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MICRO HYDROELECTRIC POWER PLANT DESIGN BASED ON A FLOW-THROUGH HYDRO TURBINE

АҒЫНДЫҚ ГИДРОТУРБИНА НЕГІЗІНДЕГІ МИКРОГЭС-тің ЖОБАСЫ

КОНСТРУКЦИЯ МИКРО-ГЭС НА БАЗЕ ПРОТОЧНОЙ ГИДРОТУРБИНЫ

Abstract. *This article presents data on the design of a damless micro hydroelectric power plant (further – «MHPP») based on a flow-through hydro turbine designed for autonomous power supply. The presented article describes the methods of development and modeling of MHPP in the CAD system of the SolidWorks program. The authors have solved a number of scientific and technical problems, which include: ensuring minimal energy losses in the flow part of the turbine; creating a turbine design and its parts that are technologically advanced in mass production. The simulation of the flow part of the turbine used in the work made it possible to ensure the correct choice of the input and output angles of the blades and to design the blade taking into account the results obtained during modeling. With the specified parameters (head, flow rate, rotation speed), the meridian outlines of the turbine flow section are selected.*

Keywords: *micro hydroelectric power plant; hydro turbine; modeling; engineering; electric power.*

Аннотация. *Бұл мақалада автономды электрмен жабдықтауға арналған ағынды гидравликалық турбинаға негізделген бөгетсіз шағын су электр станциясының жобасын әзірлеу туралы деректер келтірілген. Бұл мақалада SolidWorks бағдарламасының CAD жүйесінде шағын су электр станцияларын әзірлеу және модельдеу әдістері сипатталған. Авторлар бірқатар ғылыми-техникалық міндеттерді шешті, оларға мыналар жатады: турбинаның ағынды бөлігінде энергияның минималды шығынын қамтамасыз ету; сериялық өндіріс жағдайында технологиялық жағынан ерекшеленетін турбинаның және оның бөліктерінің құрылымын құру. Жұмыста қолданылатын турбинаның ағынды бөлігін модельдеу пышақтардың кіріс және шығыс бұрыштарын дұрыс таңдауға және модельдеу кезінде алынған нәтижелерді ескере отырып, пышфақты жобалауға мүмкіндік берді. Берілген параметрлерде (бас, ағын жылдамдығы, айналу жиілігі) турбинаның ағын бөлігінің меридиан контуры таңдалады.*

Түйін сөздер: *шағын су электр станциясы; гидравликалық турбина; модельдеу; инженерия; электр энергиясы.*

Аннотация. *В данной статье приведены данные по разработке конструкции бесплотинной микро-ГЭС на базе проточной гидротурбины, предназначенной для автономного электроснабжения. В представленной статье описываются методики разработки и моделирования микро ГЭС в CAD системе программы*

SolidWorks. Авторами решены ряд научно-технических задач, к которым относятся: обеспечение минимальных потерь энергии в проточной части турбины; создание конструкции турбины и её частей, отличающихся технологичностью в условиях серийного производства. Применяемое в работе моделирование проточной части турбины позволило обеспечить правильный выбор входного и выходного углов лопастей и спроектировать лопасть с учетом полученных при моделировании результатов. При заданных параметрах (напор, расход, частота вращения) выбраны меридианные очертания проточной части турбины.

***Ключевые слова**: микро-ГЭС; гидротурбина; моделирование; инженерия; электроэнергия.*

Introduction. Currently, the problem of lack of electricity for many people around the world is becoming more and more urgent. This is especially true for those populated areas that are geographically located far from large cities or industrial centers. This is due to the fact that equipping such areas with electricity, that is, laying the appropriate connection, is quite expensive. Therefore, the issue of solving the problem of generating environmentally friendly and economically profitable renewable electricity is currently acute, especially for the development of remote rural areas without developed infrastructure (Mahfoud et al., 2023).

To solve this problem, the construction of an MHPP is most optimally suited. This is characterized by relative economic cheapness and ease of construction and operation (Lee et al., 2021).

In all countries, the production of electric and thermal energy based on renewable energy sources is growing (Gjorgievski et al., 2021; Puksec et al., 2020; Guzovic et al., 2020). There is a tendency in Kazakhstan to increasingly understand the need and possibility of using small hydropower to electrify people's places of residence, develop small industries and improve the quality of life of the population.

Energy supply using renewable energy sources in Kazakhstan is increasingly being considered as an alternative option for rural electrification. In Kazakhstan, renewable energy projects are given priority in the transmission of electricity through networks, support for the allocation of land by Potential consumers of electricity is provided by the state represented by the Ministry of Energy of the Republic of Kazakhstan through the purchase of electricity through auctions. Consumers can also be the nearest industrial enterprises. According to the statistics department, as of 01.01.2021, 624 industrial enterprises operate in the region. Also, in case of losing the auction, agricultural production and ecotourism can become consumers (83 operating farms in East Kazakhstan region alone).

Literature review. A double damless hydraulic turbine Fedchishin B.G. is known, including a platform, coaxial rotors with blades kinematically connected by conical gears with an energy converter shaft and having unidirectional rotation (Avanesov et al., 2018). The sealed underwater generator housing is equipped with a compressed air cylinder and a gearbox (Patent No. 2018123294). The complexity of the design is due to the bevel gear, the blades are also double, the rotors are placed on consoles.

A flow-through damless hydraulic turbine is known, which contains a pontoon with a supporting rack on which inclined paired rotors are fixed (Patent No. 2019131021). The rotors interact with the power take-off shaft through hinged couplings, and through a sprocket rigidly fixed to the shaft, with a multiplier and a power unit. The design is difficult to perform due to the inclined paired rotors in the form of a shaft with blades, as well as the power take-off shafts of each pontoon do not have a kinematic connection with each other.

The Ossberger flow turbine is also known (Mehr et al., 2021). This is a radial, pressure-jet turbine with medium pressure with tangential water supply to the blades of the impeller with a horizontal shaft. According to its specific speed, it belongs to low-speed turbines. The water flow is regulated by the guiding devices in such a way that water flows through the blade ring into the inner space of the impeller, then passes through the second blade ring from the inner space of the wheel outward into the space of the turbine housing. The main disadvantages of these turbines are their limited capabilities when using the hydropower potential of lowland areas of small rivers due to the available suction pipes.

A hydraulic motor is known, including working blades mounted on fixed supports in a flow path with the formation of flow channels and connected to a power take-off mechanism made in the form of a tape, and a flow distributor made in the form of dampers installed at the entrance to the working channels and connected to a drive mechanism. The fastening is made hinged, with a power take-off mechanism, the blades are connected by other ends. The main disadvantages are: the complexity of the design, the design in the form of an endless ribbon, the flow distributor is made in the form of dampers.

The disadvantages of the above analogues are eliminated as follows. The flow turbine we offer can be installed on the platform of a floating boat pontoon, while the flow turbine is partially submerged in water. Running water through segment-ring channels through guide vanes enters the shovel-forming through-pass channel and rotates the turbine, while several hydraulic turbines are installed in series. Each hydraulic turbine is synchronized with each other through the driveshaft, as a result, the generator rotates with a total torque (Ghazi et al., 2022; Kebede et al., 2022; Gawusu et al., 2022; Baitanaeva et al., 2019; Sakharov & Karaulov, 2017; Konstantinov & Maiorov, 2018).

The purpose of this article is to develop the design of an effective free MHPP based on a flow-through hydro turbine, which ensures an increase in the efficiency of using water energy to generate electricity.

Materials and methods of research. The design of the nodes and parts of the proposed MHPP was developed using 3D visualization in the CAD program SolidWorks. The simulation of fluid flow through the structure of a hydraulic turbine is carried out by the finite element method using the SolidWorks Flow Simulation software.

Results and discussion. As a result of the design work carried out, the general design of the MHPP, as well as its main components and parts, has been developed. The proposed design of a ramjet turbine is schematically shown in Fig. 1,2. Figure 1 shows a general view of sequentially arranged flow turbines; Figure 2 shows the flow turbine itself. A flowing damless hydro turbine consists of a paired pontoon boat 1, the depth of immersion is regulated by sand 2, which is filled into the compartments of the boat pontoon 1. A platform with 3 racks 4 is mounted on the pontoon 1, a shaft 6 is made in roller supports 5 between the supports, to which a rotor 7 with external conical surfaces 8 is connected. Along the outer perimeter of the conical surface 8 of the rotor 7, series-obliquely arranged mutually contacting through channels 9 are installed, while through mutual contacts between the side walls 10 and through channels 9 are made of two-layer spiral-shaped blades 11. The hydraulic turbine is equipped with a protective casing 12, sealing rubber rings 13 are made between the inner plane of the casing 12 and the outer surface of the through channel 9, which are rigidly fixed by the outer conical surface of the through channel 9. To maintain structural strength, the turbines are connected to each other by a boat pontoon 1 using a cable, the turbine shafts of each pontoon are synchronized by rotation of the intermediate cardan shafts 14, pontoons 1 and are equipped with a submerged segment-ring channel 15 for supplying water to the turbine and guide vanes 16. The total torque is achieved due to sequentially arranged flow turbines, which is transmitted to the gearbox 17, then by means of chain gears 18, the rotation is transmitted to the generator 19. It is proposed to make a protective steel housing with a cable entry for the transformer from above, and for the generator from below, and a power cable between the generator and the switchboard.

Figure 3 shows a general view of the impeller of a microelectric turbine, including one obtained using 3D visualization in the CAD program SolidWorks. The wheel diameter was chosen taking into account the initial initial parameters, namely the river flow rate – 3-5 m/s, the depth of the local plain Irtysh river at the installation site is approximately 4-6 m, the required output power of MHPP is at least 1 kW. It is known that the main hydropotential in the Republic of Kazakhstan is geographically located in the Irtysh River basin.

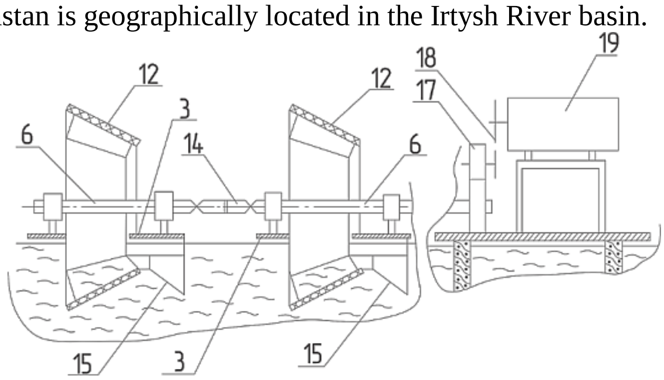


Figure 1. General view of sequentially arranged flow turbines

Note – compiled by the author

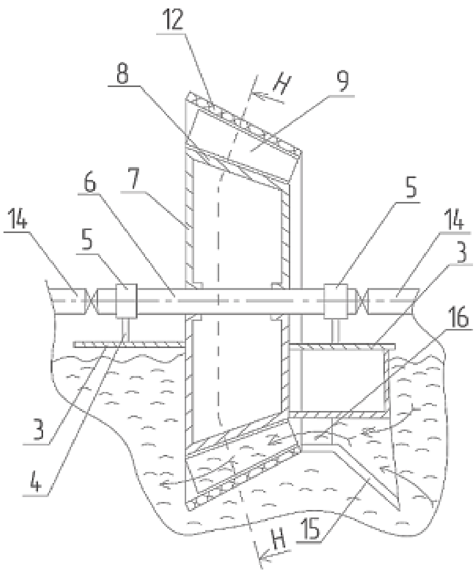


Figure 2. General view of the flow turbine

Note – compiled by the author

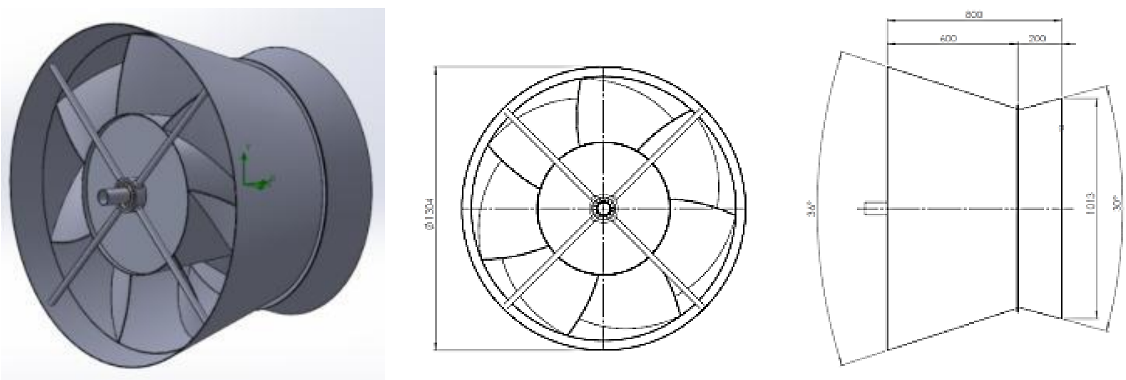


Figure 3. General view of the impeller of a microelectric turbine
Note – compiled by the author

The MHPP turbine is proposed to be subsequently manufactured from a polyethylene material. Polyethylene has a number of advantages: corrosion resistance, acid resistance, lightweight, well-processed material with various processing methods. The body of the MHPP consists of two halves: a directional channel that serves to direct the flow of water to the blades of the turbine and the main body with a turbine wheel. The outer diameter of the wheel is 1304 mm, the inner diameter is 608 mm.

Figure 4 also shows the working blades of the MHPP and the scheme of the directional channel. The height of the working blade is 606 mm, the width is 503 mm. The turbine blades are made with a complex geometry.

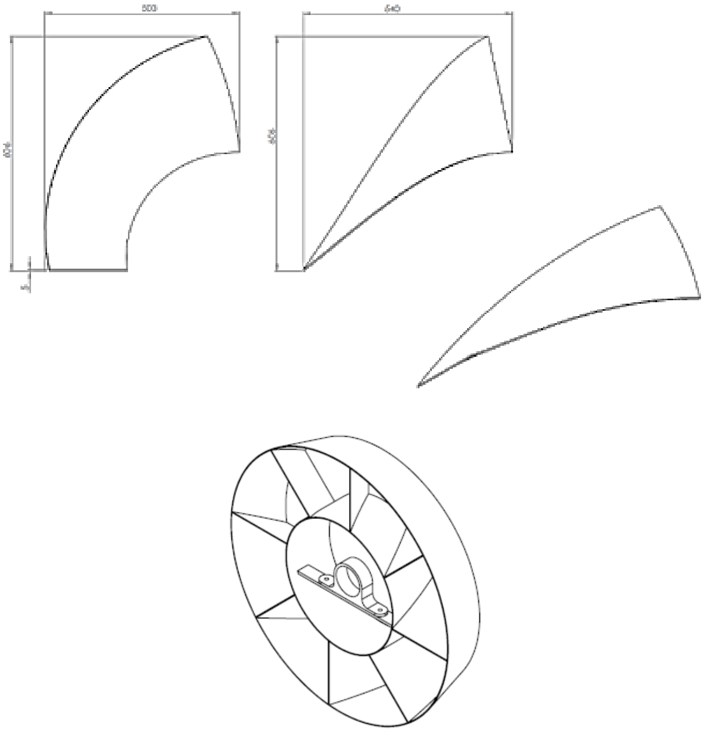


Figure 4. a) Working blades of MHPP; b) General view of the directional channel
Note – compiled by the author

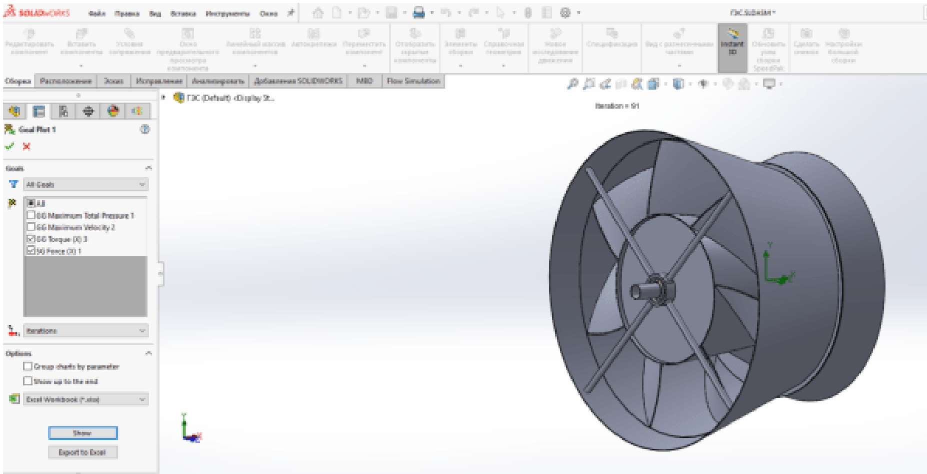
As part of the design development, the loads on the turbine wheel blades were determined in the SolidWorks CAD program. The simulation of fluid flow through the structure of a hydraulic turbine by the finite element method using the SolidWorks Flow Simulation software was carried out.

Conditions set at the boundaries of the calculation area:

• at the entrance is the flow velocity vector corresponding to the river flow;
• on the wall – friction condition (without friction);
• static pressure at the outlet.

The flow velocity set in the simulation was 1.2 m/s.

Figure 5 shows the calculated values of the moment of force and the force exerted by the flow of water on the blades of a hydraulic turbine. The value of the moment of force was 77.610 Nm. The total force acting on the blades of the turbine was 244.062 N.



Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
GG Torque (X) 3	[N*m]	77.610	82.719	77.610	87.275	100	Yes	9.158	84.171
SG Force (X) 1	[N]	-244.062	-194.755	-244.062	-151.777	100	Yes	92.285	136.012

Figure 5. Calculated values of the moment of force and force

Note – compiled by the author

Figure 6 shows the distribution of the water flow velocity through the turbine channel throughout the entire volume of the structure. The water velocity decreases evenly as the channel passes and due to the drop in speed, pressure is exerted on the blades of the turbine, which leads to the rotation of the turbine.

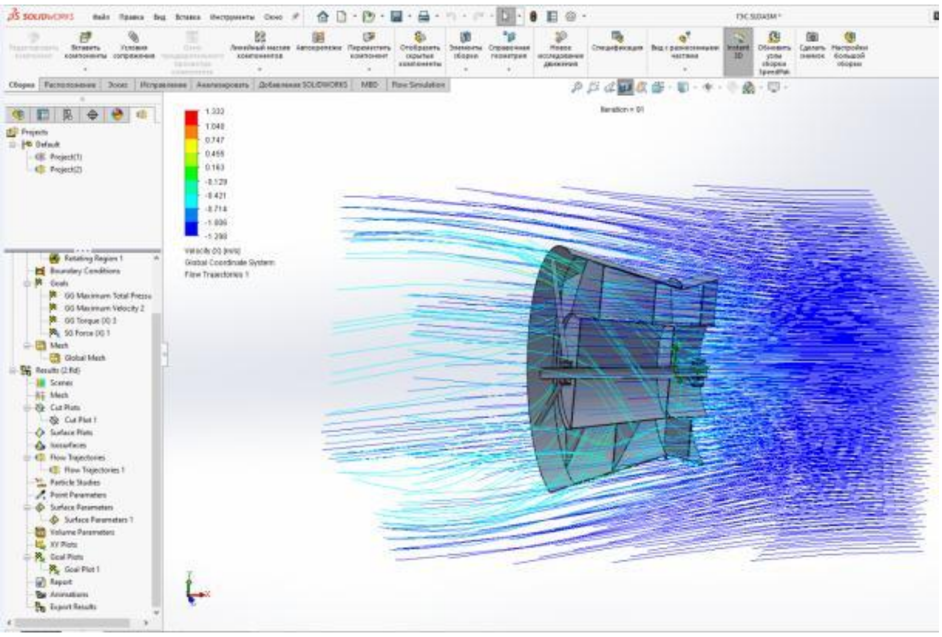


Figure 6. Flow velocity distribution in a hydraulic turbine

Note – compiled by the author

Figure 7 shows a view of the structure from the side of the guide, which shows the distribution of the force exerted by the flow of water on the blades of a hydraulic turbine.

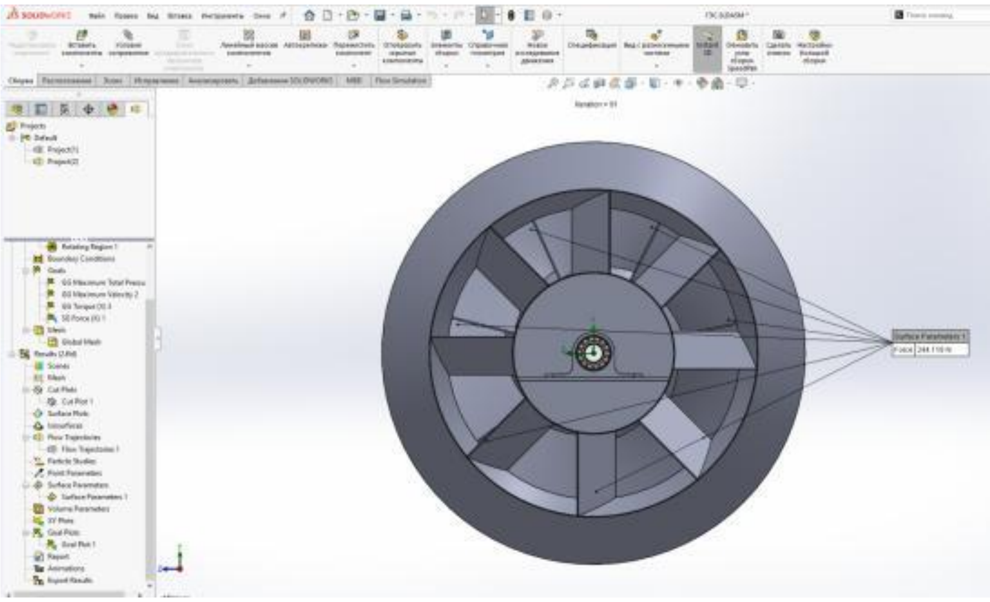


Figure 7. View of the hydraulic turbine from the directional side

Note – compiled by the author

The distribution of the absolute velocity values averaged over the channel height is shown in Figure 8. The velocity decreases uniformly towards the center of the hydraulic turbine, where there is no flow channel, in accordance with the proposed design.

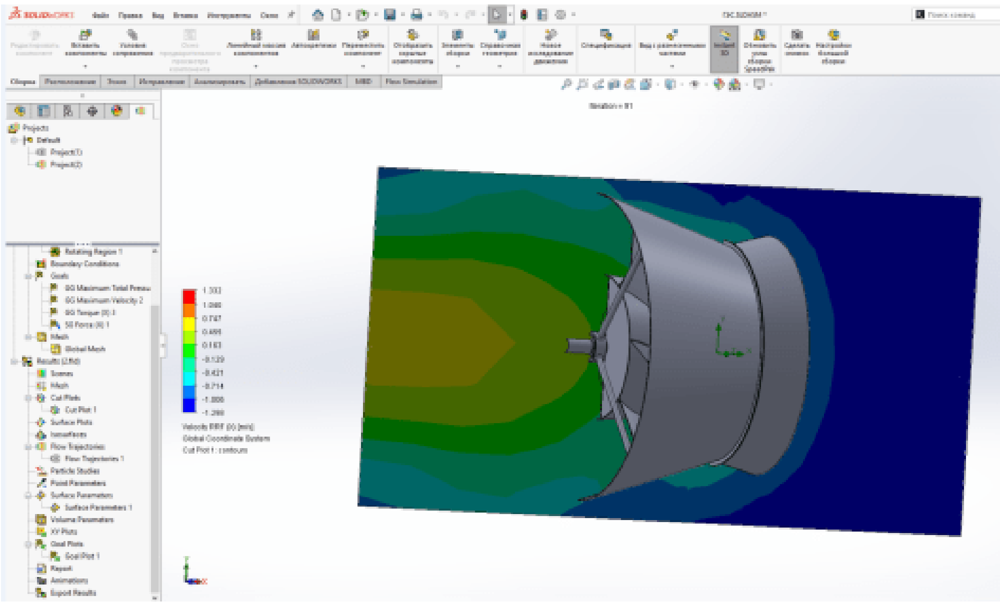


Figure 8. Distribution of velocity values along the height of the hydraulic turbine channel

Note – compiled by the author

Conclusions. The proposed type of MHPP does not require a dam and reservoir, which is a sign of an environmentally friendly power plant. The use of rivers with small flows is of scientific interest in the field of renewable energy sources. This is due to the fact that such water bodies have a high energy density of water flow and relative temporary stability of the flow regime. These indicators can be used in the field of water energy regulation, using a cheap type of conversion of electricity produced. In general, comparing damless MHPP with other types of power plants, it is possible to note the potential for producing cheaper electricity.

When creating the design of a MHPP and its turbine, a number of scientific and technical tasks were solved, which include: ensuring minimal energy losses in the flow part of the turbine; creating a turbine design and its parts that are technologically advanced in mass production. These studies will allow us to develop and unify the requirements for such equipment.

In this article, the authors developed the design of an efficient MHPP based on a flow-through hydro turbine, which provides an increase in the efficiency of using water energy to generate electricity, which made it possible to determine the correct choice of the angles of entry and exit of the blades, as well as to build the blade itself. With the specified parameters (head, flow rate, rotation speed), the meridian outlines of the turbine flow section are selected.

The implementation of these studies will make it possible in the future to manufacture a new MHPP plant design based on a flow-through hydraulic motor and test a prototype with a capacity of ~ 1 kW, while the total power can be increased by sequentially arranging hydraulic turbines.

Conflict of interest. The authors declare no conflict of interest.

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