.

The root mean square of the tidal's height, determined the possible power output of a tidal power plant must calculate by real information of tidal regime. Approximately from (10) and (11) follow:

$$A_{averaged} = \sqrt{}\ (A_{max}^2 + A_{min}^2)/2 = 1.1\ A_0 = 0.754 A_{max} \qquad (12)$$

Or $\quad A_{max} \approx\ 1.33\ A_{av} \qquad (13)$

Using (13) it may be rewritten (7) and (9) in the same forms included averaged (mean) tidal range A_{av}:

$$P_{max}\ (kW) = 288\ \Omega(km^2)\ A_{ay}^2(m^2) \qquad (14)$$

$$E\ (MWh) = 552\ \Omega(km^2)\ A_{av}^2(m^2) \qquad (15)$$

In reality the energy from TPP can be received only in the case, when the water level in the basin differs from the sea level. Our results reflect this condition. These estimations are thru, if the power basins have a regular form about circle with one narrow water entrance-exit.

In other limited situation the basin would be as a channel (for example, Strait of Uldolmok in Myongyang Channel , South Korea). The flow in this channel is the function of difference of the water elevation between the inlet and outlet of channel. The power N_0 lost by the flow under everyday conditions at the moment of maximum of flow speeds (when $\partial U_0/\partial t = 0$) is determined by the following expression (per unit of water discharge):

$$N_0 = \rho g \Delta H = (\lambda L/R + 1)\rho U_0^2/2 \qquad (16)$$

Here λ is the reduced factor of the hydraulic resistances of the channel, L is the length of the channel, R is the hydraulic radius of the channel.

After the building of power station in one of the sections of the channel the water discharge through the channel will change and the flow speed at the approach to the power site will take on a value U less than U_0. Assuming that the dropping between the ends of the channel ΔH caused by external causes remains constant, let us rewrite the equality (16) with the introduction of the concentrated pressure drop Δp (power loss of the flow) at the power station:

$$(\lambda L/R + 1)\rho U_0^2/2 = \Delta p + (\lambda L/R + 1)\rho U^2/2 \qquad (17)$$

The pressure drop and the change of flow strength in the channel before and after the building of power station are connected as following:

$$\Delta p = (\lambda L/R + 1)\rho(U_0^2 - U^2)/2 \qquad (18)$$

The power P withdrawn in the entire water flow by section Ω passing through the power station comprises:

$$P = \Delta p U \Omega = (\lambda L/R + 1)\rho U(U_0^2 - U^2)\Omega/2 \qquad (19)$$

In order to find the maximum value let us equate to zero the derivative of the right side of expression (19) by the parameter U:

$$\partial P/\partial U = (\lambda L/R + 1)\rho(U_0^2 - 3U^2)\Omega/2 = 0 \qquad (20)$$

Thus the withdrawing power is maximum, if

$$U = U_0/\sqrt{3} \qquad (21)$$

Under this condition the value of the maximum withdrawing power is equal to:

$$P_{max} = (\lambda L/R + 1)\rho U_0^3 \Omega/3\sqrt{3} \qquad (22)$$

The relative value of maximum power which can be withdrawn in the flow in the channel (in fractions of initial maximum power) comprises

$$P_{max} / N_0 U_0 \Omega = 2/3\sqrt{3} = 0.385 \qquad (23)$$

Or

$$P_{max} = 0.385 \rho g \Delta H U_0 \Omega \qquad (24)$$

This result is fundamental estimation free from specific hypotheses.

The stated principle of TPP designing and building can be efficiently realized, in particular, with the use of the orthogonal turbines according to the Russian patent of the author No. 2242634 (13) C1 with the priority of 05 May, 2003.The idea of this turbine consists in the use of pull force of the wing flowed around with the attack angle smaller than the critical one (that is common for orthogonal turbines), but at that owing to the relatively large diameter of blades route the recovery of flow energy at the approach to the rear order of the blades takes place and the effectiveness of turbine turns out to be above usual one. The turbine consists of two (or more) ring hollow rotors (fig. 2) in the form of regular polygons or tores located one above another and moving towards each other, on which the blades of aerodynamic profile, oriented in opposite directions, are vertically fixed. The upper ring rotor, which carries the inductors of linear generator, is connected by the stretchings with radial thrust bearing, located at the top of the hollow central pylon. The lower hollow ring rotor, which carries a strip from current-conducting material and magnetic core and has the excessive buoyancy, is pressed to the upper ring rotor owing to the excessive buoyancy and the electromagnetic interaction of the inductors and the magnetic core. In other variant the motionless inductor of linear generator may be located between the rings. *The use of such very turbine in the proposed approach is not the only possible one, however, the installation of type under study has the following advantages over other known schemes:*

- The counter rotation of rotors releases the central pylon from the torque, developed by the blades, and ensures the mutual compensation of transverse forces, acting on the rotors; that reduces the summary load on the central pylon, decreases the specific consumption of materials and increases the reliability of the installation.
- The counter rotation of rotors, each of which bears the blades, oriented in opposite directions, ensures high relative speeds between the inductors of linear generator and the conducting plate; that reduces the mass of inductors and increases the efficiency of the installation.
- The counter rotation of rotors releases the central pylon from the torque, developed by the blades, and ensures the mutual compensation of transverse forces, acting on the rotors; that reduces the summary load on the central pylon, decreases the specific consumption of materials and increases the reliability of the installation.

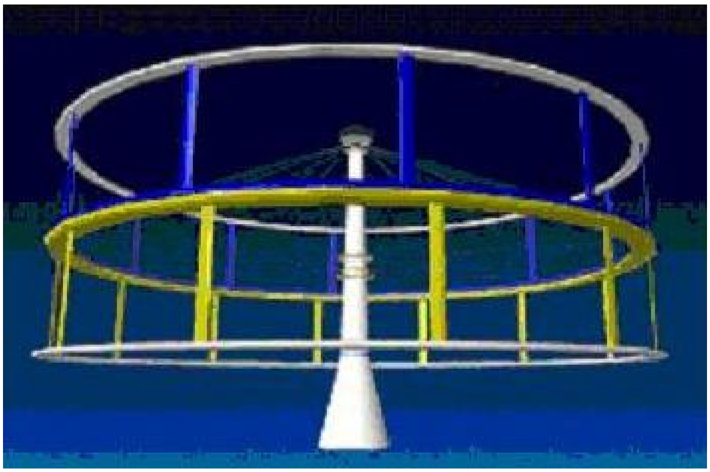


Fig 2 General view of the orthogonal multiblade power unit. The top of the central pylon is located at the level of the upper rim but under the lower edge of ice.

- The combining of the inductors into the units with different rated speeds of armature allows to begin to use the energy of flows from relatively small values of flows speed and ensures high energy effectiveness of installation in the entire significant range of changes of flows speed due to the optimum selection of rotational speed of rotors for each range of changes of flows speed.
- The control of circulation on the blades allows to enlarge the range of flow speeds, which correspond to the maximum efficiency, and owing to that enhance the power production and increase the effectiveness of the installation.
- The installation does not influence on the ecological situation in the basin – the distance between the blades is great and their speed of motion is small (only 2-3.5 times more than the flow speed). Fish have the opportunity to pass freely through the installation or go around it.
- In case of need the spatial arrangement of installation can be changed both by the depth and in the plan. The installation can be manufactured in the dry dock, delivered or towed to any given place and installed there with minimum installation works.
- The power production of the installation is determined by the regime of the flows speeds regardless of their direction. Under the conditions of stable flows typical, for example, for the straits of Cook Inlet, Gulf Stream or Southern Kuriles ridge, the total hours of utilization of the installed capacity per year can reach 6000-8000 hours, while under the conditions of tidal flows in case of optimum project it can reach 3400 hours per year.
- In connection with exceptional simplicity of construction the cost of the installed kilowatt in case of calculated flow speed of 3 m/s for the units of average capacity of about 2-5 MW or more is evaluated within the limits of 500 – 600 dollars/kW in case of manufacturing of 10 and more sets. The expedient capacity of one unit amounts from 2 to 75 MW.
- The installation practically does not have the wear parts. Its operation life is determined only by the processes of corrosion and/or fouling by microorganisms. Both these processes can be controlled by contemporary technologies.

The torque developed by the blades on the upper and lower rings of the power unit during the work must be identical. Practically this is achieved by the fact that the absolute speed of the upper ring increases and of lower ring decreases (with the maintaining of the relative speed of rings) with the corresponding decrease of the torque on the upper ring and increase of the torque on the lower ring till their alignment.

The turbine power P depending on the speed of the incident flow U and the linear speed of blades V can be represented in two forms:

$$P = C_p \rho U^3 A_t /2 \qquad (25)$$

$$P = C_N \rho V^3 A_t \sigma /2 \qquad (26).$$

Here $A_t = D H$ is the area of the axial section of the figure swept by the blades, $(A_t \sigma)$ is the area of the median (chord) surface of working blades, $\sigma = ib/D$ is the turbine solidity, i is the quantity of the blades in one tier, b is the blade chord. Presentation (25) is traditional one, presentation (26) is introduced by the author for describing the asymptotic properties of orthogonal turbines characteristics. The efficiency factor C_p and the power factor C_N, which depend on the outlines of the turbine and the correlation of speeds V/U, are connected by the identity

$$C_N = C_p (U/V)^3/\sigma \qquad (27).$$

The overall sizes of installation are determined by the design flow speed. At flow speed of 2 m/s the energy flow density amounts 4 kW/m^2 and in case of hydropower unit effectiveness of 50% the necessary cross section amounts 0.625 m^2 per kW of required power. For example, for obtaining of 1000 kW the cross-sectional area of installation A_t= 625 m^2 is necessary. The blades height (length) is determined according to the minimum depth of the flow taking into account the reliable lowering of the upper point of installation under ice. All basic units of the proposed installation were tested experimentally. Under one and the same boundary conditions the form of the turbine – blades and traverses quantity and form of section, flow speed and turbulence – has a great impact. The energy effectiveness determined on the large hydraulic model (fig. 3), which reproduced both tiers of blades but without the opposing motion, proved to be noticeably higher than 50% (fig. 4).

Fig. 3. The model of multiblade rotor in the hydraulic channel.

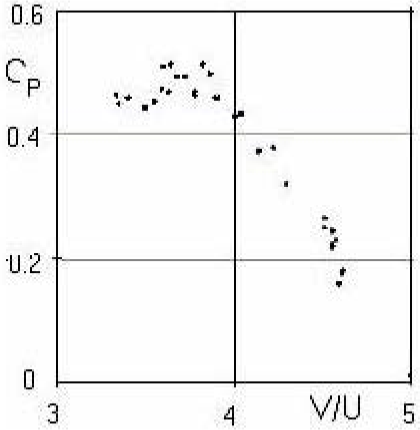


Fig. 4. The efficiency factor of rotor of multiblade hydropower unit according to the test data in the water tunnel. The diameter of rotor is 3.34 m in the channel with the width of 6 m and the height of 2.5 m. Blades height is 0.72 m, chord is 0.12 m, solidity 0.22.

According to the calculation and test data the power factor C_N is approximately described by the linear function (fig. (5)

$$C_N = B\,(U/V - B_0), \text{ if } B_0 < U/V < 1 \qquad (28).$$

Thus the energy characteristic of the turbine can be approximately specified only by two parameters B and B_0. Parameter $1/B_0$ is the maximum relative speed of the blades, reached by the turbine without braking,

$$n_{max} = 60U/\pi DB_0 \text{ (rpm)} \qquad (29).$$

According to the data of fig. 5 for the model of the proposed hydroturbine

$$B = 0.55,\ B_0 = 0.205 \qquad (30).$$

The power output of the turbine depends on the rotational speed and the flow speed

$$P = B\rho\pi^2 D^3 H\sigma n^2 (U - B_0\pi Dn/60)/\ 7200 \qquad (31).$$

The maximum power P_{max} will be in case of optimum rotational speed n_{opt}

$$n_{opt} = 2/3\ n_{max} = 40U/\pi DB_0 \text{ or } V_{optimum} = 2U/3B_0 \qquad (32),$$

$$P_{max} = C_{Pmax}\ \rho\ U^3 A_t/2\ ,\ \ C_{Pmax} = 4B\sigma/27B_0^2 \qquad (33).$$

All basic design features of the power unit except the counter rotation of different tiers were reproduced at the hydraulic model. In particular, the linear generator for power output was reproduced.

The described version of orthogonal turbine is the best, but not the only possible one for implementation of the general idea of the use of tidal flows energy. Within certain limits the construction schemes of «helicoid turbines» (V.M. Lyatkher, I.V. Semenov – certificate of authorship of USSR №1150395 with the priority from 17.01.1983, A.M. Gorlov, Patent of USA 5451137, 19.09.1995,), which ensure self-starting and the torque constancy, Davis turbines and any other the turbine blocks can be used. The drawbacks of these solutions are noted above. However in principle all these solutions are applicable, but according to the proposed idea these turbines or turbine blocks should not necessarily completely cut off the estuary of the used basin! To day any professionals begin to understand these general ideas and to construct the new kind tidal power plants without the dams using the usual propeller turbines – generators on the pillars, fixed on the bottom, or swimming (Hammerfest Strom Co., Marine Current Turbines Co., SMD Hydrovision with TidEl technology and other).

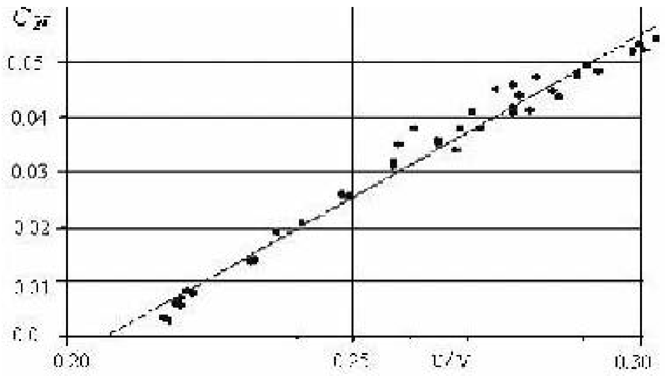


Fig. 5. The power factor of the multiblade turbine C_N in the function of the relative flow speed.

The proposed turbines as well as any other orthogonal machines are highly effective only in case of specific correlation of the flow speed and the blades speed. The speed of the tidal flow continuously changes. Therefore it is necessary either to change the turbine rotation speed or select this speed as a constant one, which ensures the maximum production.

It may be shown [1], that for periodical tidal with maximum speed of flow U_m
The maximum value of power from one speed our new orthogonal turbine will be with
optimum speed of the blades motion

$$V_{optim} = 0.57\ U_m/B_0 \qquad (34).$$

For our experimentally studied turbine $B_0 = 0.205$ and

$$V_{optim} = 2.78\ U_m \qquad (35).$$

For helicoid three-bladed turbine with the solidity $\sigma = 0.41$ and the blades profile NACA 0020 in the best layout the parameters have the following values (our processing of A.M. Gorlov's experiments) $B = 0.60$, $B_0 = 0.34$, $Cp\ max = 0.35$.

In this case the optimum speed of blades motion of one-speed turbine amounts

$$V_{optim} = 1.7\ U_m \qquad (36).$$

At that in any version the average power will have the maximum value equal to 0.378 from the maximum power of the turbine, which is possible in case of the given maximum flow speed. If the rotational speed of the turbine was not constant, but varied in proportion to the flow speed with retention of the maximum effectiveness of the turbine, then its average power would amount 0.42 from the maximum value. Thus in case of accepting the constant rotational speed we lose approximately 10% of possible power production. With the use of two-speed generator this loss can be decreased approximately 2 times.

The power production of the installation is determined by the regime of the flows speeds regardless of their direction. Under the conditions of stable flows typical, for example, for the straits of Southern Kuriles ridge or Shantarskiye Islands, the total hours of utilization of the installed capacity per year can reach 6000-8000 hours, while under the conditions of tidal flows in case of optimum project it can reach 3400 hours per year.

In connection with exceptional simplicity of construction the cost of the installed kilowatt in case of calculated flow speed of 3 m/s for the units of average capacity of about 2-5 MW is evaluated within the limits of 500 – 600 dollars/kW in case of mounting of 10 and more sets. The installation practically does not have the wear parts. Its operation life is determined only by the processes of corrosion and/or fouling by microorganisms. Both these processes can be controlled by contemporary technologies.

Such hydropower units are installed in the strait, which connects the basin with the sea, where the flow speeds are sufficiently great. The optimum flow speeds for the proposed units vary from 2 to 4 m/s. If such speeds are not reached in the natural conditions, the preliminary or subsequent contraction of the strait by the coast dams or the ground enrockment is possible.

The proposed units can be produced in the dry docks of industrially developed centers and transported afloat as a whole or in partly assembled form to the site of installation. The expedient capacity of one unit amounts from 2 to 20 MW. The maximum quantity of units in one strait, which determines the maximum total power of TPP, is found from condition (3), (14) or (24). If the section of the strait is completely occupied with the proposed turbines, then according to the tests the coefficient of hydraulic resistance can be taken as $\xi = 1.3$. The proposed floating hydropower units installed in one row across the strait in many instances do not ensure the optimum value of parameter α and do not enable to obtain the maximum energy-conversion efficiency from the basin under development. In such situation the turbines should be installed in several rows located from each other at a distance sufficient for restoring the normal velocity field. This solution is also useful for retaining the ecological clearness of the object. Comparatively slowly moving blades of the turbines, mounted in the machines sufficiently sparsely, are not dangerous for the fish, but the presence of tranquil flow zones between the rows of the turbines can be useful for the rest of the fish and does not require additional material expenditures.

The proposed solution can be used for any basins.

For example, the Bay of Fundy is one of the best places in the world for using the energy of flows, whose height here reaches the record values of 18 m. Many projects of tidal power plants (TPP) worked out for this

region during past 100 years are known. One of them for the capacity of 20 MW in the region of Annapolis Royal was even implemented.
For Cobequid Bay, whose surface area is 264 km^2, the average rise of tide is 11.8 m, the width of the strait between the Ekonomi and Tenni capes is 8 km, the depth (maximum) is 42 m, the parameter α approximately amounts 1.6 10^{-4}. The maximum flow speed in the natural conditions should be about 0.75 m/s. In order to approach the optimum value of α, it is possible, for example, to decrease the width of the channel up to 2 km and install the turbines in 12 rows. In this case $\alpha = 0.031$, the possible capacity of TPP approaches to the maximum value equal to

$$P_{max}\,(kW) = 163x264x\ 11.8^2 = 6\ GW,$$

and the annual output will approximately amount 20 TWhr. In Canadian project of 1982 the capacity of this TPS in traditional assembling was determined as 4 GW and the production as 12.26 TWhr.

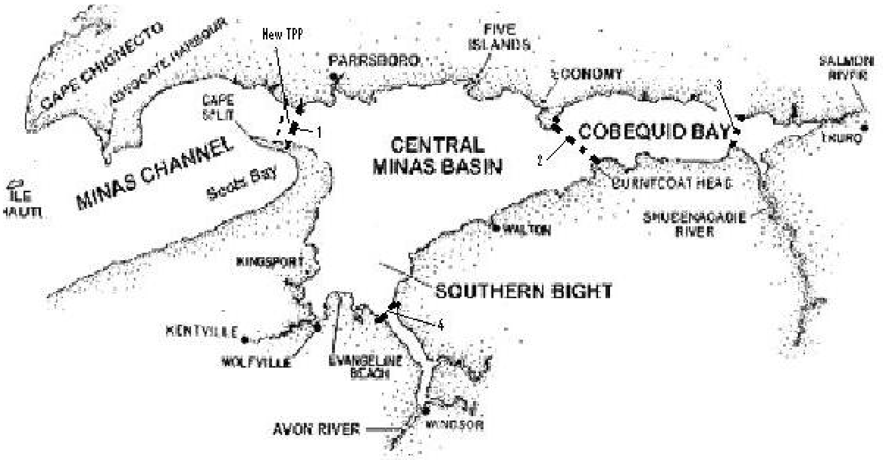


Fig. 6. The tidal power station in the eastern part of Bay of Fundy (Minas Basin) in Split cape site. The width of the strait in TPP site is 6 km (between Partridge island opposite Parrsboro city and Blomidon cape – 5 km), the area of Minas basin is 1150 km^2, the maximum rise of tide is 16 (18) m, the average rise of tide is 11.8 m. The maximum power of TPP is 48 GW, the maximum average annual production is 89 TWhr/yr. 1 – the site of the units of the proposed large TPP. 2-4 possible TPP to produce basis power.

The proposed hydropower units in case of flow speed of 3 m/s and overall sizes of 48x24 m^2 can have capacity of about 8 MW each. 60 – 70 such units can be installed in one row. Their total capacity will amount 5760 – 6720 MW. It would be expediently to begin the implementation of the proposed approach in Canada not from such major projects, which require specific construction work (contraction of strait by the dams), but from more modest scales. It is proposed to arrange the first experimental-industrial units in the bay near Saint John. The assembling of serial production can also be arranged there. The following serious step is the arrangement of the units with capacity of 20 MW, the diameter of 48 m and the calculated flow speed of 4 m/s in the Split Cod region, opposite Parrsboro city in the strait, which connects Minas Basin with the Bay of Fundy (fig. 6). In this site, where in the everyday conditions the maximum flows speeds reach 4 m/s, 100 power units with total capacity of 2000 MW can be installed in one row practically without the additional construction work. Specific capital investments into this TPP will not exceed 600 US dollars per kW of the installed capacity in case of 5.5 thousand hours of usage per year. In succeeding years it is possible to increase the capacity of TPP up to the maximum value of 48 GW, determined according to (7), with a certain decrease of total hours of utilization of this capacity – the production up to 89 TWhr per year.

Favorable conditions for the building of TPP according to the proposed scheme exist in the bays of northern and west gulfs of Australia. For example, in the straits of Van Dienen Gulf, located near Darwin town, may be constructed TPP with installed capacity 84.7 GW and annual output about 163 TWhr per year. In Derby Bay capacity TPP may be up to 14.4 GW and out put 27.6 TWhr per year.

Good conditions for the building of TPP according to the proposed scheme exist in the bays of West seas of India. In the Gulf of Kutch with square of basin 170 km^2 and mean tidal range 5 m (maximum 6.6 m) the tidal power plant can have the maximum capacity of 1.2 GW with the production of 2.3 TWhr per year. In the Gulf of Khambat (area 1970 km^2, mean tidal range 7 m) maximum capacity of TPP may be 27.7 GW, annual power output – 53.3 TWhr per year.The tidal range in New Zealand varies from place to place; for example, at Wellington the maximum range is 1.35 m only, while at Auckland it is more 3.6 m (mean 2.7m). On the Manukau Harbor of Auckland (fig. 7) is the good conditions to construct the tidal power plant with new technology. The installed capacity of this plant without a dam may be up to 1.3GW and annual power output about 2.6 TWhours. We proposal to begin the installation in this bay the floating power units with capacity 20-30 MW and power output about .50÷100 GWhours per year each. The numeral of these units will be determined by the investment possibility. The plant capacity (and the investment) may be increase step by step – from one power block to another. The first testing plant may be constructed in the narrow channel leading into Tasman Bay between D'Urville Island and the mainland of South Island. The currents here reach speeds up to 3.5 m/sec, and the cost of the power would be the cheapest. Tidal currents in Cook Strait are particularly interesting. High water on the North Island side of the strait occurs five hours before high water on the opposite side, which means that when it is high tide on one side it is almost low tide on the other

Fig. 7. TPP without the dam near Auckland. 1- TPP general, capacity up to 1.3GW, 2-3 – possible TPP to produce the basis power

This difference in sea level across the strait gives rise to strong tidal currents. The speed and duration of these currents are made quite variable by the heavy gales which are often encountered in this area and by other meteorological conditions. Particularly strong tidal currents which reach velocities of 2.5 to 3 m/sec are found off Cape Terawhiti. In the other side, the difference of the tidal regime may be used to receive the basis component in the total tidal power – when one plant will stay, the other will generates maximum capacity. Favorable conditions for the building of TPP according to the proposed scheme exist in the bays of northern and east seas of Russia. In Tugurskaya Bay (fig.8), where the rise of tide reaches 10.1 m, the tidal power station can have the maximum capacity of 19.4 GW with the production of 48 TWhr per year. Hydrological conditions there are sufficiently favorable – everyday speeds exceed 2 m/s. The first experimental units with high economic effectiveness can be arranged in Lindgolm Strait (fig. 8), where the measured natural flow speeds exceed 4 m/s. Very tempting conditions exist in the northern part of Penzhinskaya Bay with the area of 5650 km^2 (fig. 9), where the large and very effective TPP of the proposed type can be arranged between Elistratov and Mametchinskiy peninsulas without the changes of the ecological regime of the sea and conditions of navigation. Penzhinskaya Bay is relatively narrow water basin, which juts into the continent by 306 km, its average width is about 63 km. The narrowest place of the bay – narrow entrance to bay – stretches in the length on 7 km with the width of approximately 26.5 km. The tidal wave entering into Penzhinskaya Bay from the Sea of Okhotsk considerably increases. In the apex of the bay the magnitude of tide reaches 13.4 m, that is the maximum value in Russia and the second largest value in the world after the Bay of Fundy. In the quadrature the maximum flow amounts about 5 m, thus the root-mean-square value of rise of tide approximately amounts 10 m.

Fig. 8. The tidal power station in the narrowness of Tugursky Bay. The width of the strait is 15 km. The maximum rise of tide is 10.1 m, the average rise of tide is 8.6 m.. The area of the exploitable par of the bay is 1400 km^2. The maximum possible power of TPS is 19.4 GW. The maximum average annual production is 48 billion kwhr/yr. 1 – the site of the units of the proposed TPP, 2 – zone of arrangement of the first pilot unit of large capacity. 3 – possible TPP to produce basis power.

According to the formula (7) the maximum installed capacity of TPP corresponding to the maximum rising tide can be 165 GW, and the average annual production, calculated according to (9) for the root-mean-square rise of tide, will amount 312 TWhr/yr. For conditions in question the turbine was drafted according to the scheme of fig. 1 with the length of the blades of 12 m and the diameter of the blades route of 100 m. These turbines with the height of approximately 30 m (including lower pontoon) are installed at the different depth of flow with the shifting along and across the flow for ensuring the freedom of maneuvering during assembling and repairs (fig. 10). With calculated flow speed of 4.8 m/s the power of one turbine is about 75 MW, the power of one conditional block, which occupies the total depth of the flow amounts from 300 to 75 MW for the depths from 120 to 40 m. The coast sections of the strait with the depth less than 40 m remain free for navigation and are used for the energy purposes in last turn. In one site by the width of the strait up to 100 units of TPP of total capacity near 20 GW are installed. Eight or nine such sites are installed along the length of the strait at the distance of approximately 1 km one from another, forming the total capacity of TPP of approximately 160-180 GW. The average annual production of this TPP is expected not less than 312 TWhr/yr. The boundaries of turbines location are marked by the pneumatic screens creating the local inclinations of free surface of water, which impede penetration of ships and large fishes into the turbines zone. The prime cost of energy of TPP under the conditions in question will not exceed 0.002-0.005 $/kwhr**.** For the filling of power dips of off-system individual tidal power station the integration of tidal power stations of the proposed type with the tidal power station of the traditional type, whose power is proportional to rise of tide at the given moment, can also be used [3**].** All elements of the proposed unit are individually studied and tested in the experiments. The designing and manufacturing of demonstration experimental-industrial model with real capacity, for example, of 10-50 MW is of current importance.

Hydropower units are installed in the strait, which connects the basin with the sea, where the flow speeds are sufficiently great. The optimum flows speeds for the proposed units vary from 2 to 4 m/s. Such speeds in the tidal flows are observed in many places of the straits of many Countries.

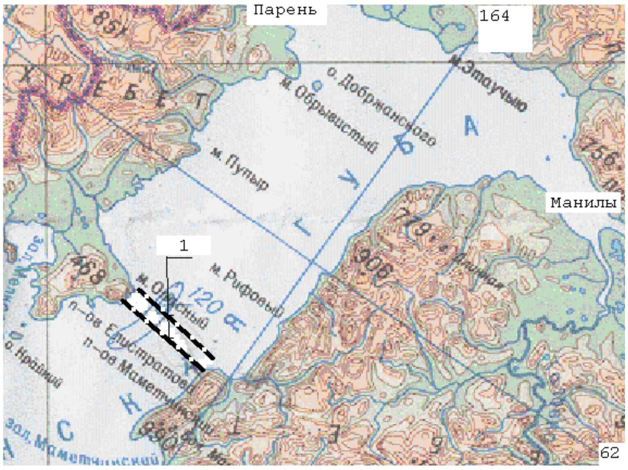
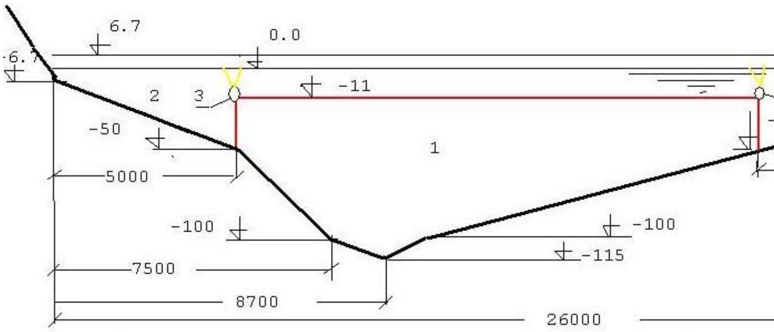


Fig. 9. The tidal power station in the northern part of Penzhenskaya Bay. The area of the basin is 5650 km^2, the width of the strait in TPP site is 26.5 km, the maximum rise of tide range is 13.4 m, the average range of tide is 10 m, the maximum power of TPP is 165 GW, the maximum averaged annual power output is 312 TWh/yr. 1 – the site of arrangement of the units of the proposed TPP.



a)

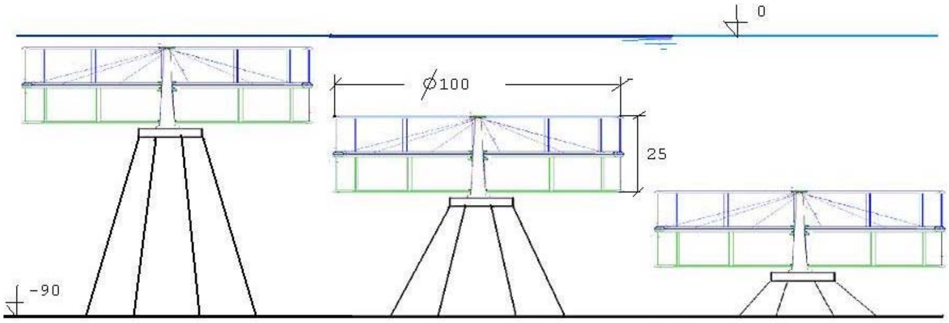


Fig. 10. The conditional cross section (a) and the unit of the turbines (b), located in the deep section of TPP site. The power of unit is 225 MW. 1 – zone of TPP units, 2 – navigation area, 3 – pneumatic enclosure of TPP.

The proposed scheme of tidal power station with the new units is highly economical and very effective in respect of execution of works and capital investments. However, it is not free from the changeability of the issued power in the time depending on the regime of tidal flows. This drawback can be removed by electrical integration of separate TPP of the proposed type installed in the zones of tidal flows with phase displacement. In spite of severe ice conditions TPP under consideration with the units of new type can be very effective.

In Nature this phase displacement. may be for the long distance points only. More general solution is follow: at the small bay locates the TPP with maximum capacity and the power's phase late 4.65 hour from the tidal level maximum. At the nearest large bay locates the other TPP with the same capacity, but relatively smaller possible capacity in this place. The phase of the power of this plant will be equal phase of flow (3.1 h from maximum tidal level) about. The total power of these plants will have the large constant component. These two different TPP may be located in the narrows of one large basin (figs 6&7). It will be efficiency because the most difference of the tidal range in the sea and basin would not more 22%, but phases difference will be 48 degree and more (fig.3). The total power of these two TPP with described new multiblade orthogonal units is

$$P_\Sigma = P_0(t) + P_i(t), \qquad (37)$$

here $P_0(t) = 0.55\,(0.36\left|\mathrm{Sin}\,(2\pi t - \varphi_0)\right| - 0.205)\{A_t\, \sigma\, \rho\, V^3\}_0 /2$, если $0.57 < \left|\mathrm{Sin}(2\pi t - \varphi_0)\right|$ (38)

$P_0 = 0$, if $0.57 > \left|\mathrm{Sin}\,(2\pi t - \varphi_0)\right|$

$P_i(t) = 0.55\,(0.36\left|\mathrm{Sin}\,(2\pi t - \varphi_i)\right| - 0.205)\{A_t\, \sigma\, \rho\, V^3\}_i /2$, если $0.57 < \left|\mathrm{Sin}(2\pi t - \varphi_i)\right|$ (39)

$P_i = 0$, if $0.57 > \left|\mathrm{Sin}(2\pi t - \varphi_i)\right|$

The long time the sum (37) may be more the fixed numeral for different conditions.

For example, in distance about 10 km from Reykjavik (Iceland – fig.11) locates the bay Hvalfjordur (square35 km^2). The tidal range in this area is 4.7 m and capacity of TPP ma be 126 MW. On the north, near Stykkisholmur the bay Hvammsfjordur has the square of 400 km^2 with tidal range 5.2 m and phase difference ½ hour. The possible power of TPP in this point may be 1763 MW. The TPP of 130-200 MW will no change tidal regime here. The complex of these two units will have the basis capacity about 100 MW or more. Many same complexes may be built in Iceland and other Countries.

Fig.11 The bays of Iceland to build TPP with basis power

For the filling of power dips of off-system individual tidal power station the integration of tidal power stations of the proposed type with the tidal power station of the traditional type, whose power is proportional to rise of tide at the given moment, can also be used [3]. The universal method of compensating for the changeability of issued power is the organization of production of gaseous or liquid hydrogen, accumulated at the site of production of electric power and transported to the place of consumption by means of pipe-lines, special sea or aviation transport facilities. TPP capacity can be increased gradually and in principle may not be brought to the maximum value, remaining within the limits of economic optimum with simultaneous development of power-consuming production. For example, such production can be the production of liquid hydrogen for the energy purposes. In view of orientation on the achieved energy intensity indices of this production – 53 kWhr/kg of gaseous or 65 kWhr/kg of liquid hydrogen – Penzhinskaya TPP will allow to produce almost 4.8 million tons of liquid hydrogen per year or on average 2.14 m^3/s. In the composition of the prime cost of hydrogen the energy costs amount up to 60÷80% [4]. Therefore the price of hydrogen, produced at Penzhinskaya TPS, can be less than 0.5 dollars per kg . There exist experimentally substantiated proposals on abrupt (several times) reduction of energy intensity of the process of obtaining hydrogen from the water (Mogilevsky I.N., Surikov A.K., Ovsennikov E.M., the patent of Russia 2224051 with the priority from 17.02.03).

Thereafter the volume of hydrogen production can be increased and the costs can be reduced. The obtained hydrogen is either accumulated during the winter period and removed by tankers in the navigation season or removed during the whole year with the aid of specialized aerostatic apparatuses (elaboration of prof. O.A.Chembrovsky). With the expansion of the scales of the use of ecologically clean renewed energy sources in this region, for example, owing to the building of other tidal or large wind power stations the creation of cryogenic pipeline transport system with the use of high-test and flexible piping from the quartz glass, laid at the bottom of the sea, can be economically expedient. The same cryogenic pipes can also be used as cable channels with superconducting conductors from pure aluminum.

Conclusion

It is proposed to use the energy of tidal flows without the creation of solid head front and cutting off the area of water of power station basin from the sea. This approach allows to repeatedly decrease the initial capital investments, drastically reduce the terms of setting in operation the first units, repeatedly decrease the volumes of the works, carried out in TPP site. In this case the new type of the orthogonal multiblade turbines of large capacity, proposed by the author, can be very effective. The optimum flows speed for the orthogonal turbines amounts from 2 to 4 m/s. Such speeds have a place in the straits of large bays in Canada and the east seas of Russia, which permits to raise the question about the effective use of these flows with the aid of floating power stations of new type without carrying out the construction work in TPP site.

It is expedient to use the energy of flows in the regime of the maximum turbines effectiveness. In the region with the developed power system (Canada, Australia) this energy can be issued into electrical network, displacing the capacities of usual hydraulic or fuel power stations. In the uninhabited regions (east of Russia) it is expedient to direct the energy of TPP on the production and accumulation of liquid or gaseous hydrogen. This hydrogen can qualitatively change the energy situation in the Far East of Russia and can also serve as the object of export into Japan, Korea and China, substituting traditional hydrocarbon fuel.

Reference

1. Lyatkher V.M. Tidal Power Plants without the Dams, “Hydrotechnical Construction” 4, 2006, Moscow
2. Lyatkher V.M. Power Potential of the Tidal Power Plants, “Izvestia RAN” 4, 2006, Moscow
3. Lyatkher V.M. Complex of tidal power plants, ensuring the established schedule of issuing of power, “Hydrotechnical Construction”, 12, 1998, Moscow
4. .Walter Peschka, Liquid Hydrogen: fuel of the future. Springer-Verlag, 1992