The problem of using renewable resources is especially acute nowadays. Utilising river flows as a source of energy is one of the directions for solving the problem. The paper reflects the objectives and problems, that can be resolved through a sustainable use of the river flow energy. An impact of various factors on interaction between energy and extraction systems has been shown. The essence of the new approach to making hydroelectric units using the quantity-related component of the flow, and the prospects for creating hydroelectric units in this direction are represented.

The presented analysis of some developments incorporates the specific features of the utilised working organs of free-flow micro HPSs in their interacting with the river flow. It serves a basis for suggesting a new trend in their developing and the use of a quantity-related flow component, i.e. the momentum, in particular.
Keywords: Systems, hydraulic flow, momentum, energy extraction, hydraulic gradient, generator, polymers.

I. Introduction

In the development of utilising renewable energy sources, micro HPSs have become increasingly important. Free-flow micro HPSs are remarkable in this area. The nature of extracting energy from the flow set free-flow micro HPSs apart from the other groups. Supposing that this extraction is based on utilising the hydraulic flow energy of natural watercourses or water courses created for other purposes, for example, irrigation systems, to conserve these watercourses, their hydraulic regime, flow rate, provided the extracted energy is restored, is the problem behind the direction of searching for a solution. Free-flow micro HPSs correspond with these requirements to the maximum extent.

Based on the specific features of extracting energy, the structural relationship between the flow energy extraction and conversion system could be expressed in the form of its relationship with the utilised extraction system. The structure of the relationship is given in Fig. 1.

![Fig. 1: Structural relationship between the system elements](image)

Each of the presented system components is characterised by its own internal relationship, that reflects the design concept of the energy extraction system.

The energy source has its own internal components shown in Fig. 2.

![Fig. 2: Flow energy components](image)

The main characteristics of the hydraulic flow involve its quantitative and head-related indicators, initial in designing hydroelectric units, since they are representative of kinematic and dynamic parameters.

The relationship is defined by the following formulas:

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volumetric flow rate \( Q = \int_S v dA \), or mass flow rate \( Q = \int_S v dS \rho \).

momentum flux \( Q = \int_S v dS \) 

kinetic energy flow \( Q = \int_S \frac{v^2}{2} A \).

and is characterised by the components of Saint-Venant equations.

\[
\frac{\partial v}{\partial t} = \mathbf{F} - \frac{1}{\rho} \nabla \rho + \nu \nabla^2 \mathbf{\hat{e}}, \tag{1}
\]

where \( \frac{\partial v}{\partial t} \) – complex acceleration of liquid particle;

\( \frac{1}{\rho} \nabla \rho \) – acceleration caused by mass forces;

\( \nu \nabla^2 \mathbf{\hat{e}} \) – acceleration caused by pressure forces;

\( \nu \nabla^2 \mathbf{\hat{e}} \) – acceleration caused by viscosity forces.

Head flow characteristic shall be considered with respect to Bernoulli equation:

\[
H = z + \frac{E}{\rho} + \frac{v^2}{2g}, \tag{2}
\]

where \( H \) is the total energy in the considered flow cross-section. In hydraulic engineering, it is generally accepted to call it the full pressure.

\( z \) – potential energy of position, referred to as static (geometric) pressure;

\( \frac{E}{\rho} \) – potential energy of state, referred to as hydraulic pressure pressure;

\( \frac{v^2}{2g} \) – kinetic energy, referred to as velocity pressure.

When evaluating the flow characteristic, it is commonly supposed that the flow motion, limited by solid walls from all sides, is a motion under pressure; when there is a free surface, it is referred to as a “gravity-flow” motion that corresponds to the expression “with no energy”. The word “energy” itself derives from the Greek and defines the concepts of “activity”, “operation”. It was first used by the English physical scientist Thomas Young early in the XIX century.

In hydromechanics “energy” is a physical value, characterising the ability of the liquid body to do mechanical work. When this type of energy exists, there is a certain velocity of liquid motion, with which it can do work.

Free-flowing liquid can be observed while considering on the horizontal surface some volume of liquid, which, when subjected to its proper weight, runs all over the surface to the degree, specified by surface tension forces and wettability between liquid and contacting surface (Fig.3).
This state of equilibrium is characterised by a limiting contact angle (cont.) of a liquid droplet on the solid surface, defined by the Young equation:

\[
\cos \theta_{\text{cont}} = \frac{(\gamma - \gamma_2)}{\gamma_1}
\]  

Fig. 3: State of liquid equilibrium on the solid surface

When there is a slope, this volume of liquid will start moving due to gravity. This motion is commonly called the flow, what once more is indicative of inconsistency in the “gravity-flow” term for open streambeds and use of “free-flow” term.

II. Materials and Methods

The main characteristics for the free-flow motion are as follows: velocity, flow rate, head, which are related to such parameters of the streambed as: flow depth – h; cross-sectional area – \( \omega \); wetted perimeter – \( \chi \); hydraulic radius – R.

Hydraulic radius is defined as the ratio:

\[
R = \frac{\omega}{\chi}
\]  

Average velocity and flow rate in the streambed relate to hydraulic radius as follows:

\[
V = C\sqrt{Ri};
\]

\[
Q = \omega C\sqrt{Ri};
\]

where \( C \) – Chezy coefficient, related to the streambed surface characteristic along the wetted perimeter; it shall be defined by empirical dependences:

Manning formulas:

\[
C = \frac{1}{n}R^{5/3}
\]

Pavlovsky formulas:

\[
C = \frac{1}{n}R^{3}
\]

It follows from these formulas that velocity and flow rate depend on geometric dimensions of streambed, defined by hydraulic diameter and hydraulic gradient “i”. It is conventional to call gradient the ratio between streambed head and its length of the defined segment. This parameter is expressed in percentage, degrees, m/km or ppm. It amounts to 0.1-0.2 m/km for lowland rivers, and 10-20m/km for mountain rivers.
The total river head is also commonly defined for riverbeds as the difference in metres between its source and mouth altitudes, however, this indicator is not taken into consideration in computations.

It is common practice to separate hydraulic gradient $i$ into the flow free-surface slope and bottom slope. There are flows with direct slope, when the streambed bottom shelves down in the direction of flow. In this case, free surface hydraulic gradient is usually the same as the bottom slope (Fig.4).

![Fig. 4: Characteristics of the streambed free surface and bottom:](image)

a) – streambed with direct bottom slope; b) – with horizontal bottom slope; c) – with reverse bottom slope

In the streambeds with the bottom slope reverse to the flow direction, the free surface slope does not follow the bottom slope, and the flow depth increases. In the case of horizontal bottom surface, free surface of the flow also does not follow the streambed surface.

The position of free surfaces to the streambed slope shows that liquid moves in the flow due to not only gravity, but kinetic energy of the flow as well. It once more reflects inconsistency in the “gravity-flow” term.

The state of the free surface also characterises the streambed flow. For lowland rivers the free surface is relatively smooth; when there is an obstacle, backwater curve is smoothly connected with backwater and water surface. Mountain rivers have uneven water surface with arising local waves and hydraulic jumps, characterised by formation of back waves.

Structural interrelation between the flow and extraction system is based upon the dependence of converting translational motion of the flow into rotational motion of the driven member of the system device, transferred to generator. The extraction system working organ, interacting with the flow, provides this interrelation. In terms of the pattern of extracting energy and the system layout, and based on the analysis of the known technical solutions, the extraction systems may be presented in the form of the structural diagram in Fig.5.
In motion, stationary

- Energy extraction systems
- With translational motion of organ along the flow
- With translational motion of organ across the flow
- With rotational motion along the flow
- With rotational motion across the flow

Fig. 5: Structure of interrelation between the flow and working organs

Motion of working organ with respect to the flow follows the direction of the flow motion and is perpendicular to the flow motion. In terms of orientation of the working surfaces with respect to the flow, the latter ones may be oriented normally or at some angle, with some angle of inclination with respect to the flow sectional plane or the flow free surface plane.

Kinematic connections of working surfaces of such bodies with the flow for extraction systems are presented in Fig.6 (a,b,c).

Fig.6a presents the case, when the body is stationary \( V_b = 0 \), and the flow with velocity \( V_f > 0 \) runs over its frontal surface. When there is a flow over the solid body, unevenness in the flow velocity distribution across its depth should be taken into account. The flow depth-wise profile of velocities defined by the medium viscosity is shown in Fig.6a.

Fig. 6: a. Stationary body is in the flow

Flow resistance force is defined by the formula

\[
F = 0.5C_x \rho V_f V^2 S.
\]  

(9)

where \( C_x \) – drag coefficient in the direction of flow

\( \rho \) - density of medium

\( V \) - flow velocity
S – flow resistance area.

Distribution of the velocity value across the surface taking into account its viscosity shall be obtained using Newton’s formula:

\[
\tau = \mu \frac{dv}{dy},
\]

(10)

\[
\frac{dv}{dy} = \frac{1}{2} \int dv = \int \frac{\tau}{\mu} dy, \text{ or}
\]

\[
v = \frac{\tau}{\mu} y + C
\]

(11)

Fig. 6b presents the case, when vectors of the body and flow velocities are mono directional. The body velocity can be equal to the flow velocity in modulus or be less than the flow velocity.

\( V_b > 0 \)

![Fig. 6: b. A body in motion in a movable medium](image)

When a body moves in a movable volume of liquid, its frontal surface will experience flow resistance force, which shall be defined by formula:

\[
F = C x 0.5 p (V_f - V_b)^2 S
\]

(12)

\( V_f \) – flow velocity, \( V_b \) - body velocity.

\[
m \frac{dv}{dt} = \frac{1}{2} sp (V_f - V_b)^2
\]

(13)

\[
\frac{dv}{(V_f - V_b)^2} = \frac{sp}{2m} dt, \quad \frac{1}{V_f - V_b} = \frac{sp}{2m}
\]

\[
V_f - V_b = \frac{2m}{sp}
\]

\[
V_b = V_f - \frac{2m}{sp}
\]

(14)
Interaction between a moving body and stationary medium (Fig.6c) is defined by the constant value of the displacement velocity of all points of the frontal body surface and unevenness of hydrostatic pressure forces absorbed by this surface.

![Image of a body in motion in a stationary medium](image)

**Fig. 6:** c. A body in motion in a stationary medium

When a body moves in a stationary volume of liquid, its frontal surface will experience flow resistance force, which shall be defined by formula

\[ F = C \times 0.5 \rho V^2 \Delta \]  \hspace{1cm} (15)

where \( V \) - velocity will be equal to the body velocity.

### III. Results

Working organ in the so called free-flow micro HPSs usually serves to convert translational energy of the flow into rotational motion of the generator shaft.

Hydropower installation capacity is defined as

\[ N = M_{1a} \]  \hspace{1cm} (16)

where \( \omega \) – angular velocity of the generator shaft, connected with driving members, interacting with the flow, by kinematic parameter.

M-moment on a driven drum, connected with electric engine shaft (possibly, through transfer mechanism), defined by the active force:

\[ M = Fr \]  \hspace{1cm} (17)

where \( r \)-arm of force \( F \), created by driving members. It follows from formulas (1) and (2) that capacity is a function of geometric parameters, defined by radius \( r \), kinematic parameter \( \omega \) and dynamic parameter of force \( F \). Kinematic parameter \( \omega \) of a driven drum member is connected with kinematic parameter of driving links – working organs by velocity:

\[ V = \frac{\omega}{r} \]  \hspace{1cm} (18)
The considered characteristics of interaction between working organs and flow were applied in various structural concepts of micro HPSs. Rotational motion along the flow was implemented in the device known as hydraulic wheel shown in Fig. 7.

Fig. 7: Layouts of hydraulic wheels: A, B – head wheels, C- free-flow wheel

Structural diagrams A and B are characterised by the force applied to the blades of static head component and, therefore, are not free-flow. Interaction between blades 1 of free-flow wheel 2 and the flow is presented in Fig. 8 [19] Working organs move in the same direction as the flow moves, however, here, their working surfaces will be oriented towards the flow velocity vector at some variable angle.

Fig. 8: Interaction between hydraulic wheel working organs and flow

Active force $F$ is resolved into components: normal and tangential. Vectors of tangential components change the direction, when the blades go out of the flow. The numerical value of normal component shall be defined by the angle of the blade entering the flow $N = F \cos \theta$, what characterises a reduced efficiency of rotational moment on the wheel shaft due to the flow-induced forces.

Rotational motion of working organ with the axis directed along the flow is implemented in micro HPSs with the so-called Archimedes screw (Fig. 9). The flow interacts with the spiral surface and creates a rotational moment.
Fig. 9: Screw micro HPS

Structural designs of practically applied screw micro HPSs imply creation of water head upstream of the device, what also cannot characterise them as free-flow structures.

Propeller micro HPSs shown in Fig.10 shall be classified as the devices with rotational motion across the flow.

Fig. 10: Propeller micro HPSs

Propeller micro HPSs with translational motion of the flow towards working propeller blades create the force, normal to them and inducing rotational moment. When propeller rotates, a so-called swept area is created, which is a moving force of the propeller blade and a negative resistance force of the propeller micro HPS.

A device with translational motion of working organs, directed crosswise of the flow, has been incorporated into the design of Lunev micro HPS (Fig.11).
Working organs in Lunev micro HPS are directed at the angle to the flow current lines. Normal components of force $F_1$, shown in Fig. 11, are transformed into moving force $F_3$, which displaces blades 3 across the flow, causing rotation of elements 1 and 2. Positioning of the device blades across the flow with their translational displacement creates a backwater for the flow. It increases the potential component of static head and, simultaneously, predetermines formation of vortexes that can locally destroy the flow streambed. It should also be noted that in translational motion non-working surface of blade experiences the load from the liquid mass, thus reducing the value of force in the direction of blades motion.

The above-stated structural schemes of free-flow micro HPSs and their shortcomings revealed require seeking new solutions, aimed at the rational impact of the flow on the surfaces of working organs and potential increase in their quantity to perceive the flow of energy. Such a solution has been found in the device described below: free-flow hydropower installation with copyright certificate No.1636592.

Its general view is presented in Fig. 12a, Fig. 12b – the same view after rotating the frame; Fig.13 – plane view; Fig. 14 – blade structural design.
The structure of free-flow hydropower installation comprises frame 1 with the two drums 4 and 5 mounted on shafts 2 and 3, and endless strap 6 strained thereon with blades 7. Shaft 2 of drum 4 is fixed on stationary support 8 above free level 9 of the flow, frame 1 is installed to be possibly rotated with respect to shaft 2. The installation is equipped with strap-tensioning device that comprises upper and lower rollers 10 and 11, mounted to be able to contact upper and lower branches of strap 6 and connected by cranks 12 and 13, respectively, with shafts 3 and 2, not fastened and located on fixed support 8, and fastened on the last stationary element 14 and ram 15, connected by crank rods 16–18 with rollers 10 and 11 and stationary element 14 and mounted on frame 1, lying in the plane, passing through longitudinal axes of shafts 2 and 3. Each blade I is made in the form of triangular pyramid 19 with open base 20, fixed on one of faces 21 on the strap and oriented vertex 22 along the way of strap displacement, and drum 5 has a positive buoyancy. Installation also has electric generator 23, connected with shaft 2.

Free-flow hydropower installation operates as follows. When the flow runs over blades 7 under the influence of velocity head, they come into motion and displace...
endless strap 6, which, in its turn, rotates drums 4 and 5. Torque moment from shaft 2 of drum 4 is transferred to the shaft of generator 23.

In case of changing level 9 of the flow (increase or decrease) frame 1 rotates around shaft 2. Since element 14 is stationary, change in frame 1 position with respect to element 14 is stationary, change in frame 1 position with respect to member 14 leads to displacement of ram 15 by crank rod 16, what, in its turn, causes displacement of rollers 10 and 11, connected with ram 15 by crank rods 17 and 18. Thus, when level 9 of the flow decreases, upper roller 10 approaches frame 1, and lower roller 11 moves away from it, providing parallel alignment of lower branch of strap 6 and the flow current direction.

Making each blade 6 in the form of triangular pyramid 19 with open base 20, oriented vertex 22 along the way of strap displacement, due to choosing angle $\alpha$ enables ensuring optimum position of blade 6 with respect to level 9 of the flow. This factor and the fact that there is no need for monitoring the level using pontoons or other devices to track the flow level, allows, without reducing the efficiency of transforming the flow energy into mechanical energy, to decrease the mass and sizes of installation, what expands its area of application and enables using it, for example, in narrow waterways.

This device is characterized by decreased mass and size, since the shaft of one of the drums is fixed on the stationary support above the free flow level, the frame is installed to be possibly rotated with respect to this shaft. The device makes it possible to place several working organs in the flow, while in the previously known equipment one and the same organ was in the flow. In terms of the structure and sizes, the driven element is proportionate to those of the known structural designs, and, by assessing the forces transferred to working organs of these devices, the relationship will take place, which is estimated as transfer coefficient of efficiency as follows:

$$\eta_{sp} = \frac{F}{S}$$

where $\eta_{sp}$ – coefficient of transferring flow energy to hydroelectric unit.

$F$ – force acting on a single working organ.

$S$ – area of force action.

It shall be obtained for the above device

$$\eta_{sp} = \frac{F}{S}n$$  \hspace{1cm} (19)

where $n$ is the number of elements, which are in the flow simultaneously.

Linear positioning of multiple working organs along the flow allows to reduce the size of the driven element with the same number of working organs.

A compound body motion that comprises rotation around the axis and translational motion along this axis is commonly referred to as a vortex motion. Mozzi theorem describes vortex-induced displacement in classic mechanics as the most common displacement of the solid body. In medicine: a phenomenon of forming vortex blood flows is found in cardiovascular system. It is observed in natural vortexes, i.e. tornadoes. If rigid motion (of solid body, for example) involves rotation around the axis and translational motion along this axis, such motion of the body is called helicoidal motion; this axis is called helical axis or axis of rotation - sliding. If there are two random positions of the body moving in space, transition from position I to II
may be made by one helicoidal motion around the specifically positioned helical axis (Chasles' theorem); here, rotational and translational motions can be performed either simultaneously or sequentially in any order. Considering the entire displacement of the body in space as the motion comprising infinitesimally elementary displacements and applying Chasles’ theorem to each of them, the following statement is obtained: any motion of the body in space constitutes a number of infinitesimally helicoidal displacements around instantaneous helical axes, which change their position and direction in space at every instant, forming vortexes. In genetics, such motion creates helicoid DNA structures. In astronomy: motion of spiral-shaped galaxies; V.A. Sadovnichev, V.A. Samsonov in formulated the problem about the existence of spatial helical mode of braking fireballs. Motion and rotation of molecules, elementary particles are known in physics. In medicine, Samsonov V.I. – “Numerical and asymptotic analysis demonstrates the pattern of helically-formed anisotropy in the blood flow (due to anisotropic properties of blood vessels, what is the reason for helicoidal blood motion), and oscillatory reflective mode of vessels brings the originally “swirled” stream of blood into laminar flow with reduction of geometrical characteristics of vessels to capillaries”. These examples are taken from theoretical mechanics, genetics, astronomy, controlling orientation and motion of bodies in space, theoretical physics, medicine.

Flowing of liquids and gases in nature or engineering application is helicoidal motion as well. Helicoidal motion of water is observed in pipes, in case of laminar flow and turbulent flow. Rotation of infinitesimal volumes with formation of vortexes is due to the fact that the velocity of liquid on the wall surface is zero because of adhesion, and it rapidly increases when moving away from the walls, so that as a result of viscosity, the velocities of neighbouring layers considerably differ from one another, and owing to inhibiting effect of one layer and accelerating effect of the upper one (Fig. 15) rotation of particles, i.e. helicoidal motion, occurs.

**Fig. 15:** Distribution of velocity across the pipe section;

**Rotation of Infinitesimal v Volumes is Shown**

As is known, separation of laminar boundary layer from the cylinder surface is caused by the increased pressure in diffuser segment of the flow. Friction forces lead to losses of kinetic energy by liquid particles in the boundary layer and, respectively, their inhibition. And at some distance from the point of minimum pressure downstream, the energy of these particles becomes insufficient to overcome pressure in the external flow, what stops the liquid motion. As a result, a reverse flow occurs in the lower part of the laminar boundary layer, which pushes back the upper layers.
of liquid from the cylindrical surface. It causes separation of boundary layer and formation of the flow vortex fields.

Vortexes, separated from the cylinder surface, constitute unstable structures. Their formation is accompanied by discrete displacement of discontinuity points and oscillation of hydrodynamic forces. Hence, even with fixed values of Reynolds numbers, the position of discontinuity points constantly changes.

It is possible to assess the influence of hydrodynamic conditions of flowing around tandem cylinders on the flow separation pattern to the first approximation, when there is spatial flowing of viscous liquid around them. In this case, the relationship between the position of discontinuity points and the mode of the liquid motion-Reynolds number and the distance between cylinders is the most typical.

An ambiguous nature of the viscous liquid flow separation when flowing around cylinders, closely resembling free surface, complicates theoretical studies of this phenomenon, since there are surface jets.

According to the studies of G. Shlikhting, I.D. Idelchik, when there is a crosswise flowing around cylinder, boundary layer separation is observed for numbers $Re > 50$ (Reynolds number for cylinder). From 60 to 5000 Reynolds numbers, Karman vortex street is formed beyond the cylinder, in the form of a regular sequence of separated vortexes. When $Re > 5000$, there is no vortex street, and a complete turbulent mixing occurs in the trail line beyond the cylinder.

When there is a crosswise viscous liquid flowing around cylinder, vortexes are formed, and their alternate separation further occurs. Since pressure in vortexes is lower than in the main flow, at the moment of separating one of them, lifting force $F_y$ will act on the cylinder, caused by pressure drop $\Delta P = P_{n1} - P_{n2}$. Here, $P_{n1}$ and $P_{n2}$ are average values of total pressures on the cylinder surfaces,

$$ P_n = 0.5 C_p P_\infty + P_e = 0.5 C_p U_{\infty} \frac{\nu}{\lambda} + P_e $$

(20)

where $C_p = 1 - \sin^2 \phi$ – pressure coefficient; $P_\infty$ and $P_e$ – dynamic and static components of total pressure, Pa.

High values of longitudinal and crosswise oscillatory components of the flow velocity are typical of the vortexes separated from cylindrical surface, according to Paul K. Chang. These oscillations are transmitted to the trail line, where they decrease with distance from the cylinder. In this case, crosswise oscillatory velocity components reach their maximum values.

Alternate vortex separation and asymmetry of the flow in the trail line beyond the cylinder cause periodic change in the drag and lift force coefficients.

In the real conditions of flowing around cylindrical bodies, oscillating changes in hydrodynamic parameters of viscous flow are observed, and the relationship between the discontinuity point position and velocity of oncoming flow is not always unambiguous. Therefore, the considered displacement of discontinuity point is possible only within narrow range of Reynolds numbers.
Let the velocity of oncoming flow \( U_\infty \) change from \( U_i \) to \( U_n \).

The following assumptions should be made:

- certain value of velocity \( U_\infty = U_i (U_i < U_t < U_n) \) and pressure drop \( \Delta P \) correspond to the discontinuity point of laminar boundary layer \( \alpha = 108.8^\circ \);
- when inequality \( U_d \leq U_t \leq U_n \) is satisfied between the discontinuity point and velocity of the flow oncoming on the cylinder, there is a directly proportional dependence \( a = f(U_\infty) \).

The relationship between pressure drops \( \Lambda P \) and \( \Lambda P \) shall be presented as follows

\[
\Delta P^* = k_1 \Delta F,
\]

where \( k_1 = f\left(\overline{U_\infty}^2, \overline{E}, \overline{l}\right) \geq 0 \) – empirical coefficient, which takes into account the change in energy parameters of viscous liquid in laminar boundary layer on the cylinder surface \( k_1 = 1 \) when \( U_\infty = U_i \) and \( \overline{U_\infty}^2 = U_\infty^2 U_t^2 \) – squared nondimensional velocity of oncoming flow; \( \overline{E} = \overline{u}_t^2 \overline{u}_p^{-2} \) – non-dimensional value of kinetic energy of the liquid particle next to the boundary of viscous sublayer; \( \overline{u}_t, \overline{u}_p \) – longitudinal components of velocity of the liquid particle in close proximity to discontinuity point \( \alpha \) and at the point of minimum pressure \( \left( U_d \leq U_\infty \leq U_n \right) \), \( \overline{I} = I_t I_p^{-2} \) - non-dimensional value of turbulence intensity in laminar boundary layer; \( I_t, I_p \) - intensities of turbulence, which correspond to velocities \( u_t, u_p \).

It should be taken into consideration that at the discontinuity point of boundary layer, the conditions are met: \( u_t \approx 0, F \approx 0 \) and \( \overline{E} \approx 0 \). This is due to the fact that there are losses of kinetic energy of viscous liquid flow in laminar boundary layer at the section between the minimum pressure point and the flow discontinuity point.

When there is a crosswise flow around stationary cylinder, drag and lift forces are considered the main hydrodynamic forces acting upon it on the part of viscous liquid. Since drag coefficient is much higher than lift coefficient and it is of prime importance, than when studying specific aspects of flowing around tandem and single cylinders, this value can be neglected. There is an influence of the width of fissure in separating element owing to the increase in the area captured by viscous liquid within a fissure and a decrease in pressure near it. Fig. 16 presents the picture of instantaneous current lines of viscous liquid flow, when it flows around two tandem cylinders.
Fig. 16: Current flow lines of viscous liquid when flowing around

Fig. 16 shows that when $s = 2D$, trail line beyond the first cylinder has two points of flow connection and two points of flow discontinuity on the surface of tandem cylinder, and frontal surface of the second cylinder is in the zone of the influence of vortexes beyond the first cylinder. For the case when $s=4D$ (Fig.17), it is seen that the viscous liquid flow beyond the first cylinder is asymmetrical. This is because there is an alternate vortex separation from the surface of the first cylinder and propagation of swirls to both sides of trail line, therefore, it leads to distorting current lines and asymmetrically distributing the viscous liquid velocity and pressure.

To visualise current lines when flowing around tandem of cylinders, installed at different distance from one another, food colorant was used. Based on the analysis of flowing patterns (Fig.18), a minimum distance between cylinders was found, which is equal to their diameter.

Fig. 17: Flow around tandem cylinders
Thus, the results of flowing with spatial stream of viscous fluid around tandem cylinders indicate that moving force depends on their number.

In devices with translational motion of working organs along the flow, the direction of force that acts on their surface, is the same as the flow direction.

Resistance forces $F_r$ of working bodies do useful work, where resistance force is defined by the formula:

$$F_r = 0.5C_d\mu(v - u)^2s,$$  \hspace{1cm} (22)

### IV. Discussion

A variable-mass working organ has become a solution to potential change in conditions that characterise the resistance force (Fig.18).

![Fig. 18: Calculation diagrams of: a – empty cylinder, b – filled cylinder](image)

I.V. Meshcherskiy discovered the main equation for the material variable-mass point. The equation is usually presented as follows:

$$m \frac{dx}{dt} = F - \mu \frac{du}{dt}$$  \hspace{1cm} (23)

where

- member $-\mu \frac{du}{dt}$ is called a reaction force,
- $F$ – external force.

Calculation diagrams are given in Fig.18 for the case in question. Meshcherskiy equation is obtained in the following form:

$$(m_0 + m_x) \frac{\partial^2 \phi_x}{\partial x^2} - \frac{\partial (\mu_x m_x)}{\partial x} + C_x \frac{\partial (\mu_x u_x)}{\partial x} = 0,$$  \hspace{1cm} (24)

where the first component of summand $\frac{\partial (\mu_x m_x)}{\partial x}$ is provisionally called pseudo reactive force, that reflects an increment in the mass of a body in motion.

The second summand defines the resistance force of working organ to the flow.

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When empty cavity of working body is filled in, the oncoming flow loses momentum, and working body, pursuant to the law of momentum conservation, receives the respective amount of momentum. For the working body in this case, the momentum equation shall be written as follows:

\[ m \frac{\partial u}{\partial t} = (v - u) \frac{\partial m}{\partial t} + C_x \frac{(v-u)^2}{2} S - F_b, \]

where \( F_b \) - brake force arising due to current generator operation.

The obtained mass facilitates the use of force from momentum.

The incremented mass will constitute a quantitative parameter or momentum of working organ \( M^* u \), where \( M \) - mass of rollers of the working chain, and \( u \) - velocity. Based on the equation of changing momentum: \( M^* u_2 - M^* u_1 = F^* t \), when entering the flow \( M^* u_1 = 0 \) and \( M^* u_2 - 0 = F^* t \), from which \( F^* = (M^* u_2)/t \). The speculations given have shown that it is possible to increase the device capacity, when overall dimensions remain the same, at the expense of increasing the mass.

It is common practice to define such interaction between the flow and solid body, when the body attaches and moves, as a whole, as inelastic shock, described in Fig.19.

![Fig. 19: Inelastic shock](image)

The flow of mass \( M \) with horizontal velocity \( V \) acts on the body with mass \( m \) and carries it away with velocity \( u \).

Then, according to the law of momentum conservation

\[ m v - (M + m) u ; \quad u = \frac{m}{M + m} v. \]

A mechanical energy loss occurs when liquid flows over the body:

\[ \Delta E = \frac{m v^2}{2} - \frac{(M + m) u^2}{2} \]

where the ratio \( M/(M + m) \) - a portion of kinetic energy of the body, transformed into internal energy of the system:

\[ \frac{\Delta E}{E} = \frac{M}{M + m} \]

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The dependence could be analysed as follows:

When \( m \ll M \), almost all kinetic energy of the flow is converted into internal energy.

When \( m = M \), a half of the initial kinetic energy is converted into internal energy.

When \( (m >> M) \), the ratio is zero.

This speculation, which clarifies the influence of the incremented mass on energy transmission and hydroelectric unit operation, is taken as the basis for creating schemes of innovative hydropower installations, which convert the flow energy into electrical energy, produced by electrical generator.

Output generator voltage is unstable due to variable rotation frequency of the shaft, driven by hydraulic power unit.

To stabilise voltage at the generator unit output, regulated electrical supply package should be installed, which changes excitation current, supplied to the synchronous generator rotor winding.

Output three-phase voltage can, through the three-phase line, be directly supplied to consumers, who have no strict requirements for electric reliability. For electrical consumers with more stringent requirements for uninterrupted supply, a power supply unit (generator unit) has to be equipped with the rechargeable battery pack (RBP).

RBP recharges the amount of electricity, when generator unit operates at the rated parameters. When the output capacity from generator unit is lower than normal, RBP compensates for the power deficiency. RBP has to ensure interconnected operation of storage batteries and generator, namely, to have constant rated voltage across terminals, track output consumed power, and so on.

Consumers of only active power can receive electrical energy directly from switchboard at the RBP output. For motor domestic load, it is compulsory to use AC voltage, hence, it is suggested that inverter should be utilised for supplying such electrical receivers.

Electrical assembly incorporates two three-phase 400WPM generators with 12V output voltage made in China of 400W capacity and 690rpm with low starting torque on permanent magnets.

The device disadvantage is associated with its preferable limited use when the flow velocities are low and less than 1m/sec, even with high circumferential forces, since a considerable multiplication of rotational frequency will be required.

**V. Conclusion**

1. The use of small rivers flow energy, implemented in the designed structural concepts of hydro generators, is the most promising direction of supplying electricity to consumers in remote areas.

2. The known structural concept designs of hydro generators have shortcomings due to interaction between the flow and working organs in these devices.
3. So called longitudinal-flow hydropower installations make it possible to increase the coefficient of hydraulic flow energy transfer to the working organ, and they should be classified as a new second class of hydropower installations that utilise the river flow energy.

4. It is suggested that a quantitative component of the flow, i.e. the momentum, should be used when designing free-flow hydro generators. This idea has been implemented in the device: “Longitudinal-flow hydropower installation” patent No.156588. To apply the proposed solution in practice requires the development of comprehensive and extensive theoretical backgrounds for calculating and designing longitudinal-flow micro HPSs, what constitutes a subject for further research studies.

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