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HYDRO-ELECTROSTATION OF HYDROCYCLONE TYPE OF SMALL POWER FOR LOCAL ENERGY SUPPLY

Abstract. The results of the analysis of the structural features of the existing mini hydroelectric power stations operating with the use of a circulating effect are presented to improve the rotation of the turbine and protect its surface from the ingress of mechanical impurities.

It is shown that the developed structure differs from existing ones, where the water intake of the hydraulic station is made in the form of a cylinder-conical hydrocyclone capsule inside which the turbine is coaxially located and attached to the capsule by means of a discontinuous septum from curved plates in the direction of water twist. Advantages of the improved version of the laboratory stand for testing the hydrocyclone mini hydro-power plant and its main dimensions are indicated.

It is noted that when using the proposed solution, the working capacity of the hydraulic unit is increased, the power characteristic of the unit is improved to 10-15%. The degree of water purification in hydrocyclones during operation in the pressure regime reaches 95-97%. The simplicity of the design of the hydroelectric power station and the technological layout scheme reduces the manufacturing costs by up to 20%.

Key words: low-power hydroelectric power station, hydraulic turbine, abrasive wear, design development, hydrocyclone, laboratory bench, preliminary test.

Experience in the use of most mini and small HPP has shown that one of the problematic issues in the system of development of various types of hydroelectric power stations is the maintenance of operational reliability in general and the protection of hydroturbines from abrasive wear [1-12].

As the results of patent information search in this direction show, a number of known technical solutions to the problem of wear protection are based on preliminary cleaning of the supplied water from the water source into the hydroturbine [13-20]. For example, in the invention with the name "Hydro-electric power plant on a spiral flow of water" [13], 27.10.2009, in order to improve water treatment, the booster tank is designed as a spiral tray, the output part of which runs under the bottom of the input part of tray with offset. In this case, before the flow out of the tray, a threshold that is movable in the vertical plane is installed, which to some extent complicates the design and operation of hydroturbine when the depth of watercourse changes. In addition, the lack of a node for continuous removal of trapped mechanical impurities in the dump leads to an overestimation of operating costs.

«Gravitational vortex station» of Franz Zotlöterer from Switzerland used in practice [15], including the water supply system, the circular pool with a spiral swirl outlet in the center, works by using tangential effect of water supply to central part of the station, which creates swirling flow and rotation hydro turbines located in the center of the funnel. However, this mini hydropower plant construction requires a large water flow per unit of output power with a low head (0.7-1.0 m). The significant diameter of the pool (more than 5 m) and the complexity of the layout scheme lead to an increase in construction costs, complicates maintenance and to some extent leads to a decrease in the power characteristic.

It has been established that the main shortcomings of hydroelectric power plant, equipped with settling tanks that capture suspended solids, are the cumbersome structure, passivity of water purification

processes, due to the precipitation of mechanical impurities through its own weight. Poor-quality water treatment leads to the erasure of the surface of water conduits and turbines, a significant drop in coefficient efficiency, therefore, to a decrease in power and generation of electricity from hydroelectric power plant.

The closest in terms of the technical essence to the proposed development is "Circulating mini-hydroelectric power station" [16]. It contains a water intake from the river supply water conduit, cylindrical tank, hydro turbine, and generator, characterized in that in the bottom of the cylindrical container there is an aperture with a shell, in front of which there is nano-collecting gallery, the output part of which passes under the bottom of a cylindrical vessel. In this case, sediment deposition in the annular nano-collecting gallery is carried out tangentially.

However, the following disadvantages are inherent in the said hydroelectric power station. Water intake execution basin of circulating action in the form of cylinder to a certain extent reduces its sand separating capacity from incoming water and complicates accumulation and removal of trapped mechanical impurities into the dump. The presence of rectangular cross, on which the hydro turbine is attached, prevents rotation of flow inside the cylindrical basin.

The task of the proposed development is simplification of design mini-hydroelectric power stations of circulation action and ensuring purification of water entering the working hydro turbine from mechanical impurities by using rotational effect in hydrocyclones.

The goal is achieved by the fact that water intake of station is made in form of cylindrical-conical hydrocyclone capsule inside which a turbine with smaller diameter is coaxially located to cylindrical part, the hydro turbine axis to the capsule being attached by means of a discontinuous baffle plate from curved plates in the direction of water twist, tangentially fed to the water intake (applied NIIP №2018/0169.1 or 15.03.2018y.).

Figures 1 and 2 show the scheme and general view of the hydrocyclone type mini hydroelectric power station developed. It includes an advance chamber 1, gate valve 2, supply water conduit 3, hydrocyclone-receiver 4, hydro turbine 5, partition 6, drainage branch 7, sand hole 8, generator 9, belt transmission 10 and tensioner 11.

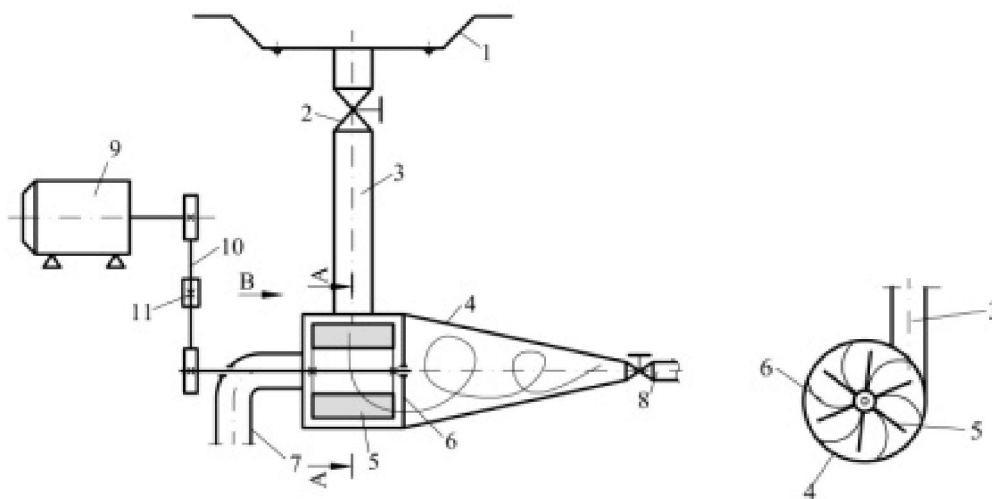


Figure 1 – Constructive diagram of mini hydroelectric power plant hydro-cyclone type

The developed mini hydroelectric power plant works as follows. When the hydroelectric power plant is put into operation pressurized water, which from the pre-chamber 1 with mechanical impurities through the gate valve 2 along the supply conduit 3 enters tangentially into the hydrocyclone-receiver 4 where the hydro-turbine 5 is coaxial.

Due to the tangential input of water, a strong rotational motion is formed, i.e., the circulation of the flow, which acts on the upper surfaces of blades and rotates the turbine fixed inside capsule by means of a discontinuous septum 6 of curved plates in direction of water twist.

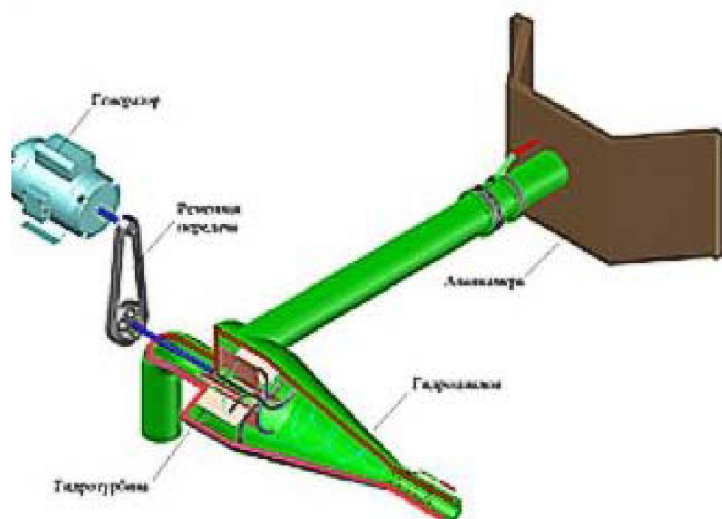


Figure 2 –
Scheme of mini hydroelectric hydro-cyclone, made in 3D

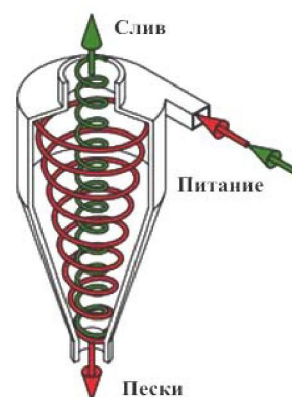


Figure 3 – Types of external and
internal swirling water flows in the hydrocyclone

In the separation and carrying away solid particles towards the sand hole 8 of hydro-cyclone, the internal swirling flow of purified water rising to the top of the spout 7 enhances the rotation of the turbine shaft from the inner side (figure 3).

The interaction of two surface swirling flows significantly increases the efficiency of the hydraulic unit and increases the power by 15-20%.

Rotation of the turbine through the belt transmission is transmitted to the generator 9. The generator generates an electric current.

The mechanical impurities trapped in the hydrocyclone, predominantly in the form of fine sand, accumulate at the sand hole and are ejected at the expense of the residual head into the dump through the pipe.

In the mini hydropower plant technological scheme, if necessary, i.e. when the water level in the river fluctuates to a smaller or larger side can be used a tensioner 11 provided with an additional wheel with a spring.

Minihydroelectric power station is mainly adapted for individual use in mountainous conditions, where the water supply is sufficient.

The first version of this development for a small hydroelectric power plant was demonstrated at EXPO-2017 among 28 domestic projects [17, 18].

When developing a new mini hydroelectric power plant of hydrocyclone type, the calculated power output was determined by the formula:

$$N_p = 9,81 Q_t H_t, \quad (1)$$

where Q_t – water flow to the turbine, m^3/h ; H_t – water pressure at the hydroturbine, m.

Then, the power on the turbine shaft is $N_t = N_p \eta_t$, where η_t is the turbine efficiency, N_t is in kW.

The value of the efficiency of the turbine depends on the change in the load. For small turbines, with a diameter of the impeller less than 1 m, efficiency is 0.89-0.91; for large turbines 0.94-0.96. Electric power of the unit N_u (kW) at the generator terminals is less than the turbine power by the amount of losses in the generator

Estimated water flow for one turbine:

$$Q_t = \frac{N_a}{9,81 \cdot H_p \cdot \eta_a}; \quad (2)$$

To determine the diameter of the impeller, we use the universal characteristic of the executed turbine.

The diameter of impeller D of a hydroturbine is determined by the formula:

$$D = \sqrt{\frac{N_t}{9,81 \cdot Q'_l \cdot H_p \cdot \eta_T}} \quad (3)$$

where N_t – nominal power of the hydroturbine, kW; Q'_l – reduced flow at the design point, m³/s; H_p – rated head of the turbine, m; η_T – the full efficiency of the full-scale hydroturbine, corresponding to the mode of its operation at the design point.

The initial data for the calculation of the hydrocyclone body for providing the hydroturbine of mini hydro power plants with water purified by water were adopted:

The flow rate of water passing through the hydrocyclone is Q_p , m³/h;

The pressure drop of the liquid at the entrance to the hydrocyclone and the exit from it $-\delta H$, m;

Density of water with mechanical impurities $-\rho_h$, kg/m³;

The content of suspended particles before purification is γ , mg/l.

Then, according to the method described in [19], the diameter of the cylindrical part of the hydrocyclone:

$$D_c = \sqrt{\frac{Q_H}{0,13 \times k_1 \times \sqrt{\delta H}}} \quad (4)$$

where Q_p – water flow through the hydrocyclone, m³/s; k – experimental coefficient of dimension, $k = 0.45-0.65$; δH – pressure drop of the fluid at the entrance to and exit from the hydrocyclone.

Usually for hydrocyclones of medium and large diameters, depending on the inlet pressure, δH is (15–25) H_{out} ;

Diameter of the discharge pipe

$$d_{dis} = \frac{D_c}{k_2}, \text{ m}, \quad (5)$$

where k_2 is the coefficient determining the ratio of the diameter of the discharge pipe to the diameter of the cylindrical part, $k_2 = 3.5 \dots 4$.

Figure 4 shows a diagram of a laboratory bench for testing a hydro-cyclone mini hydroelectric power plant. The stand is placed on two tables [20].

On the first table is the main part of the research stand, made on the basis of a centrifugal pump 1.5KM with step-by-step power control, parameters of the pressure hydrocyclone and a hydroturbine. To change the operating mode, special valves, electronic pressure sensors, installed at the assembled units of the hydraulic unit, as well as an electronic flowmeter were used. Under the table was a container with water for circulating water supply, into which liquid is supplied from the suction pipe of the model of a small hydroelectric power plant.

On the second table a personal computer with a monitoring program of the stand installation and a communication cabinet with control and measurement elements, as well as a module for interface of measuring sensors with a personal computer, are installed.

The basic pump of the stand has a capacity up to $Q = 20-25$ m³/h and a head $H = 30$ m. A hydro-cyclone body with an internal diameter of $D = 200$ mm at rated operating conditions can provide a purified water capacity of up to 20 m³/h. Connecting and distribution pipes have diameters in the range of 32–40 mm. The water tank is designed for 70–80 l. Based on these parameters of the basic units, the power produced by the hydroturbine was determined to 4–5 kW.

Preliminary experiments show that the value of the generated power (energy) directly depends on the pressure on the line and frequency of rotation generator shaft. Increasing the pressure on the impeller of the turbine increases the speed of rotation and thereby increases the technological capability of unit to maximize the use of energy from water resources.

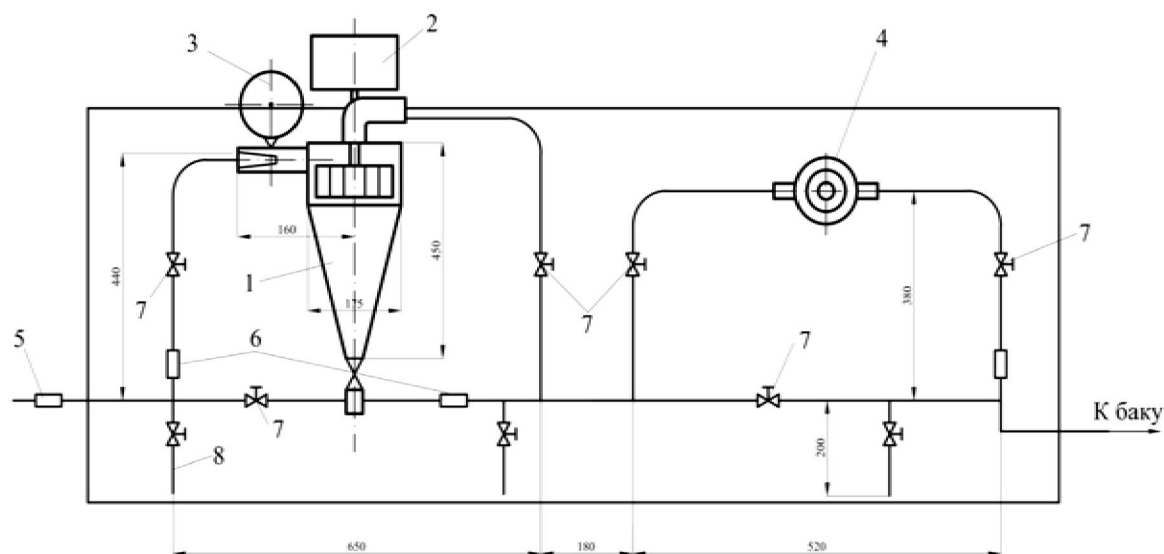


Figure 4 – The stand-alone diagram of a laboratory stand for testing a hydro-cyclone minihydroelectric power plant type:
1 – hydrocyclone with a hydroturbine; 2 – generator; 3 – dispenser; 4 – small hydroelectric unit;
5 – electron flowmeter; 6 – electronic pressure sensors; 7 – gate valve; 8 – drainage

As indicated in work [1], the modeling of water purification processes in the hydrocyclone allows to determine the data for designing production plants that provide the most productive work. In this way, modeling the operation of the hydrocyclone significantly reduces the number of model and full-scale tests.

Based on the results of the analysis, it is established that to use computer simulation data the numerical model must be verified by a physical experiment. Therefore, numerical analyzes of the processes were carried out on the basis of STAR CCM + 6.04 software package using the results of experimental studies of the hydrocyclone water treatment unit, set forth in the scientific report [1].

A positive feature of the upgraded booth is that its design provides possible modes of operation for different layouts, for example: pump-hydrocyclone, pump-hydrocyclone-hydraulic turbine and pump-tank. Using the adopted technological closed line, it is possible to carry out experiments in a continuous mode and to study the parameters of the main elements separately and in aggregate.

In general, the minihydropower plant under consideration, in contrast to the existing analogs, makes it possible to use mini hydro power plants in the capsular version and to master the hydrocyclone effect for separating the solid phase from the liquid in the water supply of the hydroturbine. At the same time, the working capacity of the hydraulic unit is improved, the power characteristic of the unit is improved to 10-15%. The degree of water purification in hydrocyclones during operation in the pressure regime reaches 95-97%. The simplicity of the design of the hydroelectro station and the technological layout scheme reduces the manufacturing costs by up to 20%.

The considered mini hydroelectric power station of hydrocyclone type is developed according to the target program "Creation of the basics serial production of Kazakhstan renewable energy sources of the world level" (BR05236263, NASRK, 2018-2020).

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БӨЛЕК ОРНАЛАСҚАН НЫСАНДАРДЫ ЭНЕРГИЯМЕН ҚАМТАМАСЫЗ ЕТУГЕ АРНАЛҒАН ШАҒЫН ҚУАТТЫ ГИДРОЦИКЛОН ТИПТЕС ГИДРОЭЛЕКТРОСТАНЦИЯ

Аннотация. Гидротурбинаның айналуын жақсарту және механикалық қоспалардың әсерінен оның бетін қорғау үшін су айналымы әсерінен жұмыс істейтін қолданыстағы шағын гидроэлектростанциялардың жобалық ерекшеліктерін талдау нәтижелері келтірілген.

Қарастырылып отырған гидроэлектростанцияның бұрынғылардан ерекшелігі, яғни оның су қабылдағышы цилиндрлі-конусты түрде жасалған гидроциклондық капсуладан тұратындығы, оның ішіндегі қалақшалы турбинаның бір бойлықта орналасқандығы және оның капсулаға айналма су бағытына сәйкес қисатылған пластинкалармен бекітілгені көрсетілген.

Гидроциклондық шағын гидроэлектростанцияны сынақтан өткеруге арналған стендтің жетілдірілген нұсқасының артықшылықтары және оның негізгі өлшемдері келтірілген.

Ұсынылған шешімді пайдаланған жағдайда гидравликалық агрегаттың жұмыс қабілеттілігінің артып, қуаттық сипаттамалары 10-15%-ға дейін көтерілетіндігі, қысымдық жұмыс режимі кезінде суды тазарту дәрежесі 95-97% жететіндігі баяндалған. Гидроэлектростанция құрылымының қарапайымдылығы және технологиялық оңтайлылығы тұрғызу және пайдалану шығындарын 20%-ға дейін төмендетеді.

Түйін сөздер: мини ГЭС, гидротурбина, абразивті қажалу, құрылымды жасау, гидроциклон, тәжірибелік стенд, алдын ала сынақтан өткеру.

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ГИДРОЭЛЕКТРОСТАНЦИЯ ГИДРОЦИКЛОННОГО ТИПА МАЛОЙ МОЩНОСТИ ДЛЯ ЛОКАЛЬНОГО ЭНЕРГООБЕСПЕЧЕНИЯ

Аннотация. Приведены результаты анализа конструктивных особенностей существующих мини ГЭС, работающих с использованием циркуляционного эффекта для улучшения вращения гидротурбины и защиты ее поверхности от попадания механических примесей. Показано отличие разработанной конструкции от существующих, где водоприемник гидростанции выполнен в виде цилиндрико-конической гидроциклонной капсулы, внутри которой соосно расположена лопастная гидротурбина и она к капсуле прикреплена с помощью несплошной перегородки из изогнутых пластин по направлению закрутки воды. Указаны преимущества усовершенствованного варианта лабораторного стенда для испытания мини гидроэлектростанции гидроциклонного типа и его основные размеры.

Отмечено, что при использовании предлагаемого решения повышается работоспособность гидроагрегата, улучшается мощностная характеристика агрегата до 10-15%, Степень очистки воды в гидроциклонах при работе в напорном режиме достигает 95-97%. Простота конструкции гидроэлектростанции и технологической схемы компоновки снижает затраты на изготовления до 20%.

Ключевые слова: мини ГЭС, гидротурбина, абразивный износ, разработка конструкции, гидроциклон, лабораторный стенд, предварительное испытание.

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