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Improvement Research of a Vertical Axis Micro Hydro Power Plant

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ABSTRACT: This article presents analysis of the possibility of using vertical axis hydro power plants adapted to water flows of pumping units. Micro hydro power plant was proposed for efficient operation of pumping units and based on the simulation, the efficiency indicators (η, n) of the plant were determined at different pressure and water flow rates. It is substantiated that the maximum efficiency of the hydro turbine is 88 % and the optimal rotation speed is 60 rpm, while the angle of interaction of the water flow with the blades of the installation is $\beta_1 = 202.5^0$, and the angle of the water flow at the outlet of the guide vane is $\alpha_1 = -17.5^0$. The power of micro hydroelectric power plant can be in the range of 313…2238 W, depending on the pressure and flow rate of the water, as a result of which it is possible to provide autonomous consumers around this installation with uninterrupted electricity.

KEYWORDS: water flow and pressure, pumping unit, vertical axis hydro power plant, water wheel, guide vane, efficiency coefficient, rotation speed.

I. INTRODUCTION

Nowadays most of the local resources that allow for the construction of large-capacity hydro power plants (HPP) in the world have already been exploited, and their construction costs and negative impact on nature limit the construction of new facilities [1]. In such conditions, the importance of stabilizing the environmental problems and energy security, uninterrupted supply of energy to autonomous consumers located far from the centralized electricity supply systems is very high. As the main solution to these problems, special attention is being paid to the development and improvement of efficiency of energy devices operating on the basis of renewable energy sources, in particular, small-capacity hydro power plants. Scientific researches are being carried out on the modeling and production of HPPs, which are more stable compared to other renewable energy sources in the continuous supply of autonomous consumers with electricity [2].

Famous scientists for the development of scientific and technical solutions for the creation and improvement of efficiency of micro hydro power plants operating in water streams D. Borkovsky, G. Muller, W. Yang, X. Kim, D. Adianta, J. Yun-Man, E. Quadrantaa, J. Frayle-Ardanui, S. Bach, M. Valavi, P.P. Bezrukikh, N.K. Malinin, V.V. Elistratov, P.P. Sweet, A.D. Obozov, B.B. Kajinsky, E.V. Solomin and S.G. Obukhov were engaged. In our republic, research on the use of alternative energy sources, in particular, on improving the efficiency of micro hydro power plants was done by M.M. Muhammadiev, B. Urishev, O.O. Bozarov, D.B. Kadirov and others.

Despite the results obtained in these studies, they are used in the design of micro hydro power plants in areas far from the centralized power supply system, but in the southwestern regions of our republic, modeling of vertical axis hydro power plants adapted to variable and low-pressure pump water flows and the forces of water wheel blades acting on water flow research on determining the optimal angle of installation of the blades and increasing the efficiency of the reduction has not been carried out enough.

A vertical axis hydro power plant adapted to variable and low-pressure water flows is known, which consists of three fixed water flow-directing vanes placed in the housing, two propeller-type hydro turbines that can rotate under the influence of water flow attached to one fixed shaft, mechanical transmissions installed on the outer part of the housing,

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electric generator connected to the rotor. Through this hydro power plant, continuous electricity can be obtained using horizontal and vertical water currents. The disadvantage of the hydro power plant is its complex construction and low reliability [3].

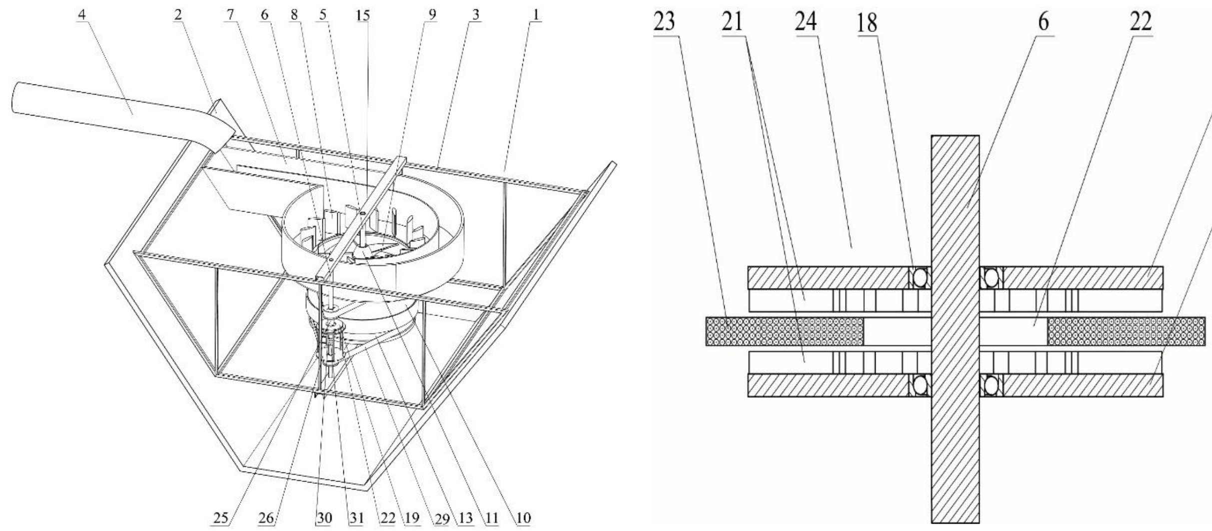
A hydro power plant for vertical water flows is known, which consists of a Kaplan-type hydro turbine with fixed blades that direct the water flow uniformly on a vertical fixed shaft. Such a hydropower device is designed for stable operation in medium-pressure water flows. The disadvantage of this hydro power plant is the low efficiency of operation in low-pressure water flows [4].

A low-pressure pump is a vertically installed hydro power plant for obtaining electrical energy using water flows. It consists of a fixed body, a pipe that directs the flow of water, a water wheel placed in a metal pipe with the ability to rotate, and an electric generator. Disadvantages of this known hydropower device: high resistance forces of water wheel blades in contact with water, efficiency of operation in low-pressure water flows and variable water consumption lead to a decrease in the reliability of electricity produced by the electric generator [5].

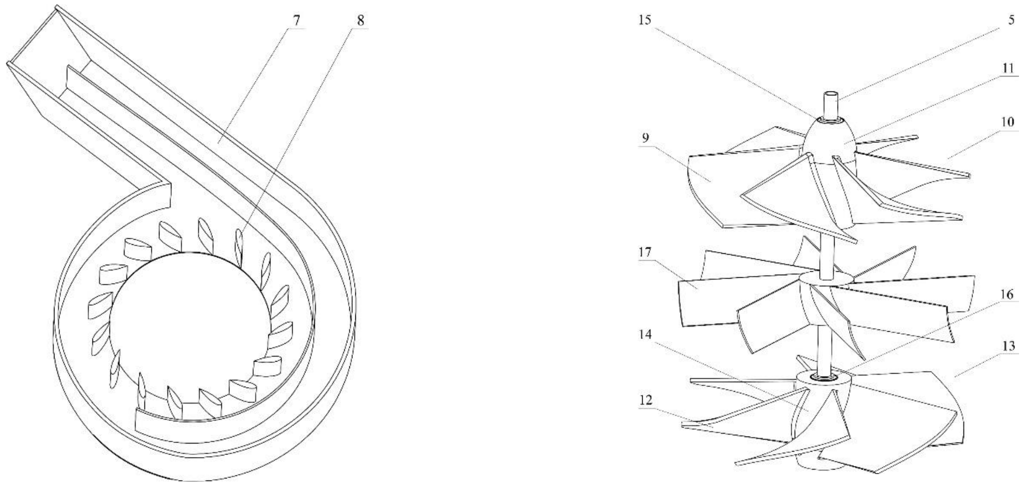
II. METHOD AND MATERIALS

The purpose of the research is to justify parameters by modeling and optimizing the vertical axis micro hydro power plant, which is adapted to the pump water flows and works efficiently in low pressure water flows.

Micro hydro power plant (1) operates as follows (Fig. 1): A metal frame (3) is installed above the water flow of the irrigation channel (2), on which a stationary vertical shaft (5) with a hydraulic turbine is mounted, driven into rotation by the flow of water coming out of the pipe (4) of the pumping unit. When the water flow interacts with the pool (7) in which the guide vane (8) is installed, the water flow receives rotational motion. As a result of the passage of water flow through the guide vane (8), a uniform rotation of the upper impeller (10) begins clockwise. The flow of water flowing from the blades of the upper impeller (10) falls on the guide vanes (17) mounted on a fixed shaft (5), which is designed to direct the flow of water to the lower impeller (13) to rotate it in a counterclockwise direction. More precisely, the impeller, through a belt drive (28), rotates a metal disk (26), which is connected to the armature of the electric generator using bushings (27). As a result, the armature (22) of the generator (24) receives a clockwise rotating motion. The lower impeller, through a belt drive (29), rotates the flange joint connected to the inductors (19), (20) of the electric generator by means of bolts. As a result, the generator inductor consisting of permanent magnets (21) receives a counterclockwise rotating motion. The voltage generated on the three-phase winding (23) of the armature (22) of the generator is transmitted through the cable to the brushes (30) with slip rings (31). As a result of the opposite rotation of the armature (22) and the inductors (19), (20) of the axial magnetoelectric generator (24) in opposite directions, high electromagnetic power is achieved [6].



a) b)

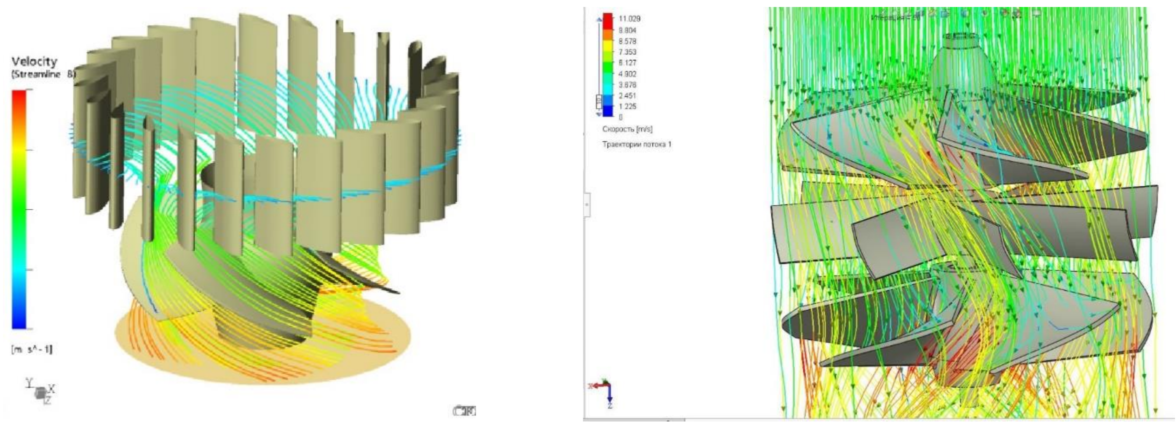


c) d)

a - general view of the vertical axis micro hydro power plant, b - electric generator, c - guide vane,
d - rotation of impeller

Fig. 1. General view and main parts of the vertical axis micro hydro power plant.

In Fig. 2 shows the results of the model built in Ansys CFD and Solidworks application package to determine the mechanical parameters of the developed vertical axis hydraulic turbine. At the same time, when assessing the rotation speed of the hydraulic turbine blades, the change in pressure, speed and flow rate of the water flow was taken into account.



a) b)

Fig. 2. Dynamics of changes in water flow in an Ansys CFD hydraulic turbine (a), dynamics of changes in Solidworks water flow rate.

Hub diameter [7]:

$$d_{hub} = m \cdot d_{run} \tag{1}$$

where: d_{run} – turbine diameter, m; m – represents the relationship between diameters and is determined depending on the pressure of the water flow.

Water flow rate [8]:

$$V_{f1} = \frac{Q_i}{S} = \frac{Q_i}{\frac{\pi}{4} \cdot (d_{run}^2 - d_{hub}^2)} \tag{2}$$

where: S – area of the blades affected by the water flow, m^2.

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Tangential speed of the hydraulic turbine [8]:

$$U_1 = \frac{\pi \cdot d_{run} \cdot n}{60} \quad (3)$$

Linear speed of hydraulic turbine [9]:

$$V_{wi} = \frac{P_m \cdot 1000}{\rho \cdot Q_i \cdot U_1} \quad (4)$$

Angle of water supply to the blades [9]:

$$\beta_1 = \text{arc tg} \frac{V_{f1}}{U_1 - V_{w1}} \quad (5)$$

Angle of water flow from the blades [10]:

$$\beta_2 = \text{arc tg} \frac{V_{f1}}{U_1} \quad (6)$$

Optimal blade angle [10]:

$$\theta = 180^0 - \beta_1 + \alpha \quad (7)$$

The dependence of the efficiency factor on water flow and rotation speed is found from the ratio of the mechanical power of the hydraulic turbine and the power of water flow [11].

$$\eta(Q_i, n) = \frac{2 \cdot \pi \cdot M \cdot n}{60 \cdot \rho \cdot g \cdot H \cdot Q_i} \quad (8)$$

where: ρ - water density, kg/m^3; g- free fall acceleration, m/s^2

III. RESULTS

A graph of the dependence of the coefficient of useful work on the speed of rotation of the turbine at different values of water flow consumption was constructed (Fig. 3). It was determined that the maximum efficiency of the hydro turbine is 88%.

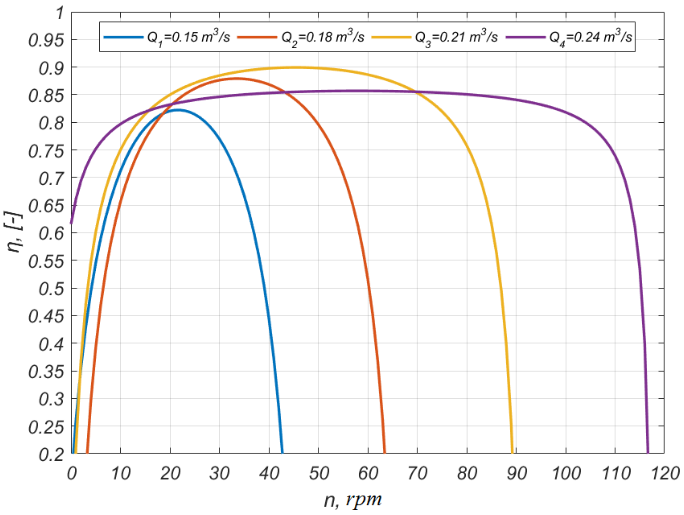

Fig. 3. The graph of the dependence of the efficiency coefficient of the hydro turbine on the rotation speed at different water consumptions.

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In Fig. 4 shows the dependences of water flow speed, consumption and pressure changes on the optimal angle of inclination of the hydraulic turbine, rotation speed and outer diameter of the hydraulic turbine modeled in the Matlab system. In this case, the input power parameters are 313…2238 W, water pressure 0…1.2 m, water flow 0.15-0.24 m^3/s, maximum efficiency 0.88, number of blades 6 and tilt angle water flow interacting with the blades of the hydraulic turbine 50.

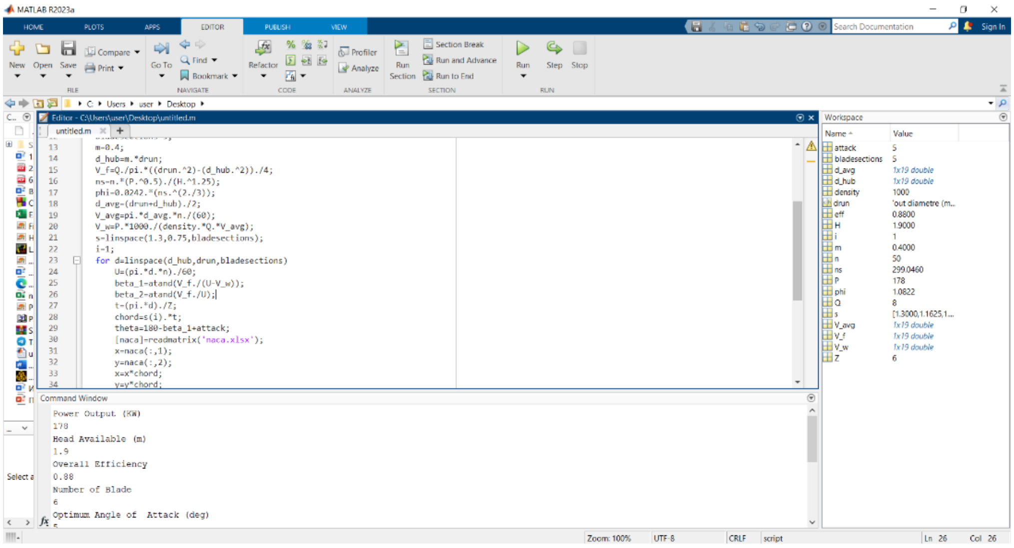

Fig. 4. Modelling of hydraulic turbines in Matlab system.

Table 1 presents the results of determining the optimal parameters of the proposed hydro power plant depending on the variable pressure and flow rate of the water flow.

Table 1.
Optimal parameters of the proposed hydro power plant.

№	Q, m^3/s	n_{opt}, rpm	P_{opt}, W	V_{f1}, m/s	U_1, m/s	V_{w1}, m/s	β_1, grad.	θ_{opt}, grad.
1	0,15	22	313	0,91	0,58	3,62	-16,6	201,6
2	0,18	32	601	1,09	0,84	3,99	-19,1	204,1
3	0,21	45	1243	1,27	1,18	5,03	-18,3	203,3
4	0,24	58	2238	1,46	1,52	6,14	-17,5	202,5

It was determined that the optimal values of the useful work coefficients of the propeller-type hydroturbine and the optimal installation angle of the blades depend on the consumption of water flow and the rotation speed of the turbine, and the results are presented in Table 1. In this case, when the diameter of the hydro turbines is 0.5 m, the diameter of the bush is 0.2 m, and the number of blades is 6, the change of water consumption in the range of 0.15...0.24 m^3/s was calculated using geometric laws and the above mathematical expressions. So, when the maximum water consumption is 0.24 m^3/s, it was determined that the geometric optimal installation angle of the fan is θ_{opt} =202.5^0.

Thus, the proposed vertical axis hydro power plant is designed for efficient operation in variable and low-pressure water flows, and due to the increase in the efficiency of the hydro turbine by 88%, we can increase the reliability of electric power of autonomous consumers and ensure continuity.

III. CONCLUSION

The proposed vertical axis hydro power plant is mainly adapted to the water flows coming out of variable and low-pressure pumping units, and based on the water flow consumption and pressure, it is based on the possibility of generating power up to 313…2238 W. As a result of modeling, it was determined that the maximum efficiency of the hydro turbine is 88 % and the optimal rotation speed is 60 rpm when the inlet angle of the water flow is 202.5^0, and the exit angle of the water flow from the guide vane is - 17.5^0. Due to the fact that the efficiency of the hydro turbine in the vertical axis hydropower plant has increased to 88%, the reliability and continuity of electric power of autonomous consumers has been achieved.

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