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Innovative solution of fine horizontal trash rack for small hydroelectric power stations

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Abstract. Alternative energy sources have a number of advantages over energy derived from fossil and nuclear power plants. In this way, the environment is protected, and many countries are encouraging the use of alternative energy sources. Large potential from this aspect has small hydropower plants, which are not expensive, they can be installed on small rivers, and in this way the received electricity is much cheaper. One of the problems that need to be solved is to prevent the penetration of impurities into turbine plants. This is solved by placing protective trash rack on water intakes. The paper presents an innovative solution for horizontal fine trash-rack with cleaning function for small hydro-electric power stations.

1. Introduction

Energy trends have been mostly focused on renewable energy sources in recent years. In the world, about 20% of electricity is produced using energy of water flows - hydropower with a total installed power of 720 GW. The energy obtained from hydroelectric power plants is significantly cheaper than the energy generated from fossil fuels or nuclear energy.

As an alternative energy source, especially in remote areas where other energy sources are not available, small hydropower plants are used. They can be installed on small rivers or streams with little or negligible impact on the environment. When installing a small hydroelectric power plant, it is necessary to take into account the amount of water that is permanently available, since insufficient rain can jeopardize the operation of the power plant, as well as the height drop, ie the height difference between the operation and the outlet of the water.

Water for hydroelectric power plants comes from mountainous areas and passes through its various paths through various forested, uninhabited and populated areas, carrying large amounts of impurities or waste. For the correct and undisturbed operation of turbines, water intakes, and water drainage systems, it is necessary to prevent the penetration of impurities into turbine plants. This is achieved by the installation of appropriate trash-racks. Due to the long distance of the water intake, there is a problem of cleaning these trash-racks. Various automatic cleaners are installed for cleaning, but electric power is required for their operation. Given that these sites are also several kilometers away and in an inaccessible terrain, the application of this solution is unrealistic, increases the production of kilowatts in hydropower plants and requires additional labor. For this reason, the idea was to develop



an innovative solution of a completely autonomous trash-rack with a unified function and a cleaner as well as a reliable performance of the function.

2. Solutions of trash-rack cleaner

Most often, trash-racks made of longitudinally placed rods at the appropriate distance and transversely positioned rods for securing the position of longitudinally placed rods are most often used for the protection of turbine plants. Depending on the dimension of the trash-rack, transverse support brackets are also installed. The design shape and dimensions are shown in Fig.1 [4].

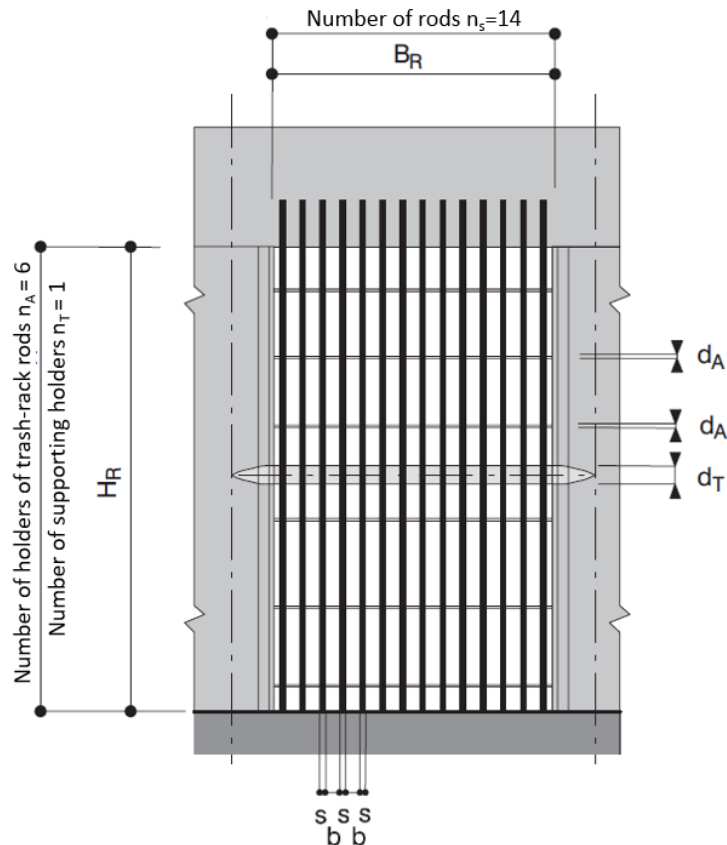


Figure 1. Design shape of trash-rack.

From the point of view of energy losses, an important parameter of the trash-rack is the degree of resistance to the passage of water - the degree of openness of the trash-rack (Verbauungsgrades) P , which is determined as the ratio of the surface of the A_P resistance and the total area of the arc A_{RF} :

$$P = \frac{A_{RS} + A_{AH}}{A_{RF}} = \frac{A_P}{A_{RF}} \quad (1)$$

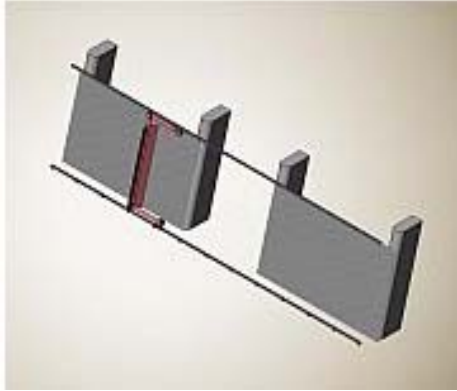
$$A_{RS} = n_s \cdot s \cdot (H_R - n_A \cdot d_A - n_T \cdot d_T); \quad A_{AH} = B_R \cdot (n_A \cdot d_A + n_T \cdot d_T); \quad A_{RF} = B_R \cdot H_R \quad (2)$$

In practice is degree P in the limits between 0,1 and 0,4.

There are different types of trash-rack cleaner (ger. Rechenreiniger) hydropower plants. The principles on which they work can be manual, electrical, electromechanical, automatic, semi-automatic, etc. The shape and principle of the work largely depend on the type of trash-rack.

It can be concluded that there are no completely autonomous trash-rack cleaner, without the need for direct connection to the power grid. This is especially true for small and mini hydro power plants, whose water intakes are far away from the machine building and inaccessible terrain. Consequently, the idea was to develop an innovative solution of a fine horizontal trash-rack with a unified grid

function and a cleaner that will be completely autonomous and use water energy for its work and with automatic monitoring of the working condition.

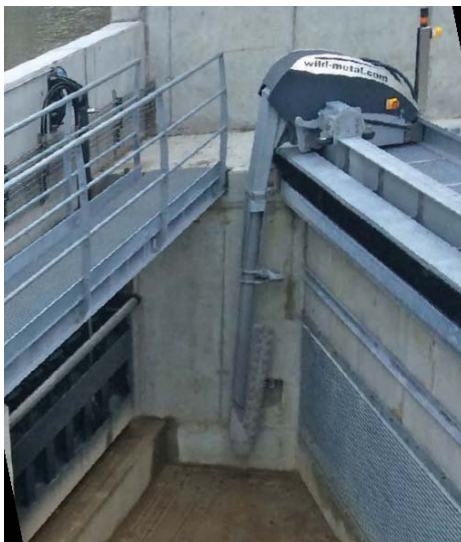


Company Fincos (<http://www.fincos.eu/rechenreiniger.html>) has also developed and manufactured a horizontal trash-rack cleaner. The cleaner of the appropriate construction is placed in the guides and at the appropriate time intervals it moves horizontally along the trash-rack, cleaning it from impurities. It belongs to a group of fully automatic cleaners, but it requires electricity for its operation.

Fincos manufactures and grates (rough and fine) for the protection of turbine plants from impurities. The distance of the rods in the fine trash-rack is 15 mm, which enables reliable protection of turbine plants.



Company Lukas (Fa. Lukas Anlagenbau GmbH) has developed a cleaner for small hydropower plants, which, during cleaning, covers a working width of up to 2 m and a cleaning length of up to 1.5 m. The cleaning brush is made of plastic with smooth and serrated work. This is an articulated sweeper intended for handling and cleaning on-site. It can also clean horizontally and vertically the trash-rack.



Company Wild Metal (www.wild-metal.com) has developed a family of trash-rack cleaners with horizontal movement of the cleaning part. The cleaners are fully automated with electro-mechanical drive. The device for movement is protected by a hood from the influence of the outside environment. Cleaning brushes have plastic teeth.

Figure 2. Overview of trash-rack cleaners for hydropower plants.

3. Designing the conceptual solutions

Ideas of variant solutions describing the mode of operation are shown in Figures 3, 4 and 5.

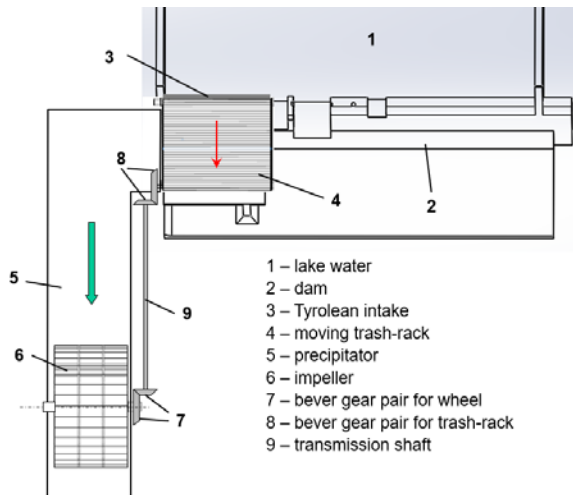


Figure 3. Trash-rack – variant 1.

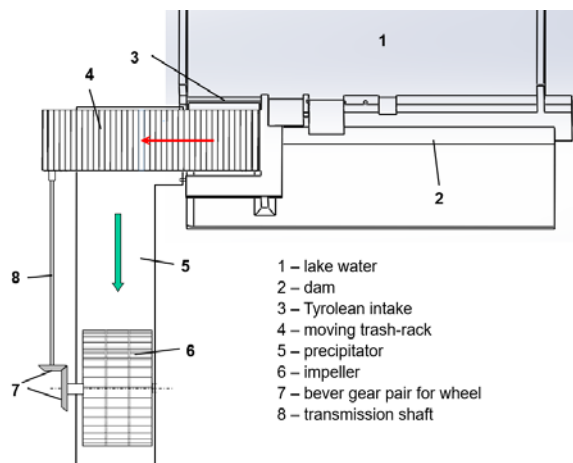


Figure 4. Trash-rack – variant 2.

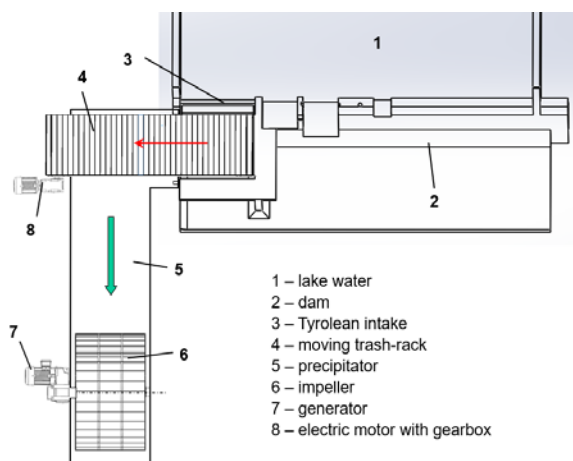


Figure 5. Trash-rack – variant 3.

The trash-rack is mobile and is made according to the model of the conveyor belt with chain drive. Perforated sheet metal is used to prevent the penetration of impurities into the inlet pipeline or turbine plant. Water from the lake over the Tyrolean intake 3 comes to the trash-rack 4 and through the holes on the perforated sheet flows further into the precipitator 5 and the pipeline. In the waterfall of the precipitator, a working wheel 6 is installed, which receives a drive from the flow of water into the precipitator bed. A conical gearing pair 7 is mounted on the output shaft of the impeller. The shaft 9 moves through the shaft 9 and the cone pair 8 via the chain conveyor. With its motion of the trash-rack, it immediately expels the possible penetration of impurities from the lake, or the surrounding environment, which ensures the reliable operation of the turbine of the hydropower plant.

The conceptual solution of the 2 fine trash-rack variant is similar to the solution of variant 1. The difference is that the trash-rack is set transversely in relation to the direction of flow of water over the Tyrolean intake. The trash-rack is driven by a drive from the conical pair 7 and the shaft 8, which is directly connected to the drive chain of the sprocket. This variant is more favorable than the variant 1, because the drive is simpler, and the water is easier to pass through the grate. In addition, the collected impurities go away, making it easier to remove it.

In contrast to variant 2, here the transmission of the drive from the working point to the trash-rack is not carried out directly by mechanical connection, but indirectly by electrical means. A current generator 7 is installed on the impeller of the impeller through the corresponding multiplier. The drive unit is now running via an electric motor with gearbox 8, which is connected to the chain drive chain. This variant is more expensive compared to variants 1 and 2, but provides a number of advantages.

4. Evaluation of variant solutions

The analysis and evaluation of the variant solutions is given in Table 1. Based on the analysis, it was adopted for the further development of the construction of the variant 3. Regardless of the fact that this is more expensive, the variant enables reliable execution of the operating function and has a number of advantages in relation to variant 1 and 2.

Table 1. The analysis and evaluation of the variant solutions.

Variant	Advantages	Disadvantages
1	<ul style="list-style-type: none"> Combining the trash-rack function (preventing the penetration of impurities) and cleaner (unhindered passage of water); A simple design solution; Low price 	<ul style="list-style-type: none"> Direction of water flow and movement of grids coincide, which may interfere with operation; Vital drive parts (shaft, gears) are exposed to the environmental impact, which can affect the performance of the function. Filling the operating function depends on the flow of water. It is not possible to automatically monitor the state of operational correctness.
2	<ul style="list-style-type: none"> Integrated trash-rack functions (preventing impurity penetration) and cleaners (unhindered passage of water); A simple design solution; Low price; The direction of flow of water and the movement of the grid does not match, which positively influences the fulfillment of the function; 	<ul style="list-style-type: none"> Vital drive parts (shaft, gears) are exposed to the environmental impact, which can affect the performance of the function. Filling the operating function depends on the flow of water. It is not possible to automatically monitor the state of operational correctness.
3	<ul style="list-style-type: none"> Integrated trash-rack functions (preventing impurity penetration) and cleaners (unhindered passage of water); Fully autonomous cleaner; The direction of flow of water and the movement of the trash-rack does not match, which positively influences the fulfillment of the function; Filling the operating function does not depend on the flow of water. Automatic control of operating status. 	<ul style="list-style-type: none"> More expensive than variants 1 and 2

5. Further development of an innovative solution

5.1. Design solution of drive system

Small hydropower plants are characterized by flow-through operation with very small accumulation. The low overflow threshold or the Tyrol intake is intended to slow the water stream before entering the feed channel. Considering the working conditions in which the flowing mini hydroelectric power plant works, it is advisable to choose a water wheel as a solution for the operation of the trash-rack cleaner.

Guide wheels have a number of advantages for autonomous operation. They are simple constructions, they have a low price, are reliable in operation and do not require special working conditions. They have adequate inertia in operation and stability of the speeds. They can work for normal flow rates. There are several types of these wheels [5]. For the conditions on the water intakes of the power plants for construction reasons as the driving wheel, the Poncelet water wheel was selected (Fig. 6).

For the flow of water in small hydroelectric power plants, the following starting data can be taken:

$Q_{\min} = 0,027 \text{ m}^3/\text{s}$ - the minimum amount of water flowing through the trash-rack to enable the hydroelectric plant turbine to work;

$Q_{\max} = 0,24 \text{ m}^3/\text{s}$ – the maximal amount of water flowing through the trash-rack to enable the hydroelectric plant turbine to work;

$Q_{\text{BM}} = 0,011 \text{ m}^3/\text{s}$ – biological minimum – minimal amount of water for the drive of wheel.

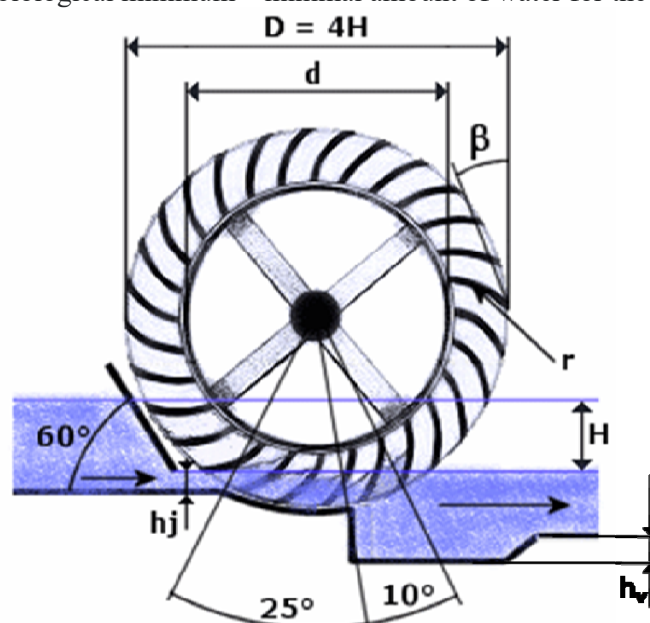


Figure 6. Design measurements of Poncelet water wheel [2].

The power of the Poncelet water wheel for water fall values in the range of 0.2 m to 4 m is:

$$P_t = \eta_t \cdot \rho \cdot g \cdot Q \cdot H \quad (3)$$

- P_t - Power of water wheel [kW]
- g - gravitational acceleration ($g = 9.81 \text{ m/s}^2$)
- η_t - Level of efficiency of water wheel
- ρ - Water density ($\rho = 1000 \text{ kg/m}^3$)
- Q - flow [m^3/s]
- H - Netto fall [m]

For slow moving water as the value of drop H , the difference between the input and the output water level is taken, which in our case is $H = 400 \text{ mm}$. The usefulness of the Poncelet wheel is $\eta_t = 0.65$. Accordingly, the maximum power is:

$$P_t = \eta_t \cdot \rho \cdot g \cdot Q \cdot H = 0.65 \cdot 9.81 \cdot 1 \cdot 0.24 \cdot 0.4 = 0.612 \text{ kW} = 612 \text{ W} \quad (4)$$

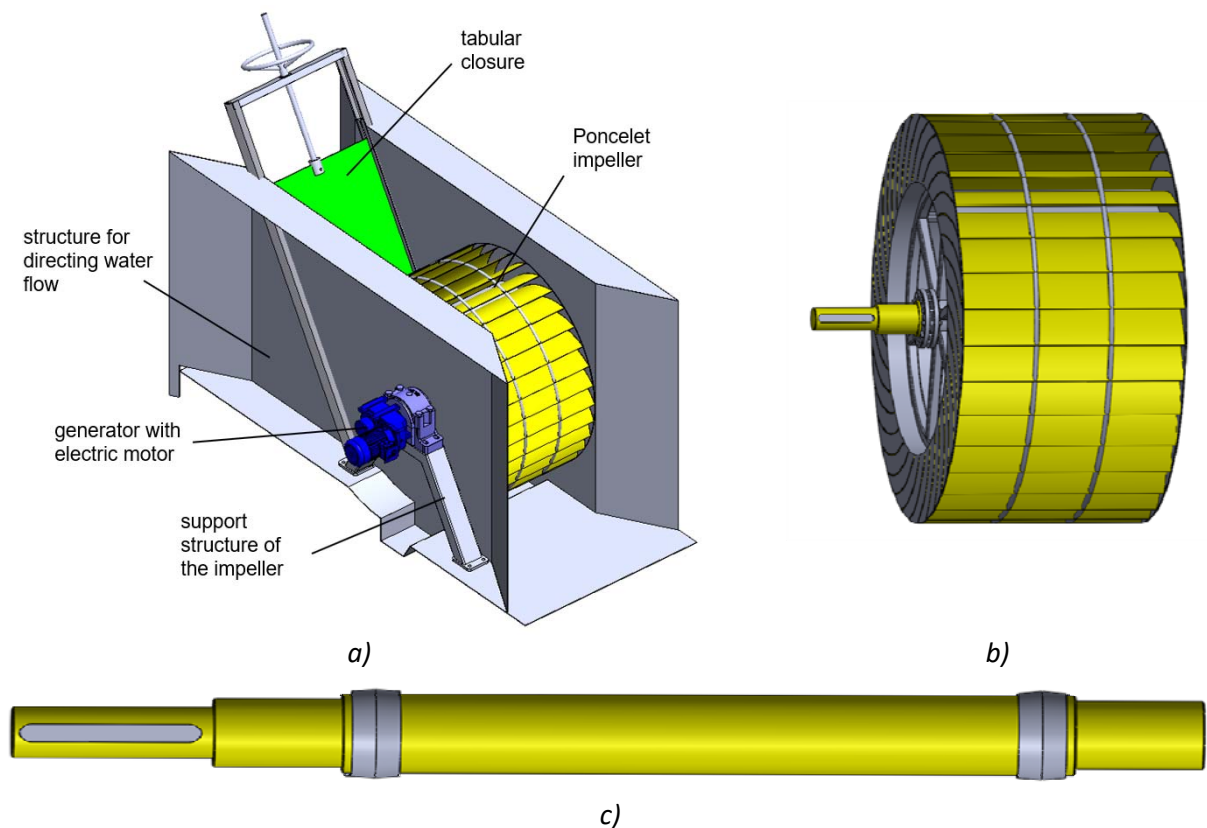
The diameter of the Poncelet wheel (Fig.6) is: $DRK = 4 \cdot H = 4 \cdot 400 = 1600 \text{ mm}$. Other technical data are given in Table 2.

According to the data given in Table 2, the constructive solution of the Poncelet wheel shown in Fig. 7, b. The supporting structure of the wheel is made of structural steel by welding from the steam-rod rods. The hub point is connected with a wreath with 6 paws symmetrically arranged on both sides of the wheel. The supporting rings are longitudinally also connected by rectangular cross-reels. Through this construction, a drum is placed with blades. Due to the large width of the impeller ($B_k = 930 \text{ mm}$), two circles of circular cross-section are installed as the blade holder.

The width of the blade is $b_1 = 89 \text{ mm}$, length $l = 930 \text{ mm}$, and the radius of curvature $R_1 = 440 \text{ mm}$. The fixation was carried out evenly at 4 places along the length of the blade. The blade is inserted into specially designed arched holes, and in length it is additionally attached to 2 hoops so that it has a stable operating position.

Table 2. Technical data for Poncelet water wheel.

Size		Unit	Value
Power for $Q_{\max} = 0.24 \text{ m}^3/\text{s}$	P_t	kW	0.612
Speed at maximum power	n_t	min^{-1}	16.24
No load speed	n_{t0}	min^{-1}	32.5
Torque	T_t	Nm	360
Efficiency	η_t		0.65
External diameter	D_{RK}	mm	1600
Internal diameter	d_t	mm	1080
Maximal width	B	mm	1000
Impeller width	B_k	mm	930
Depth of the water jet	h_j	mm	100
Depth of water at the exit (Fig.6)	h_v	mm	240
Speed of the jet	v_m	m/s	2.72
Blade width	b_l	mm	89
Blade radius	R_l	mm	440
Blade angle	β_l	$^\circ$	28
Number of blades	ZI	-	35

**Figure 7.** Mini turbine plant (a), Poncelet impeller (b) and shaft (c).

The complete plant for autonomous electrical energy production is shown in Fig.7, a. It consists of side panels and sheet metal, the function of which is to direct the flow of water properly. The shape of the sheet metal is harmonized with the construction of the Poncelet wheel (Fig.6). A water flow control mechanism is also installed with the appropriate guides of the stop plate (plate closure). The flow can be regulated via a threaded spindle. On the side are the mounts on which the impellers of the impeller are fixed. For bearings are selected 22324 CCK / W33 with complete SKF sleeve SAF 22624. The torque transfer from the impeller to the generator is carried out over the stepped shaft (Fig. 7, c). The link of the shaft with the impeller is made via conical clamping rings and with the generator via the coupling.

5.2. Design solution of horizontal trash-rack

The horizontal fine trash-rack with cleaning function is constructed according to the model of conveyor belts with movable perforated plates (Fig.8). The drive is operated via a chain conveyor.

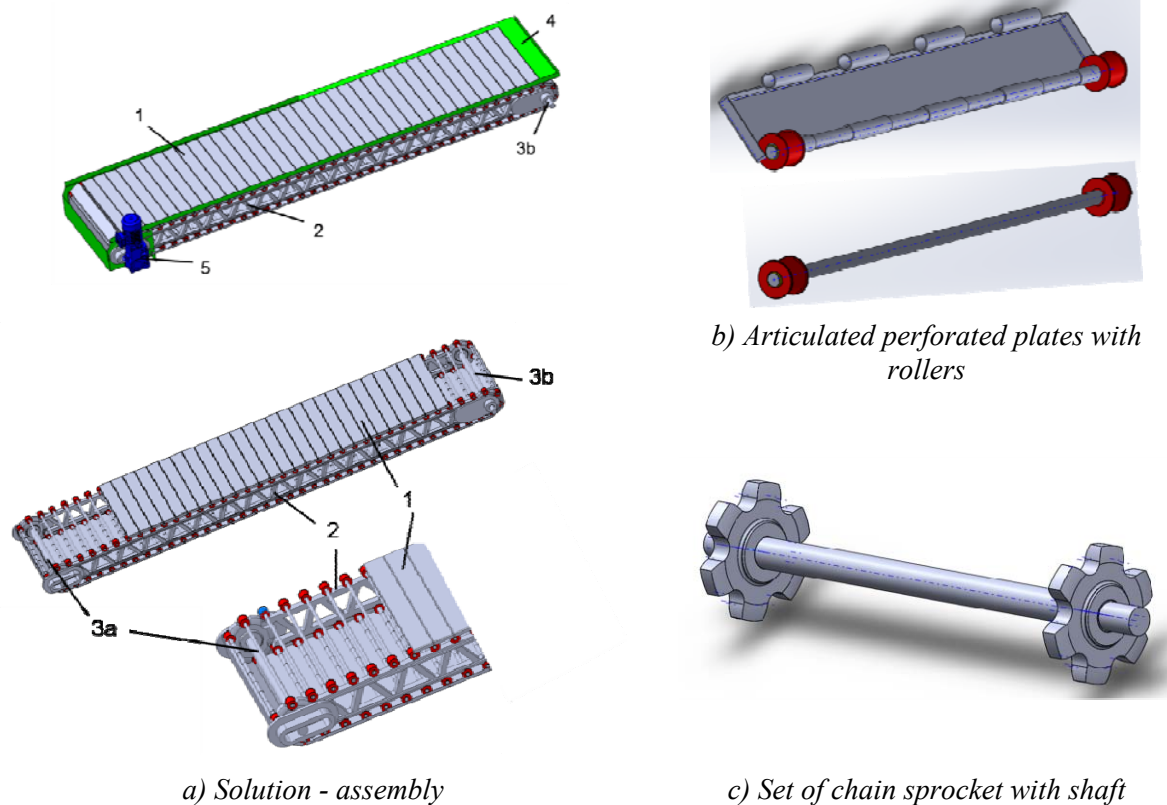


Figure 8. Design solution for horizontal trash-rack.

The basic components (Fig. 8, a) or components of the trash-rack are:

1. Perforated plates are mutually articulated with rollers for operation and guiding (Fig.8, b);
2. A supporting structure of the trash-rack, which has a guide function;
3. Set the sprocket with the drive (3a), ie the driven (3b) shaft (Fig.8, c);
4. Protective sheet for trash-rack, with a brush for removal of impurities and waste from the grid;
5. Electric motors for the peripheral motor (24V / 600W DC motors), connected to the set of drive sprockets 3a.

The innovativeness of such a construction solution is reflected in the integration of the trash-rack function (preventing the impurity from entering the turbine plant) and the cleaning function (preventing the trash-rack congestion, ie, removing impurities from the trash-rack itself). This was achieved by installing the trash-rack (Fig.8, a). The trash-rack itself is made of perforated plates, which are articulated jointly (Fig.8, b). At the ends of the sticks (shaft) are placed plastic rollers, which

move along the tracks of the supporting structure of the trash-rack (Fig. 8, b). The rollers come in the middle of the chain of the sprockets, which drives the movement through the electric motor and the drive shaft of the grate. In this way, the impurities that come to the horizontal trash-rack are immediately removed and thrown off the outside of the Tyrolean intake, with additional brush cleaning from the bottom. The complete construction of the trash-rack is made by welding with adequate protection against the influence of the surrounding environment.

Perforated panels are made of perforated stainless steel sheet 1 mm thick. The diameter of the opening is $w = 4\text{mm}$, while the distance between the holes is $t = 6\text{mm}$ (Fig.9). In this way, the conditions for reliable operation of turbine plants are fulfilled, as it prevents the penetration of all objects larger than 4mm. The trash-rack openness is 40%, which allows water resistance to water to be minimal.

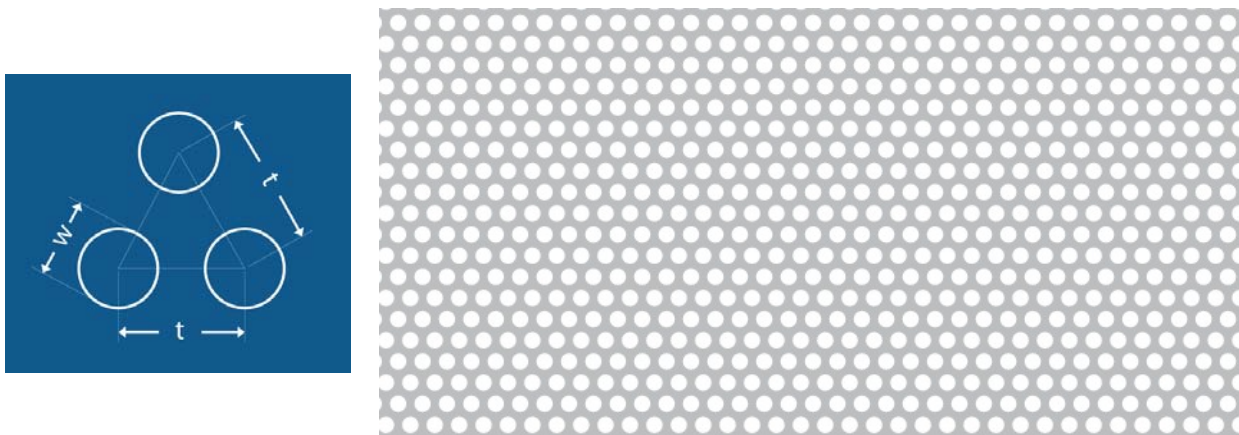


Figure 9. Perforated sheet metal for trash-rack panels ($W=4\text{ mm}$; $t=6\text{ mm}$; openness 40%).

5.3. Selection of generator and battery

Due to the power generated by the Poncelet impeller ($P_t = 612\text{W}$), the following type of 24V / 600W DC motors, PM296 of the Ningbo Jirun Electric Machine Co. Ltd. The generator is supplied with the multiplier to increase the speed with $n_t = 16.2\text{ min}^{-1}$ at $n_G = 1450\text{ min}^{-1}$.

The generator current is charged with AKU batteries and is powered by an electric motor to drive the trash-rack. The electric motor 24V / 600W DC motors, PM296 (High torque permanent magnetic brush DC motor) was selected for the trash-rack drive, with a gearbox so that the velocity of the reservoir is 0.1 m/s.

We selected 2 AKU batteries of NARADA 6-GFM-50F, power of 300W, capacity 50Ah, so that they can work for 3h without charging with full load. Since the trash-rack drive is not permanent, but, as needed, the batteries provide enough electricity for reliable protection against impurities and automatic monitoring of the working condition.

6. Conclusion

The horizontal fine trash-rack with cleaning function for small hydro power plants is designed to reliably function as a function, because its drive is via an electric motor, which is powered by over 2 battery cells. Consequently, in the event of minimal water flow, reliable cleaning of the impurities is ensured. On the other hand, the trash-rack openness is 40% with the diameter of the opening 4mm, which ensures an uninterrupted flow of water and a reliable prevention of impurity penetration into the turbine plant.

Since the energy source - the Poncelet impeller and the grating with the electric motor are physically completely separated, as well as from the aspect of the design of the trash-rack itself, universal application on water intakes with a horizontal trash-rack is enabled.

It is envisaged that the vital components and components of the cleaner are made of quality stainless material, which should enable long-term operation with minimal maintenance costs. The

cleaner prevents the penetration of impurities not only in the turbine plant, but also in its own energy source via the Poncelet wheel, which is also an important parameter of reducing maintenance costs. Since an autonomous source of electric power is provided through the generator and battery cells, it is also possible to install automatic control of the state of operational safety.

An innovative construction solution is installed on the trash-rack, which is reflected in the trash-rack integration (preventing the impurity penetration into the turbine plant) and the cleaning function (preventing the trash-rack congestion, ie removing impurities from the trash-rack itself). This was achieved by installing a trash-rack of perforated plates, which are mutually connected jointly.

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