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Development and testing of a laboratory model of a two-turbine small hydroelectric power plant

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Abstract. This article considers the main methods of regulating water consumption and power of micro hydroelectric power plants. New technical solutions for screw jet turbines adapted to low pressures and water flow rates are proposed. The Archimede's screw turbine is a cost-effective and environmentally friendly microhydropower technology that operates at high efficiency at low pressure and medium flow rates. In this case, the change in power depends on the following parameters: the number of blades, water flow, the angle of inclination of the blades and the height of the pressure. Preliminary calculations carried out by the authors show that the power of a microhydroelectric power station depends on individual factors of the area. With an increase in the speed of the water flow, the speed of the water wheel also increases, and in turn, the electric power of the microhydroelectric power station increases.

1. Introduction

One of the most important challenges in the world today is related to sustainable energy production, reducing the use of fossil fuels and preventing the increase in pollution and carbon dioxide emissions. Therefore, researchers are encouraged to conduct research on the use of clean and renewable alternative energy sources such as hydro, solar, wind and geothermal energy [1-8].

The use of water energy has been one of the most important sources of electricity generation for several hundred years, first it was used to obtain mechanical energy for mills, and then to generate electricity [9, 10]. At the same time, the role of small hydropower plants in the world hydropower is about 10 percent.

Hydropower is a type of energy that is sustainable among renewable energy sources and is of great importance for solving global environmental problems, since water energy is considered an environmentally friendly, cheap source of energy. In this place, the development of hydraulic turbines is an important issue for the further development of the field. Several types of turbines are existing nowadays [4] which are highlighted in Figure 1. From practical work on its development, research is being carried out to improve the Archimedes turbine [11-15]. These turbines represent a new direction compared to the traditional turbines used in recent years. The advantages of the Archimedes turbine over other types of turbines include low maintenance costs, ease of mechanical use, and a good choice for locations where other types of turbines cannot be used.

Several parameters affect the efficient operation of an Archimedean screw turbine. These include: screw length, inner and outer diameters, angle of inclination, number of revolutions and flow rate [16, 17]. The principle of operation of a screw turbine is that the propeller blades resist the pressure of water hitting the turbine blades and cause a decrease in water speed, this pressure rotates the turbine and drives the electric generator.

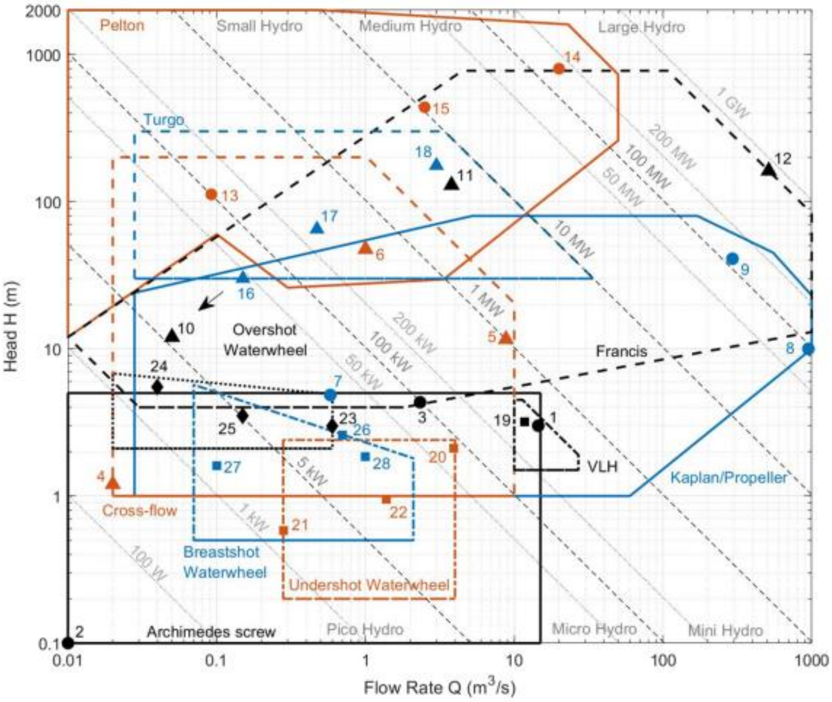

Figure 1. Summary graph of hydro turbines [4]

2. Research Methods

The available methods for manufacturing an Archimedean screw turbine have been studied [11-15, 17], on the basis of existing methods, several studies were carried out to design and calculate the technical parameters of a turbine suitable for the water flow of the republic and test the developed device. Studies have shown that the Archimed screw turbine is excellently suited for low pressure hydropower applications and is particularly suitable for small sections of water flow. Archimed screw turbines can operate at heights up to 5 m in low-pressure water flows with different flow rates. Like standard hydro generators, screw turbines also rotate at a speed of 75 to 150 rpm.

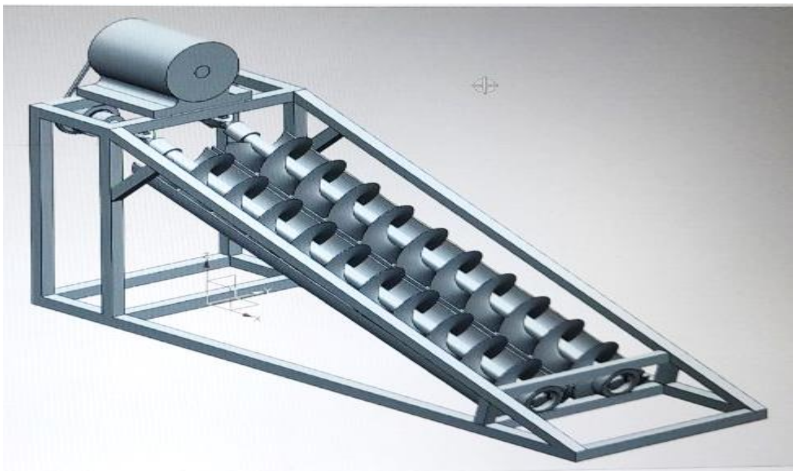

Figure 2. General view of the proposed twin Archimedes screw turbine

With Archimed screw turbines, most of the floating debris and sediment in the water passes downstream. The water moves down the length of the auger. The hydrostatic boom of water flows around the surface of the auger and causes it to rotate. Flow rate from 0.1 to 15 m^3/s, slope angle from 20 to 40 degrees [17].

In an Archimedes screw turbine, water flows through a cylindrical water path and between the blades. A generator is installed on top of the turbine, the hydrostatic pressure of water enters the propeller blades, and as a result of its rotation, it is connected to the generator through a chain drive. The main goal of the research is the efficient production of energy with low consumption of pressurized water. For this, a system for transferring 2 turbines to one generator was designed (see Figure 2).

Turbine efficiency is determined by associated losses. These losses include fluid viscosity (water content) and turbine friction losses. To achieve high efficiency, these losses are reduced to a minimum value.

$$\eta = P_{mec} / P_{hyd} \quad (1)$$

$$P_{mec} = T \cdot \omega \quad (2)$$

Where T= torque in shaft (Nm) and ω= angular rotational speed (rad/s).

Mechanical energy obtained from water energy through a turbine can be converted into electrical energy through a generator. The hydraulic power available from the Archimedean screw turbine is given below:

$$P_{hyd} = \rho \cdot g \cdot Q \cdot H \text{ (in KW)} \quad (3)$$

Here: P_{hyd} = the hydropower potential, ρ = density of water (kg/m^3), Q = flow rate(m^3/s), g = 9.8 m/s^2 gravitational constant, H = the head in meters [14-16].

3. Results and Discussions

The resulting calculations were made based on the analysis of the literature and articles carried out so far.

Based on the above expressions, we determine the dimensions of a two-turbine small hydroelectric power station according to Table 1.

The head in our case is 0.3m
The outer radius of the turbine (R_o) = 57.5mm
The inner radius of the diameter (R_i) = 25mm
The tilt angle of the turbine shaft (θ) = 24
Total number of blade (N) = 8
Now;
The total length of the screw shaft (L) is given by;

$$L = H/sin24° \quad (4)$$

L = 738 mm, The radius ratio (ρ) is calculated by;

$$\rho = R_i/R_o \;\; (0 \leq \rho \leq 1) \quad (5)$$

The radius ratio (ρ) = 0.435

Table 1. Parameters of an experimental model of a screw turbine

Parameters	Symbol	Value
Screw length	L	1262 mm
Number of blades	N	1
Inlet diameter	Di	50 mm
Outer diameter	Do	115 mm
Number of helix	m	8
Pitch	P	50 mm
Trough diameter	D	118 mm
Gap width	Gw	2 mm
Slope	α	24°

Figure 3. The process of developing a laboratory model of a small hydropower plant

The main structure of the Archimedean turbine is its structure, which is considered the outer base, and a number of parts are attached to it. Our base is designed with a slope of 24 degrees. Triangular base design, hypotenuse length 1100mm and bottom length 985mm.
To test the operating modes of the device in practice, on the basis of this (see Figure 3) developed technological scheme, it is possible to develop a laboratory model of the initial small model of a microhydroelectric power station. The most important part of micro hydro power stations operating at low water flow rates is a hydroturbine. The process of selecting the necessary equipment and parts for the development of an initial device prototype in the laboratory is shown in Figure 4a. Figure 4b shows the manufacturing process of the first small-sized model of the designed and manufactured micro hydroelectric power station.
To test the initial small-scale model of a microhydroelectric power station for low-pressure water flows in laboratory conditions, it is necessary:

- device for measuring current and voltage;
- consumer;
- water flow;
- stabilizer (voltage regulator);
- clock.

The purpose of the experiment is to test the process of development, preparation and operation of the initial small-sized sample in laboratory conditions to create a prototype microhydroelectric power station.

a) Exam preparation process *b) The process of obtaining test results*

Figure 4. Laboratory testing of samples

The procedure for checking the operation of the device in the laboratory was carried out as follows:

1. The right choice of place for laboratory research. The proximity of a water flow was taken into account.
2. Preparation of a laboratory sample of a small hydroelectric power plant.
3. Preparation of measuring instruments, equipment and other necessary equipment.
4. Direct the flow of water to the laboratory.
5. Generation of a water flow and its direction to a micro hydroelectric power station.
6. Adjustment of the generated voltage in the microhydroelectric generator using a stabilizer.
7. Using light bulbs as a load and connecting them to the resulting electrical network.
8. Measure the generated voltage and current flowing through the electric lamps with a meter.
9. When determining electrical energy, determining the time using a clock and multiplying it by the values of the measured voltage and current.
10. Record data for analysis.

During testing of a laboratory sample of a micro hydroelectric power station operating on low-pressure watercourses, some shortcomings were identified:

1. As the micro hydroelectric power station rotates, it has been found that water is trapped between the blades as they rise from the bottom water stream as they rotate. As a result, the water remaining between the wings began to fly up.
2. As a result of the aforementioned shortcoming, it was found during tests that the keels encounter resistance when lifting out of the water, which affects the speed of rotation.
3. The size of the blades of the Charkhpalak directly affects the speed of its rotation.
4. It turned out that the speed of rotation of a micro hydropower plant negatively affects the quality indicators of the electricity it generates.

5. When transfering the mechanical energy generated by the micro hydroelectric power station to the generator using a belt drive, energy losses were observed.

The workflow of the developed device has been successfully tested. We will take this small model as the basis for the development of a large-scale experimental model of a micro hydroelectric power plant operating in low-pressure water flows.

4. Conclusions

Based on the efficiency curve in the hydro turbine stack graph available, the Archimedes screw turbine is the best option due to its construction cost, simple structure, low pressure operation, and environmental friendliness, i.e. harmlessness to fish.

In this work, Archimedean screw turbines with various parameters were studied and the angle of inclination, flow rate and other parameters that increase their efficiency were studied. 2 turbines were calculated, connected through a transmission to one generator, and a small design was developed.

When installing a turbine, the efficiency is greatly affected by the angle of inclination, the length of the propeller and the number of blades.

Based on the small model developed and tested in the laboratory, a large-sized test sample of a small hydroelectric power plant was developed.

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