Experimental Study of a Micro-Hydro Power Plant Adapted to Low-Pressure Water Courses

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ABSTRACT

This article presents a theoretical and experimental study of a micro-hydro power plant that effectively operates in low-pressure watercourses with a water flow speed of 1-4 m/s. According to the results of the study, it was found that a 1.5 kW micro-hydro power plant installed on the Kuymazar canal flowing on the territory of the «Bukhoro Chorvo Omad» farm located in the Bukhara region at a water flow speed of 4 m/s is capable of generating 12,000 kWh of electricity per year. Due to the introduction of the developed micro-hydro power plant on a farm, about 9,834 toe were saved and more than 14.64 tons of carbon dioxide (CO_2) were prevented from being released into the atmosphere.

Keywords: Water wheel, low-pressure watercourses, micro-hydro power plant, experimental study, water flow speed, Fisher's F-test, Amu-Bukhara machine canal, efficiency

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 resources, as well as climate change associated with greenhouse gas emissions into the atmosphere due to the combustion of natural fuels to generate electricity. To solve these problems, it is necessary to increase the share of electricity generation from renewable energy sources [1]. According to the Renewables 2020 Global Status Report, electricity generated from renewable energy sources such as solar, wind, biomass, geothermal and hydropower accounts for 27.3 percent [2].

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 (Fig. 1) [3].

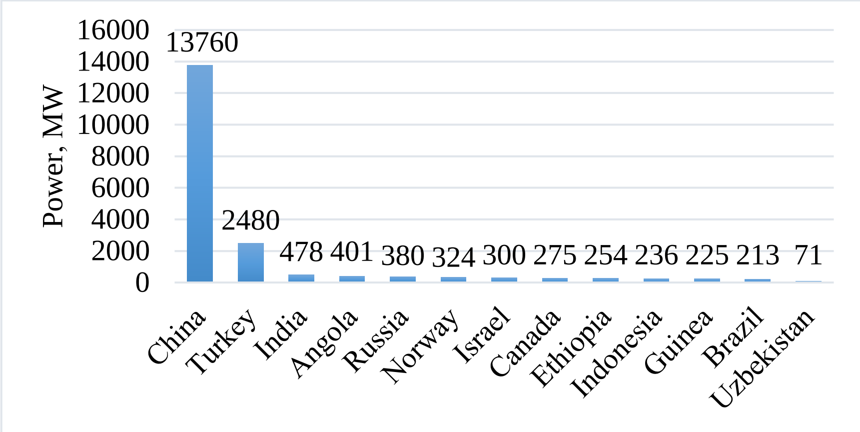


Fig 1. Added capacity by hydroelectric power plants in 2020

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. 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 evaluated in scientific research by scientists from the Bukhara Institute of Engineering and Technology. During the study, it was found that the irrigation system of the Amu-Bukhara machine canal has good potential. The estimate of the gross hydropower potential was 200.2 GWh and can serve as a solution to the problems of electrification of remote areas with uninterrupted and reliable electricity, using micro-hydro power plants that operate efficiently in low-pressure watercourses [4,5]. Based on the assessment of the hydropower potential, it was found that the irrigation system of the Amu-Bukhara canal has a good hydropower potential consisting of low-pressure watercourses. Based on this, we have developed a water wheel-type micro-hydro power plant that works effectively in low-pressure watercourses [6,7].

Method

For the theoretical justification of the effective operation of the downhole water wheel in low-pressure watercourses, it is necessary to create a mathematical model of a hydropower plant and the processes occurring in it.

Figure 2 shows the geometry diagram of a water wheel whose blades can be broken down into a curved front and a straight back.

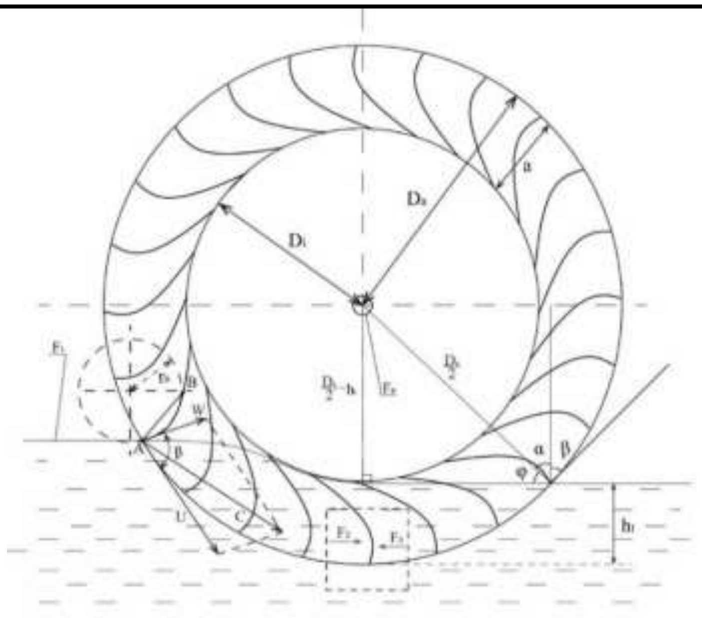


Fig. 2. Diagram of the geometric parameters of the water wheel design

The method for determining the efficiency depending on the geometric parameters of the water wheel on the properties of the water flow is determined as follows:

$$\eta_т = ((V - U) \cdot D_a \cdot n \cdot B \cdot \left((\pi \cdot D_a - 1{,}05 \cdot Z \cdot b_{sch}) \cdot (R_a - R_a \cdot \sin\beta)\right) - -\pi \cdot (R_a - R_a \cdot \sin\beta))^2) \cdot \omega_м \cdot k)/(30 \cdot V^3 \cdot S) \quad (1)$$

где, $V -$ speed of water flow, m/s; $U -$ linear speed of the water wheel, m/s; $D_a -$ water wheel outer diameter, m; $n -$ water wheel speed, rpm; $B -$ blade width, m; $Z -$ number of blades; $b_{sch} -$ blade thickness, mm; $\beta -$ optimal angle of inclination of the blade, degree; $\omega_м -$ angular velocity of the water wheel, rad/s; $k -$ hydraulic loss coefficient, H; $S -$ blade area, m^2.

Here is a method for obtaining empirical equations by processing the results of the experiment:

The regression parameters are estimated using the least squares method.

When studying the relationship between the resulting symbol "y" and the factors x_1, x_2, ... x_k using the multiple regression method, it is necessary to find the following function [8]:

$$\hat{y}_x = f(x_1, x_2 \dots x_k), \quad (2)$$

where, k - is the number of factors.

When estimating the parameters of the multivariate regression equation, the least squares method is used. For linear equations and nonlinear equations that can be represented in a linear form, the following system of normal equations is created, the solution of which allows estimating the regression parameters [9]:

$$\begin{cases} \sum y = na + b_1 \sum x_1 + b_2 \sum x_2 + \dots + b_p \sum x_p \\ \sum yx_1 = a_1 \sum x_1 + b_1 \sum x_1^2 + b_2 \sum x_2 x_1 + \dots + b_p \sum x_p x_1 \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \\ \sum yx_p = a \sum x_p + b_1 \sum x_1 x_p + b_2 \sum x_2 x_p + \dots + b_p \sum {x_p}^2 \end{cases}, \quad (3)$$

To construct a multivariate regression equation, the following function was mainly used [10]:

$$y = b_0 + b_1 x_1 + b_2 x_2 \dots b_n x_n, \quad (4)$$

You can also use the correlation index to evaluate the quality of regression models. The correlation index is determined by the following expression [11]:

$$R = \sqrt{1 - \frac{S_\varepsilon^2}{S_y^2}} = \sqrt{1 - \frac{\sum(y_i - \hat{y})^2}{\sum(y_i - \bar{y})^2}} = \sqrt{\frac{\sum(\hat{y} - \bar{y})^2}{\sum(y_i - \bar{y})^2}}, \quad (5)$$

The significance of the multivariate regression equation is assessed using Fisher's F-test [12]:

$$F_{расч} = \frac{R^2}{1-R^2} \cdot \frac{n-m-1}{m}, \qquad (6)$$

where, n is the number of experiments of various factors, m is the number of factors.

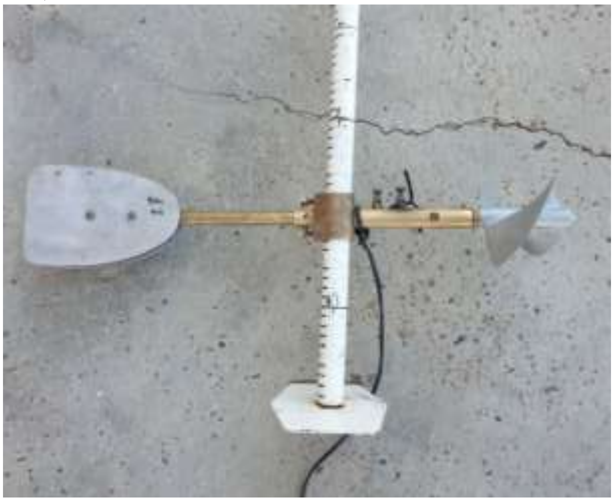
The adequacy conditions are verified using the following inequality:

$$F_{таб} > F_{расч} \qquad (7)$$

Results and discussion

The main purpose of experimental studies is to verify the accuracy of theoretical studies carried out at a micro-hydro power plant. An experimental study of a micro-hydro power plant is closely related to clarifying information about its advantages and disadvantages in field operation. One of the most important tasks of the experiment is to observe how the expected changes in the water flow rate, not taken into account in theoretical calculations, affect the design of the installation and the dynamics of the rotational movement of the water wheel, and the output parameters of the electric generator.

Figure 3 shows a general view of a metering meter mounted on a metering rod ready for operation on an irrigation canal. Figure 4 shows the process of measuring the flow rate of water in the Kuymazar canal in the presence of a hydrometer.



Rice. Fig. 3. General view of the hydrometric meter GR-21-M1

Rice. 4. The process of measuring the flow rate of water using a hydrometer vane

The main purpose of the experimental research is to determine the speed of rotation of the wheel and determine the output parameters of the electric generator at a specific value of the flow rate of water passing through the pontoons that serve as the floating base of the micro-hydro power plant and at the same time to increase the flow rate of water. The main mechanisms of a micro-hydro power plant are a floating base forming a narrowing channel, curved blades of a water wheel, an electric generator, an anchor and an inductor of which rotate in opposite directions due to the use of a mechanical transmission in the installation.

Figure 5 shows the process of conducting an experiment on the Kuymazar irrigation canal above a micro-hydro power plant adapted to low-pressure watercourses.

Fig. 5. Conducting an experiment of the developed micro-hydro power plant

Figure 6 shows the results of processing experimental data, according to which Figure 6 (a) shows the results obtained using regression equations, Figure 6 (b) presents an assessment of the similarity of theoretical and experimental results.

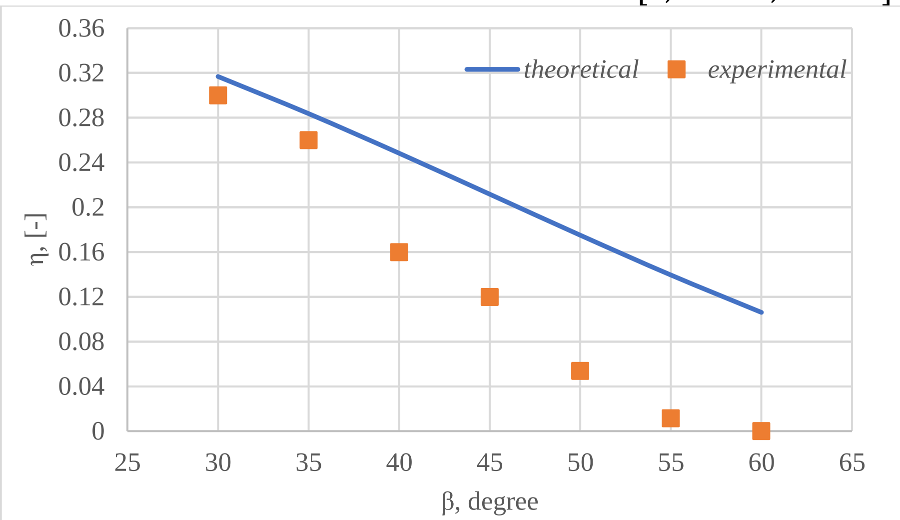
The adequacy of the regression equation is assessed using Fisher's F-test.

Let's compare the calculated values with the table values.

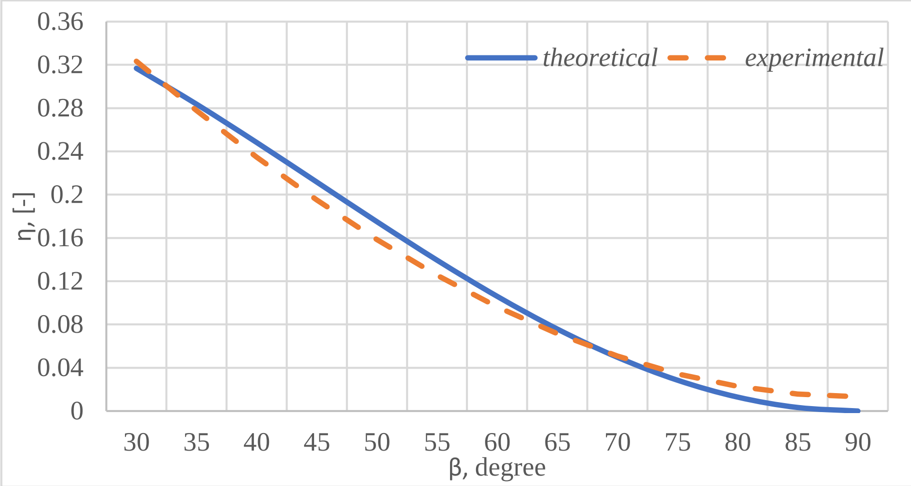
The multifactorial regression equation that determines the efficiency has the following form:

$$Y = 0{,}64 - 0{,}0045 \cdot X_1 + 0{,}00042 \cdot X_2 - 0{,}62 \cdot X_3 - 0{,}00047 \cdot X_4 + 0{,}97 \cdot X_5 \quad (8)$$

where, X_1- speed of water flow [1-4 m/s], X_2- water wheel speed [10-40 rpm], X_3- angle of inclination of the water wheel blades [30º-90º], X_4- number of blades [8-24 pc], X_5- blade thickness [0,0002-0,0004 m].



a)



b)

a - comparative analysis of simulation results and experimental data; b - results obtained using the regression equation

Figure 6. Processing of experimental results

The significance of the regression equations was evaluated using Fischer's F-test. We compare the calculated values with the values in the table. With the calculated value of the significance level 0.05 and the calculated values of the degrees of freedom γ1=84, γ2=79, it was found that the Fisher table value F Table = 1.45 is greater than the calculated value F Table=0.91. Thus, the Fisher adequacy criterion for the model we have obtained is fulfilled. The relative error of the calculation is ± 8%.

According to the results of theoretical and experimental studies, it was found that the developed hydropower plant works effectively in low-pressure watercourses with a water flow speed of 1-4 m/s, while the outer diameter of the water wheel is D_a=1 m, the inner diameter D_i=0,5 m, the number of blades z = 16, the optimal angle of inclination of the blades of the water wheel β =30º.

Conclusion

1. As a result of the operation of a 1.5 kW micro-hydro power plant in low-pressure watercourses with a water flow speed of 4 m/s, the production of 12,000 kWh of electricity per year was achieved.

2. The developed micro-hydro power plant was installed and tested in 2021-2022 on the Kuymazar irrigation canal flowing on the territory of the farm of “Bukhoro Chorvo Omad” located in the Bukhara region. Thus, the satisfaction of electricity needs on the farm was achieved due to uninterrupted and reliable power supply.

3. As a result of the implementation of the developed micro-hydro power plant on the farm, 55.7 million rubles were saved. the sum spent on fuel burned by an internal combustion engine to generate electricity is about 9,834 toe, and emissions of more than 14.64 tons of carbon dioxide (CO_2) into the atmosphere are prevented.

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