DEVELOPMENT OF A MODEL AND ALGORITHM FOR DETERMINING THE OPTIMAL ANGLE OF THE UNDERSHOT WATER WHEEL BLADES

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Annotation. *This article presents the results of theoretical studies of the undershot water wheel that works effectively in low-pressure watercourses with a water flow speed of 1-4 m/s. When developing a mathematical model of the undershot water wheel, the Matlab/Simulink program was used. According to the results of the study, it was found that for the efficient operation of the undershot water wheel in low-pressure watercourses, the angle of inclination of the blade at the exit from the water is β=30°. Also, during the study, the water flow rate and the efficiency of the undershot water wheel were determined.*

Key words: *hydropower potential, undershot water wheel, Amu-Bukhara canal, water flow speed, water flow rate, optimal position angle, efficiency.*

GIDROTURBINA LOPATKALARINIING OPTIMAL BURCHAGINI ANIQLASH UCHUN MODEL VA ALGORITMNI ISHLAB CHIQISH

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Annotatsiya: *Ushbu maqolada suv oqimi tezligi 1-4 m/s bo'lgan past bosimli suv oqimlarida samarali ishlaydigan gidroturbinaning nazariy tadqiqotlari natijalari keltirilgan. Gidroturbinaning matematik modelini ishlab chiqishda Matlab/Simulink dasturi ishlatilgan. Tadqiqot natijalariga ko'ra, suv o'tkazmaydigan gidroturbinaning kichik bosimli suv oqimlarida samarali ishlashi uchun suv chiqishidagi lopatkaning moyillik burchagi β=30°. ekanligi aniqlandi. Shuningdek, tadqiqot davomida suv sarfi va gidroturbinaning samaradorligi aniqlandi.*

Kalit so'zlar*: gidroenergetika salohiyati, gidroturbina, Amu-Buxoro kanali, suv oqimi tezligi, suv sarfi, optimal holat burchagi, samaradorlik.*

РАЗРАБОТКА МОДЕЛИ И АЛГОРИТМА ОПРЕДЕЛЕНИЯ ОПТИМАЛЬНОГО УГЛА ПОДДЕРЖИВАЕМЫХ ЛОПАТОК ВОДЯНОГО КОЛЕСА

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Аннотация: *В данной статье представлены результаты теоретических исследований поддонного водяного колеса, эффективно работающего в слабонапорных водотоках со скоростью потока воды 1-4 м/с. При разработке математической модели недоливного водяного колеса использовалась программа Matlab/Simulink. По результатам исследования установлено, что для эффективной работы недоливного водяного колеса в слабонапорных водотоках угол наклона лопасти на выходе из воды составляет β=30°. Также в ходе исследования определяли расход воды и КПД недоливного водяного колеса.*

Ключевые слова: *гидроэнергетический потенциал, недолив водяного колеса, Аму-Бухарский канал, скорость течения воды, расход воды, угол оптимального положения, КПД.*

1.Introduction.

In the world today, the rapid growth in electricity consumption associated with an increase in the population of the Earth has led to the depletion of natural fuel and energy resources, as well as climate change associated with greenhouse gas emissions into the atmosphere due to the combustion of natural fuels to generate electricity [1]. To solve these problems, it is necessary to increase the share of electricity generation from renewable energy sources [2].

According to the Renewables 2020 Global Status Report, electricity generated in the world from renewable energy sources such as solar, wind, biomass, geothermal energy and hydropower is 27.3 percent [3]. In the last decade, for the effective use of renewable energy sources, along with photovoltaic, wind, geothermal, etc. Small hydroelectric power plants have been widely used both in water intake structures [4, 5] with high water pressure, and in low-flow streams of rivers and irrigation canals [6,7,8,9].

According to the International Hydropower Association (IHA), China (13760 MW), Turkey (2480 MW), India (478 MW), Angola (401 MW) and Russia (380 MW) closed the top five in terms of installed capacity for the period of 2020. As for Uzbekistan, in 2020 it mastered 71 MW of installed capacity and took 24th place in the world ranking, which significantly exceeds in relation to 2019 with an added installed capacity of 11 MW with 40th place in the world ranking [10].

One of the most important complexes in the Republic of Uzbekistan is the system of the Amu-Bukhara machine canal (ABMK), located in the Bukhara region. The irrigation system of the Amu-Bukhara machine canal is a branch of the Amudarya River flowing on the territory of the Republic of Turkmenistan and represents the most important complex on the territory of Uzbekistan designed to provide water to the Bukhara and partially Navai regions, originating at the point with coordinates 39.219845, 63.719540 from the inlet hydroelectric complex “Double”. For the effective use of a hydropower plant, it is necessary, first of all, to accurately assess the resources of the hydropower potential and the properties of water energy in the region where the plant will be used. For the first time, the hydropower potential of the Amu-Bukhara Machine Canal was assessed in scientific research by scientists from the Bukhara Engineering and Technology Institute, which amounted to 200.2 GWh.

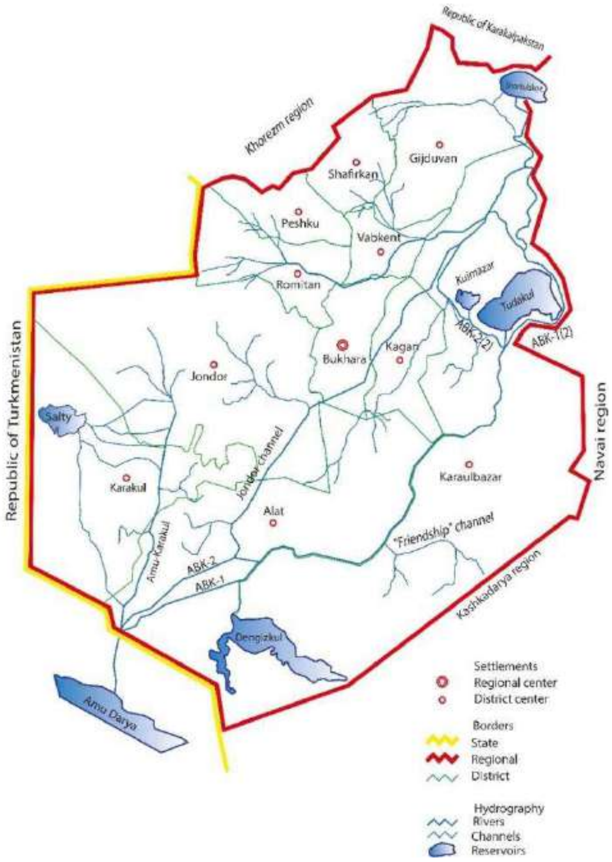

Figure 1. Layout of the main and inter-farm channels of the Bukhara region.

Also, in the course of assessing the hydropower potential, a diagram (Fig. 1) of the location of the main and inter-farm canals of the Bukhara region was built, built using a linear diagram taken from the administration of the Amu-Bukhara machine canal, as well as information obtained using satellite data based on the Google Earth application Pro [11].

The aim of the study is to theoretically substantiate the operation of a water wheel that works effectively in low-pressure watercourses, which can serve as a solution to problems with the electrification of remote areas with uninterrupted and reliable electricity [12].

2. Materials and methods.

To theoretically substantiate the operation of a hydropower plant that effectively operates in low-pressure watercourses with a flow velocity in the range of 1-4 m/s, we will construct a mathematical model for the design of a water wheel with an outer diameter of 1 m.

Figure 2 shows a diagram of the geometric parameters of the design of the undershot water wheel.

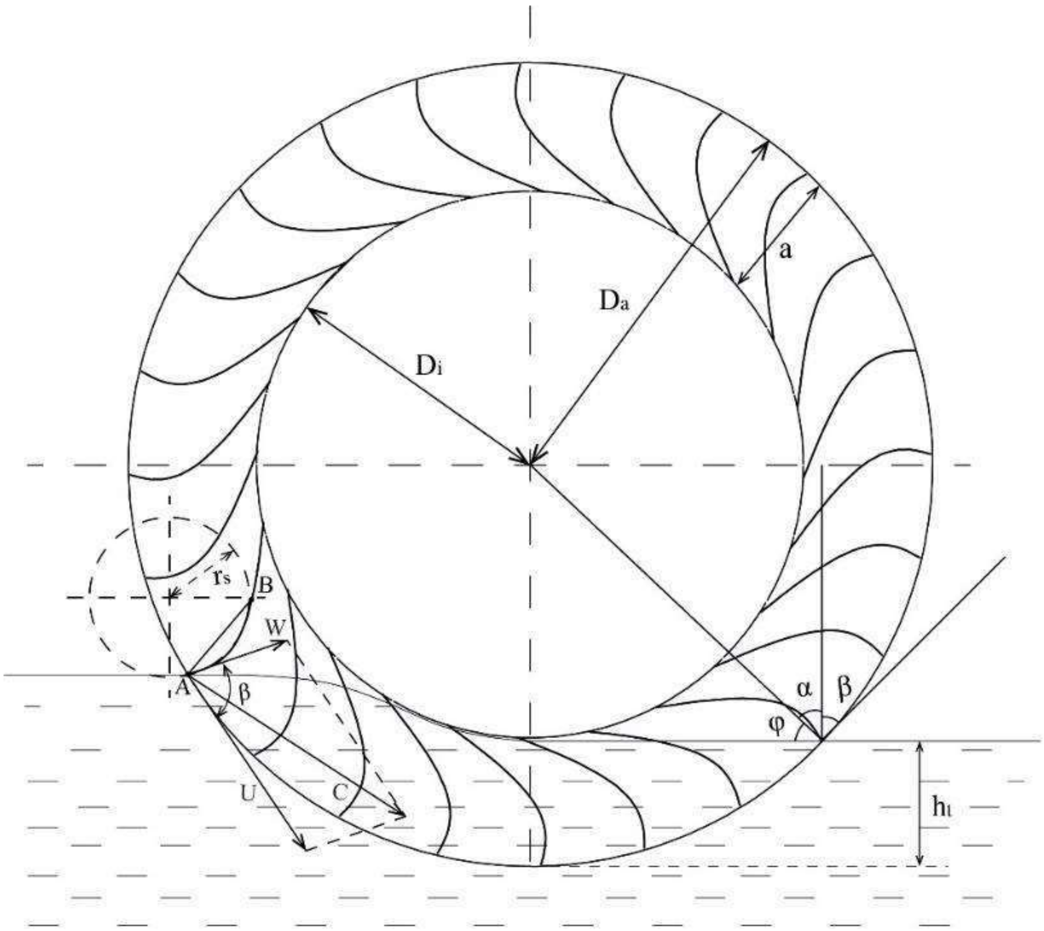

Figure 2. Scheme of the geometric parameters of the undershot water wheel design

From the geometric arrangement it follows that the values of the outer diameter D_a and the inner diameter D_i of the water wheel are interconnected by the equation:

$$D_i = D_a - 2a \quad (1)$$

The blade height “a” is calculated according to the outside diameter of the water wheel and the water flow. From scientific studies, for a flow with a water flow rate Q ≤ 0,5 m³/s, the following equation is adopted [13]:

$$a = \frac{D_a}{4} \quad (2)$$

To achieve water wheel loss reduction, it is necessary to: choose the immersion depth h_t of a curved blade, described by a calculated circle with a radius r_s, the shape of which significantly reduces the drag coefficient when interacting with water in relation to analogues with straight blades are interconnected by the equation [14]:

$$r_s = \frac{\left(\frac{D_a}{2}\right)^2 \cdot \left(\frac{D_i}{2}\right)^2}{D_a \cdot cos\beta + D_i} \quad (3)$$

The angle of inclination of the blade at the exit from the water is determined by the following formula:

$$\beta = cos^{-1}\left(\sqrt{1 - \left(1 - \frac{h_t}{D_a}\right)^2}\right) \quad (4)$$

Due to geometric laws, we determine the dependence of the angle $\boldsymbol{\beta}$ on the angle φ:

$$\begin{cases} \alpha + \beta = 90^{\circ} \\ \varphi + \alpha = 90^{\circ} \\ \alpha = 90^{\circ} - \beta \\ \alpha = 90^{\circ} - \varphi \\ \alpha = \beta \end{cases} \quad (5)$$

The immersion depth of the blade is determined by the following formula:

$$h_t = R_a - R_a \cdot sin\beta \quad (6)$$

The rotational speed of the water wheel is calculated from its diameter and circumferential speed [15]:

$$n = \frac{U \cdot 60}{\pi \cdot D_a} \quad (7)$$

U – circumferential speed, m/s;

The circumferential speed of the water wheel is equal to half the speed of the water flow at the inlet and has the following form [16]:

$$U = 2{,}33 \cdot \sqrt{H} = 2{,}33 \cdot \sqrt{\frac{V^2}{2 \cdot g}} \quad (8)$$

The formula for determining the number of water wheel blades is as follows [17]:

$$z = \frac{D_a \cdot \pi}{t} \quad (9)$$

The depth of immersion of the blade into the water, a parameter that depends on the rotation speed n, the thickness of the blade b_{sc} ,, the outer radius of the wheel R_a, the water flow rate Q, is determined by the following expression given in the literature [18]:

$$h_t = \left(R_a - \frac{1{,}05 \cdot \ _{sc} \cdot z}{2\pi}\right) - \sqrt{\left(R_a - \frac{1{,}05 \cdot \ _{sc} \cdot z}{2\pi}\right)^2 - \frac{Q \cdot 60}{n \cdot B \cdot \pi}} \quad (10)$$

Based on equation (1), we obtain a mathematical expression that determines the water flow rate:

$$Q = \frac{n \cdot B((2\pi \cdot R_a - 1{,}05 \cdot b_{sch} \cdot z) \cdot (R_a - R_a \cdot sin\ \ ) - \pi \cdot (R_a - R_a \cdot sin\beta\ ^2)}{60} \quad (11)$$

The formula for the pressure force of the water flow acting on the blades of the water wheel is as follows [19]:

$$F = Q \cdot A \cdot V^2 \cdot (1 - c) = \rho \cdot Q \cdot (V - U) \quad (12)$$

The mechanical moment is determined by the following formula [20]:

$$M = F \cdot \frac{D_a}{2} \quad (13)$$

The mechanical power of the water wheel is determined by the following formula:

$$P_{\text{м}} = M \cdot \omega = M \cdot 2 \cdot \pi \cdot f = M \cdot 2 \cdot \pi \cdot \frac{n}{60} \quad (14)$$

The kinetic energy of a water wheel is determined by the following formula:

$$P_{\text{к}} = \frac{m \cdot V^2}{2 \cdot t} = \frac{\rho \cdot S \cdot V^3}{2 \cdot t} \quad (15)$$

The efficiency is expressed by the ratio of mechanical and kinetic powers and has the form:

$$\eta = \frac{P_{\text{м}}}{P_{\text{к}}} \quad (16)$$

Figure 3 shows the algorithm developed to determine the optimal parameters of the water wheel. This algorithm allows you to determine the optimal blade angle at the exit from the water, the number of blades, water flow rate, mechanical power, kinetic power, and the efficiency of the water wheel.

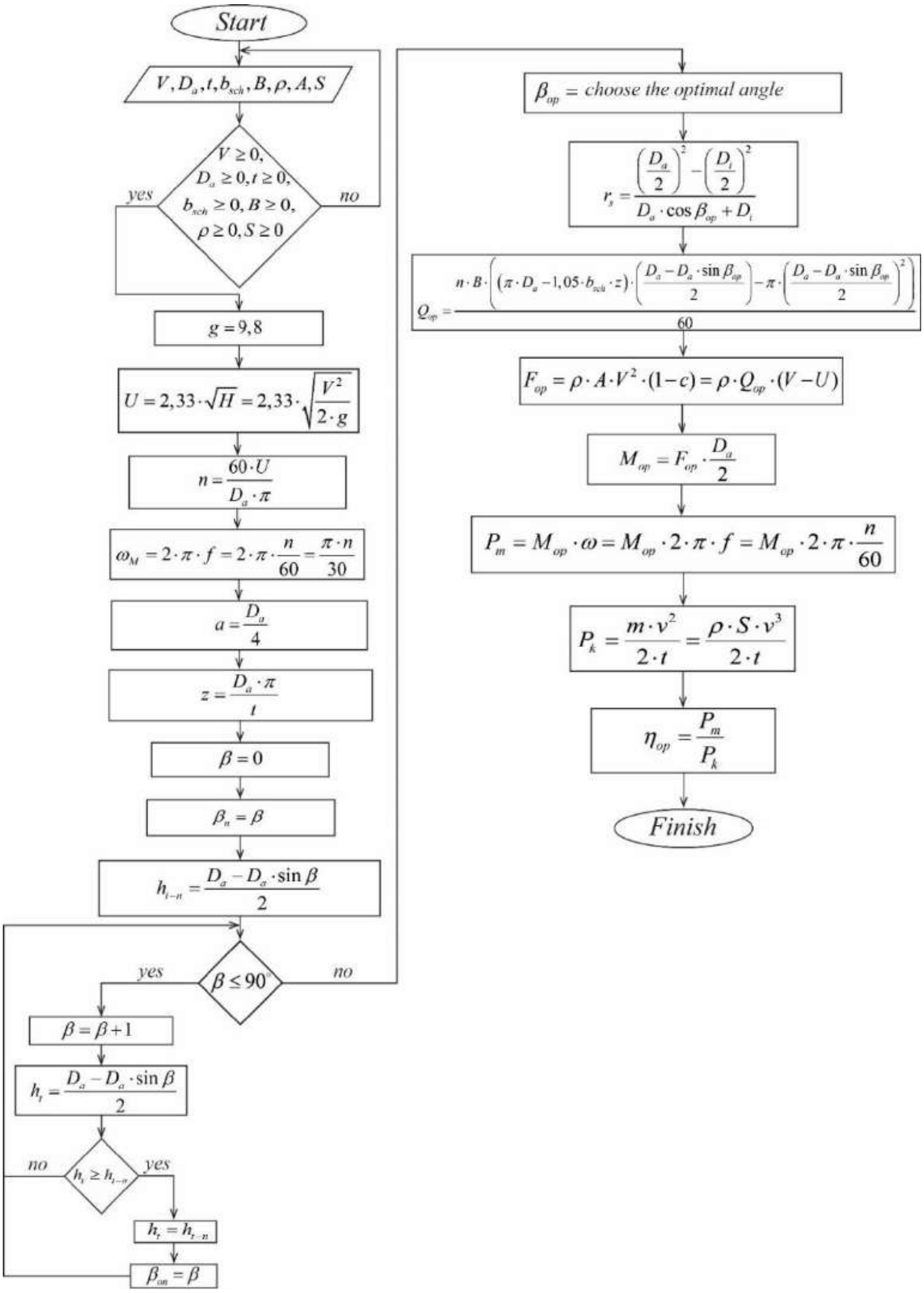

Figure 3. Algorithm determining the optimal parameters of the water wheel.

3. Results and discussion

During the study, the following results were obtained. Figure 4 shows the curve of dependence of the depth of immersion of the blade in water on h_t on the angle of inclination of the blade at the exit from the water β. It can be seen from the figure that at the angle of inclination of the blade at the exit from the water $\beta = 30^\circ$, the value of the blade immersion $h_t = 0{,}25\ m$, which is its maximum value.

Figure 5 shows the dependence of the speed of rotation of the water wheel n on the water flow speed V. The curve shown in Figure 4 shows that with an increase in the speed of the water flow, the speed of rotation of the water wheel increases, according to which at the speed of the water flow $V = 4\ m/s$ the rotation speed of the water wheel is 40 rpm.

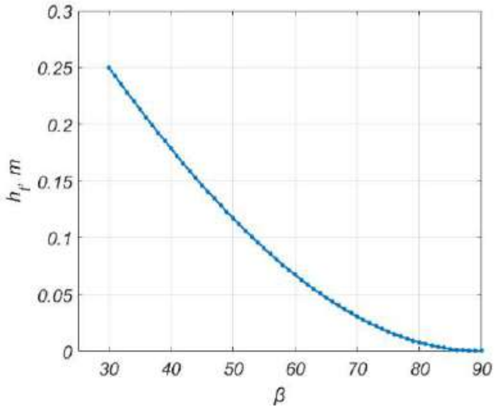

Figure 4. Graph of the dependence of the depth of immersion of the blade in the water on the angle of inclination of the blade at the exit from the water

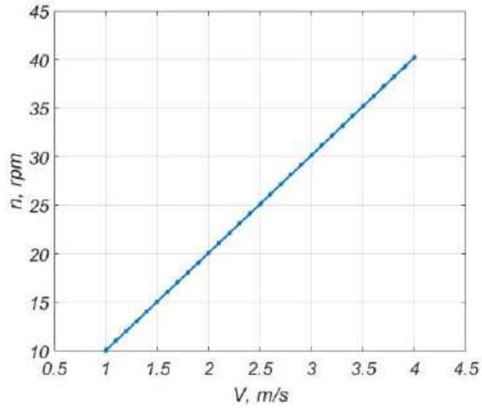

Figure 5. Graph of the dependence of the speed of rotation of the water wheel on the speed of the water flow

Figure 6 shows curves characterizing the dependence of the water flow rate Q on the angle of inclination of the blade at the outlet from the water β. It was found that at a water flow rate of 4 m/s and an inclination angle of the blade at the outlet of the water $\beta = 30^{\circ}$, the value of the water flow rate is maximum and is $Q = 0{,}475\ m^3/s$.

Figure 7 shows curves showing graphs of the dependence of the mechanical moment on the angle of inclination of the blade at the exit from the water. It was found that the maximum value of the mechanical moment was achieved at the angle of inclination of the blade at the exit from the water $\beta = 30^{\circ}$.

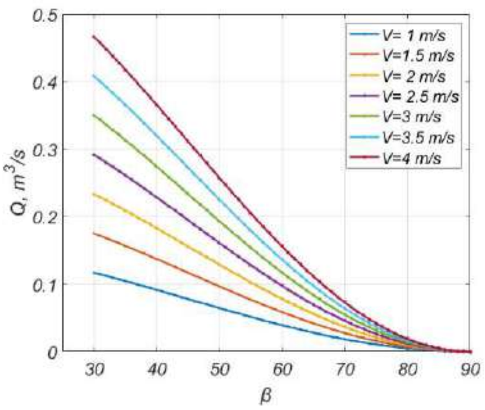

Figure 6. Graphs of the dependence of the water flow rate on the angle of inclination of the blade at the exit from the water

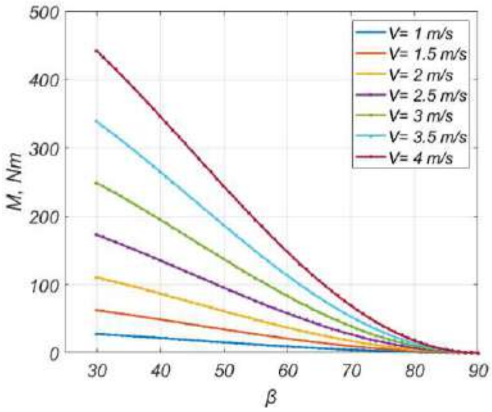

Figure 7. Graphs of the dependence of the mechanical moment on the angle of inclination of the blade at the exit from the water

Figure 8 shows the dependence curves of the mechanical power P_m on the angle of inclination of the blade at the exit from the water β. Based on a theoretical calculation, the maximum value of the mechanical power at the angle of inclination of the blade at the exit from the water $\beta = 30^{\circ}$ was 1875 W.

Figure 9 shows the efficiency vs. blade pitch angle at the exit from the water. It was found that the efficiency of the water wheel was 28% at the angle of inclination of the blade at the exit from the water $\beta = 30^{\circ}$.

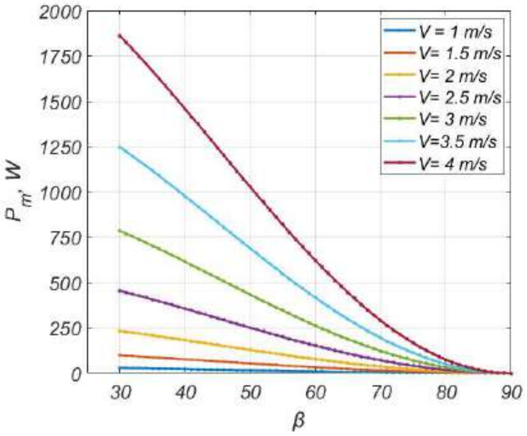

Figure 8. Graphs of the dependence of mechanical power on the angle of inclination of the blade at the exit from the water

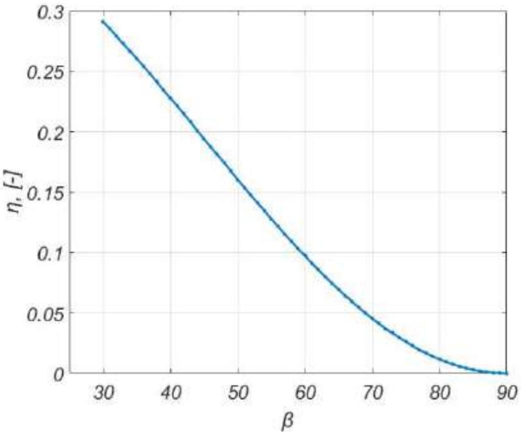

Figure 9. Graphs of the dependence of the coefficient of efficiency on the angle of inclination of the blade at the exit from the water

4. Conclusion.

In the course of a theoretical study of a bottom-hole water wheel used in low-pressure watercourses with a water flow rate of 1-4 m/s, it was found that for the effective operation of the water wheel, the angle of inclination of the blade at the exit from the water was $\boldsymbol{\beta} = \mathbf{30}^{\circ}$, while the water flow rate and the efficiency was $Q = 0{,}4 \quad m^3/s$ and $\eta = 28\%$, respectively. The use of this water wheel, which works effectively in low-pressure watercourses, can serve to provide local low-power consumers, which will lead to the development of social and economic spheres.

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