Study on screw turbine of the micro hydroelectric power plant working in low pressure water flows

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Abstract. Nowadays, the demand for electricity is becoming more and more important, so finding new, safe and renewable energy is considered an important issue. Micro hydroelectric power plants with screw turbines are ecologically clean, renewable and efficient operation in low-pressure water flows is presented in the article. This article examines the transmission of 2 parallel screw turbines to one generator through a chain drive and increasing the output power by controlling the part connected to the generator in obtaining electricity from low-pressure water flows.

1. Introduction

One of the most important challenges in the world today involves sustainable energy production, reducing fossil fuels and preventing increased pollution and carbon dioxide emissions. Therefore, researchers are advised to conduct research on the use of clean and renewable alternative energies such as hydropower, solar energy, wind energy and geothermal energy[1,2].

Modern hydropower is the most economical and environmentally friendly way to produce electricity compared to other renewable energy sources. Small hydropower is a more efficient and reliable resource in this regard. Micro and small hydroelectric power plants allow to preserve the natural landscape and environment not only in the stage of use, but also in the construction process. The use of micro and small hydropower plants in industrial and production, as well as agricultural facilities is natural, ecologically clean, safe, and economically efficient [3, 4].

It is worth noting the positive features of micro-hydroelectric power stations, in most cases, large hydroelectric power stations are stopped from the work process due to a decrease in the water level or are operated at relatively low capacities. That is, it works at maximum capacity only when there is enough water, while micro-hydroelectric power plants, on the other hand, are extremely convenient and efficient in the efficient use of low water flows that large hydroelectric power plants or large hydroaggregates cannot fully use.

A number of methods for the development of micro hydropower plants, reconstruction of existing ones and improvement of new types of special energy-efficient constructions, and the scientific works of a group of scientists who conducted scientific research in this field were reviewed and analyzed[1, 5, 6, 7, 8,]. In particular, hydro turbines operating in low-pressure water streams have attracted the attention of many field researchers. In particular, screw turbine micro hydropower plants, which are simple in use and structurally, new and efficient, are becoming more and more popular [5].

2. Methods

Many researchers are working on improving the efficiency of Archimedean screw turbines in low-pressure water flows and low flow velocities. Design, calculation and several studies were also carried out for the production of the Archimedean screw turbine. For the production of a screw turbine, it is necessary to have detailed information [5, 6, 9, 10, 11]. When designing screw turbines, it is first necessary to determine the total length of the screw and its angle of inclination. The slope angle should be determined depending on the place where the turbine will be installed and its slope. If there are minimum restrictions on the turbine installation area and angle, the value $\beta = 22^{\circ}$ can be taken into account, since many existing Archimedean screw turbines today are installed at the same slope angle in installed power plants. Care should be taken that the value of β is taken as 30° depending on the length of the screw or less than 20°

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due to the length of the longer screw [6], as it significantly reduces the torsional strength. The most important dimensions and parameters needed to define Archimedean screws are classified as external (D_o, L ва β) and internal (D_i, N ва S) parameters [5, 6].

Archimedean screw is considered as the main part of micro hydropower plant with screw turbine. Figure 1 shows the most important dimensions and parameters necessary for the selection of an Archimedes screw configured as a micro-hydroelectric plant.

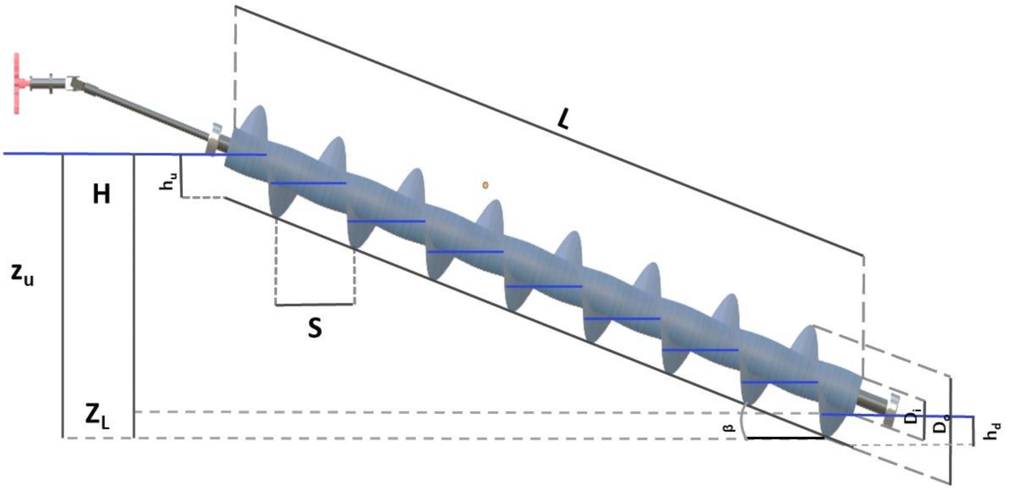

Fig. 1. Geometrical parameters of the Archimedean screw turbine model drawn through

The main important parameters of screw turbine micro-hydroelectric power stations are hydrostatic pressure generating height H and volume flow rate Q. Using continuity and Bernoulli equation, it can be shown that the pressure generating height in an Archimedean screw turbine installation is ideally the difference between the free surface heights $Z_U$upstream and Z_L downstream [6, 7].

$$\mathrm{H} = \mathrm{Z_U} - \mathrm{Z_L} \tag{1}$$

where: both $\mathrm{Z_U}$ and $\mathrm{Z_L}$ are measured from the same reference.

The slope angle β of Archimedean screws is sometimes chosen based on the slope or on the basis of a limited geometric value. Based on the known height, the length of the screw is as follows:

$$\mathrm{L} = \mathrm{H}/\sin\beta \tag{2}$$

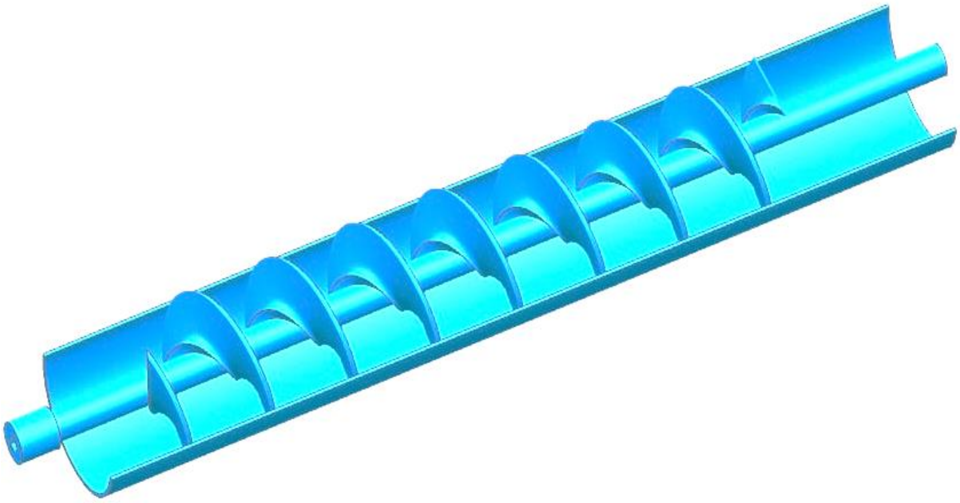

Fig. 2. Spiral-shaped screw turbine attached to the shaft

The ratio of the radius of the screw

$$\delta = R_i/R_o \ \ (0 \le \delta \le 1) \tag{3}$$

where: R_o - outer radius of the shaft with screw blade;
R_i - inner radius of the turbine
The total pitch of the screw turbine (λ)

$$\lambda = \frac{2\,\pi\,R_O}{K} \tag{4}$$

where: K - slope of the screw $K = \tan\beta$
One cycle of the blade (S)

$$S = \frac{\lambda}{m} \tag{5}$$

where: m - total number of screw
The volume of water hitting the turbine (V_T)

$$V_T = \frac{2\,\pi\,R^3}{K} \tag{6}$$

The area of the screw (A)

$$A = \frac{\pi\,D_O^2}{4} \tag{7}$$

where: D_o - Outer diameter of the screw
Velocity of water impinging on the turbine (v)

$$v = \sqrt{2\,g\,H} \tag{8}$$

To develop the presented model, we can see that the flow rate through the screw Q depends on the flow depth h_u at the inlet, the total outer diameter D_o and the speed of rotation of the screw ω.
In screw turbines, blade surfaces (F) are determined based on the volume of water between two adjacent helical blades. Impact of water on the surface of the helical blades is shown in Figure 3.

$$F = \frac{V_T\,2\,\pi}{\omega} \tag{9}$$

where: ω - Rotation speed of screw

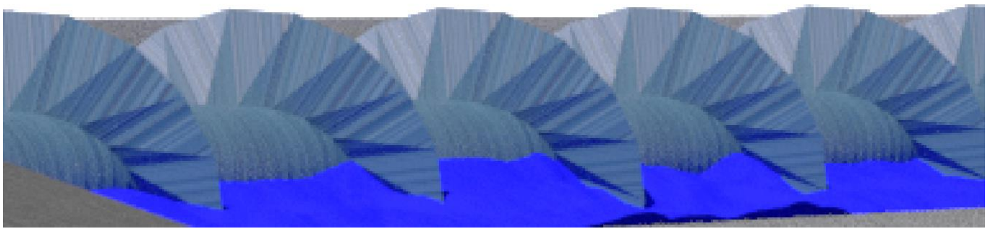

Fig. 3. Impact of water on the surface of the helical blades

The rotation speed of the Archimedean screws is determined by the following expression [6]:

$$\omega_M = \frac{5\,\pi}{3\,D_o^{2/3}} \tag{10}$$

The effective working area inside the screw (A) and the volume of current passing through the speed of the Archimedean screw (V_T) can be expressed as a function of the depth of entry of the Archimedean screw:

$$Q = A\,V_T \tag{11}$$

Hydraulic capacity of the system (P_{in})

$$P_{in} = \rho\, g\, Q\, H \tag{12}$$

where: ρ − density of water 1000 kg/m^3;
g − gravitational constant 9.81m/s^2

Number of rotations (n)

$$n = \frac{50}{2\,R_o^{2/3}} \tag{13}$$

System efficiency (η) [6].

$$\eta = 1 - \frac{0{,}01125\, D_0^2}{\frac{Q}{(2n+2)}}\,(2n+1) \tag{14}$$

Output power (P_o)

$$\eta = \frac{Po}{P_{in}} \tag{15}$$

Turbine torque (T)

$$T = \frac{P}{\omega} = \frac{P}{2\pi n/60} \tag{16}$$

3. Results

The obtained calculations were made based on the study of literature analysis carried out to date. These calculations are based on the mathematical model developed on the basis of information presented in several articles, magazines and books on the hydraulic machine [1, 10-13] and a small model of the screw hydro turbine was developed (Figure 4).

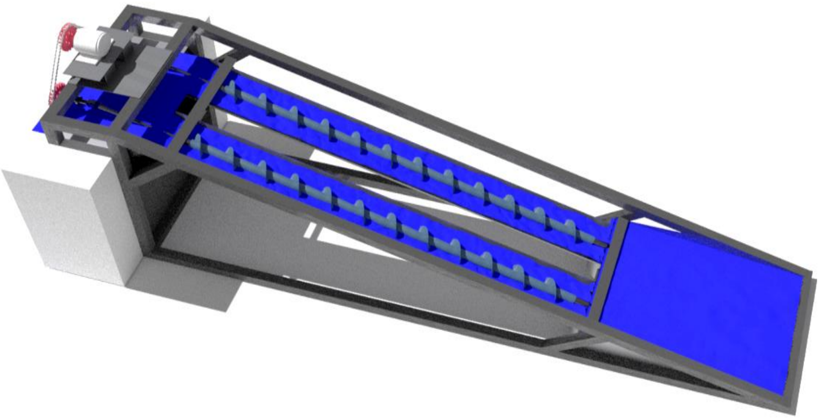

Fig. 4. A model of two parallel Archimedean screw turbines drawn by geometrical parameters

The main goal of the research was to develop a small model of a small hydroelectric power plant with two parallel Archimedean screw turbines, which is simple in terms of construction and easy to install. Power losses characteristic of Archimedean screw turbines were studied and considered based on mathematical modeling of these losses. Based on the proposed model, a small model of an Archimedean screw micro hydroelectric power station with a simple engineering design was developed and tested in the laboratory. Archimedes screws' geometry and operating variables are presented in Table 1.

Table 1. Archimedes screws' geometry and operating variables

Parameter	**Variable**	**Unit**	**Value**
Outer radius	R_o	m	0,0575
Inner radius	R_i	m	0,0287
Radius ratio	δ		0,499
Rotational speed	n	rev/min	28
Screw length	L	m	0,98
Head	H	m	0,4
Screw inclination	β	$(^0)$	24
Number of flights	N		1
Screw pitch	S	m	0,101
Total number of screw			8
The gap between the trough and screw	G_w	m	0,002
Flow rate	Q		m^3/s
Total screw Torque	T	Nm	6,89
Power	P	W	85.3

The power and torque results of the developed micro-hydroelectric power plant with parallel screw turbine for low-pressure water flows are presented in Figure 5. The angle of inclination of the turbine is assumed to be 24^0. Increasing the pitch angle and pressure generating height will affect the speed of rotation of the turbine.

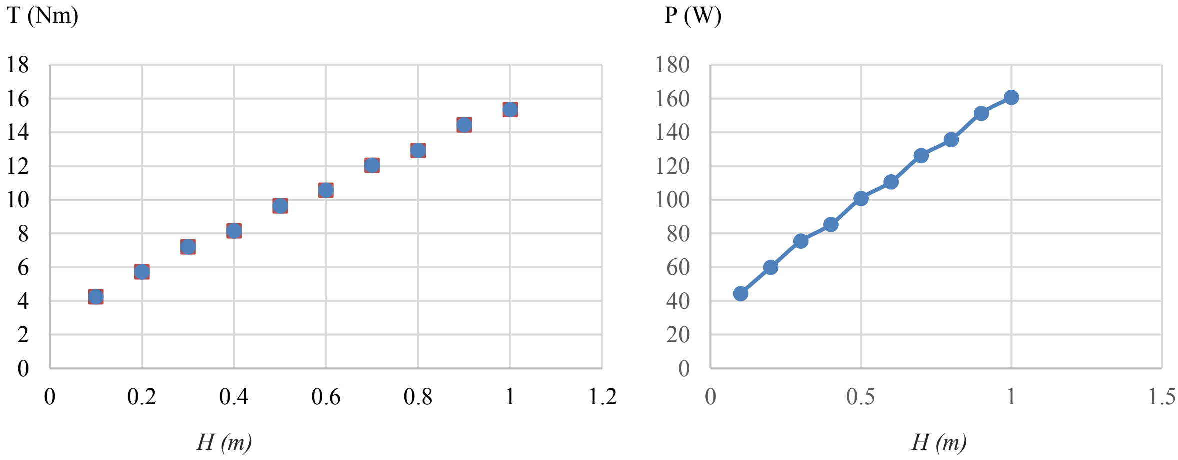

Fig. 5. Torque and Power of screw turbine as function of head for slope 24^0

4. Conclusion

The article analyzed the prospects of sustainable energy production and hydropower development, which is one of the most important problems in the world today, and their positive and negative aspects.

The potential of micro-hydroelectric power plants with Archimedean screw turbines and the effective aspects of using this technology are shown in the sustainability of small hydropower development.

As a result of the research, a laboratory model of a micro-hydroelectric power plant with a parallel screw turbine operating in low-pressure water flows was developed based on analytical equations and studies, and a description of the analytical and experimental studies conducted on these turbines is presented.

According to the results of the test, the effect of the developed screw hydroturbine slope angle on the turbine's mechanical strength and its efficiency was studied as a result of the amount of flow hitting the blades, i.e., the amount of water flowing through the blades or insufficient flow.

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