

Представлено концепцію створення пневматичного імпульсного водомету, оригінальною особливістю якого є використання для формування струменю розвинутої турбулентної течії у стані згасання. Необхідну структуру дрібномасштабної турбулентності передбачається створювати у каналі ствола за відомою процедурою застосування решітки поперек течії. Максимальна інтенсивність цієї турбулентності буде існувати на певній відстані від решітки, де потрібно встановлювати сопло для виведення турбулентної структури у струмінь. Відомі теоретичні представлення та експериментальні факти дозволяють стверджувати наявність у течії з дрібномасштабною турбулентністю стійкості до збурень. Передбачається, що ця властивість буде активною у струмені до повного згасання енергії турбулентності у процесі в'язкої дисипації. Таким чином буде існувати протидія появі великомасштабної турбулентності і відповідно затримається розпад струменю та збільшиться дальність його польоту.

Проведений аналіз дії фонтанів з прозорим струменем показав, що представлення наявності у їх течії ламінарного режиму є помилковим. Представлено обґрунтування, що особливі властивості струменів є наслідком турбулентної течії у фонтанах. Такий висновок свідчить на користь дійсності запропонованого використання турбулентності у якості інструменту проти вихроутворення. Але методику створення струменю у фонтанах принципово неможливо застосовувати для імпульсного водомету великої потужності.

Запропонована принципова схема імпульсного водомету з пневматичним виштовхуванням водяного снаряду. Очевидною проблемою поєднання імпульсної течії з утворенням дрібномасштабної турбулентності є нестійкість течії у початкову мить імпульсу. Показано вирішення цієї проблеми шляхом проведення експериментального визначення реальних характеристик течії у обраній конструкції водомета. Надані пропозиції щодо вирішення найбільш важливих питань створення водомету

Ключові слова: імпульсний водомет, стійкість струменю, розвинена турбулентність, дрібномасштабна турбулентність

THE CONCEPT OF CREATING A PULSE WATER GUN WITH A LARGE ACTION RANGE

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1. Introduction

We discuss problems of the application of a water jet, which is a free unsubmerged jet named "hydro-jet" in hydrodynamics, in this study. We use a simplified term "jet" further in the text. An area of application of jets is extremely large and it is constantly growing. We consider a part of the whole area – a delivery of water for means of firefighting or creation of water impact action on an object. In both cases, it is necessary to provide a long distance of transfer of a water portion to an object, and the portion must have a large mass or kinetic energy.

Jet technology of firefighting with a dispersed jet is effective at short distances. However, there is an increasing need to extinguish a source of ignition at a great distance in modern practice, and here the effectiveness of methods used is very low. Usually, the ratio of all spilled water to the water, which is actually useful for extinguishing, is 19:1. The ratio reaches 5:1 in the USA, Great Britain and Sweden. Thus, a need for targeted delivery of water to a fire becomes obvious.

Recently, there has been a growing interest in using the kinetic energy of a water projectile in weapons systems of warning or traumatic action. For example, water guns used by police are not effective in terms of water resource using

and a targeted impact of a jet. A use of a water projectile for destructive action at a long distance is promising, but impossibility of provision of wholeness of a projectile during flight hampers application of the corresponding technique.

Despite the apparent need to throw water for hitting or destruction, attention to the task was insufficient, apparently, for two reasons:

a) there was no clear request for expansion of potentialities of the jet application;

b) a solution to the problem required significant developments that were outside traditional research courses.

There was an expendable technology of flooding a fire site with water in firefighting. It did not cause doubts. And classic firearms or pneumatic weapons performed an impact action.

There is a limitation of a range of action of jets caused by the use of outdated technology now. However, we can replace it with new techniques. There is no fundamentally new approach to their creation yet. This study performs a search in this direction. Compared with the tremendous progress in many areas of technology, the practical base of hydrodynamics remains at the level of the last century, and the base of its development is mainly the use of a perfect mathematical apparatus and computational methods. Therefore, the

development of a new technique for creation of a stable jet of a water gun is relevant.

2. Literature review and problem statement

Fundamentals of the most of existing technologies with a use of water are the achievements of hydrodynamics created by the middle of the last century. Since then, there was no attempt to break away from the classical approaches, except for a unique breakthrough in pulse technologies caused by creation of ultra-jets [1]. Ultra-jets have a high speed, more than the speed of sound, which provides greater kinetic energy and makes possible to destruct any solid materials. However, ultra-jets are short-range because of the speed. The technology of ultra-jets is sufficiently developed. A paper [2] presents options of the corresponding pulse water guns and hydraulic guns, which differ in the method of release of a water projectile. An attempt to use such a technique at much lower speeds was not successful [3].

We noted in the introduction above that there are no known methods for obtaining of a stable jet to achieve a long range of action. There is no even discussion of the idea of such plan; therefore, there are no corresponding literary reports. Of course, there are many partial options with limited success in dealing with jet destruction, but they are of no interest. However, we should use all basic provisions of hydrodynamics in creation of a new technique presented in detail [4, 5].

Several modern developments, which apply the latest technical methods of research and theoretical concepts, can be useful for the search for a new idea of jet preservation. Extensive publication [6] considers a number of such methods. In particular, it considers positions of the jet technique that relate to mixing and diffusion in a turbulent flow created by lattices. The latest methodologies of direct numerical simulation (DNS) give important practice information on attenuation of a turbulent flow generated by fractal lattices. For example, a picture of an acoustic field of a flow was obtained [7]. It showed possibility of reducing of a noise level from a jet by transferring it to a mode of developed turbulence with a use of lattices. There are interesting results on the behavior of turbulence in a free jet obtained by direct calculations of three-dimensional Navier-Stokes equations [8]. In particular, authors discovered an inverse evolution of dimensional scales after turn off of an external perturbation generator. Authors attribute the observed effect to the action of the Le Chatalier principle in the turbulence. It leads to enlargement of scales of vortex structures.

Thus, there is a developed theoretical base of hydrodynamics, which gives us possibility to explain and predict almost all properties of jet flows. There is also a great deal of experience in analysis of these flows and their application in various technologies. However, this experience is beyond the task set in this study. The analysis carried out showed that it makes no sense to continue activities in the areas studied. We should use the accumulated experience and the level of understanding of turbulence to construct new flow models.

3. The aim and objectives of the study

The objective of the study is to develop a methodology for creation of a stable jet, which should provide a long range of action of a water gun.

To accomplish the aim, the following tasks have been set:

- analysis of possibility of a use of a pulse technique of water release without a shell at speeds of several tens of meters per second, which ensures preservation of jet wholeness;
- discovering of a way to struggle against vortex formation in a flow in a barrel channel based on modern ideas of turbulence, consideration of possibility of its realization in a water gun and assessment of its influence on stability of a jet;
- development of a schematic diagram of a water gun, which will correspond to the developed method of preservation of a jet.

4. Basic principles of the methodology of creating a stable jet

We based our decision on the choice of a particular direction of research on the following facts in accordance with the first task set.

The known inevitable destruction of a jet is the main problem in jet technologies, since it limits a distance and power of a jet action. An equal pulse of particles in a volume of liquid and a force of surface tension provide the existence of a compact initial part of a jet. The main mechanisms of destruction act due to gravity and air resistance, they lead to breaking up and then dispersion of a jet.

We are not able to affect the process of jet destruction effectively. Therefore, we use specific solutions for its preservation. For example, we can increase surface tension by addition of surfactants to liquid. This method has limited application. It is possible to increase kinetic energy in demonstration fountains and fire-extinguishing means with a use of large pressures and forces. However, such approach is too expensive for a wide use.

Pulse methods provide a portion of water with kinetic energy more effectively, since a power of a device affects not an entire jet, but its part only. Repetition of shots creates a discrete jet of individual portions of water with small gaps due to recharge of a water gun. Destruction of a discrete jet by external factors occurs more actively, since it has gaps. An action of external factors is increasing at high speeds, so ultra-jets are short-range.

The pulse technique of water throwing ensures wholeness of a water projectile in a container. Its use is diverse: from balls with paint in an elastic shell for paintball to a projectile in the form of a plastic bottle with water, which can destroy a brick wall without fragments, dust and a blast wave. Metal cans became a convenient shell for fans of original shooting with a use of gas mixture explosion due their standard sizes. However, the cost of creating a projectile discredits the attractiveness of the container method for water throwing.

Thus, it is necessary to use a pulse method of water release with a long length of a continuous part of a jet in a pulse for creation of a water gun of long-range action. However, we can take into consideration none of the known methods, which are the closest to the task set, since none of the methods provides the required length of a jet. It is not possible to solve the problem in the framework of classical approaches to jet creation, so it becomes necessary to search for its non-trivial solution.

The search for solutions to the second task of the study requires an examination of the nature of turbulence.

A phenomenon of the turbulence of a flow in a barrel channel appears at flow rates assumed in a water gun, in ad-

dition to the considered factors of jet destruction. It affects stability of a jet significantly. Actually, turbulence limits a flow speed of a whole jet in a jet technology. Indeed, a release of water at a speed greater than several tens of meters per second occurred as a dispersed jet that was dispersed rapidly in all known cases, including authors' experiments [3]. Turbulence is the most important factor in destabilization of a jet. It triggers external mechanisms of destruction. Provision of a smooth flow near walls of a channel and a nozzle shifts the beginning of the turbulence process, but does not eliminate it. Turbulence is not considered in generation of ultra-jets by means of hydraulic guns and as the option – pulse water guns – as it is a part of more significant dynamic processes.

Consequently, creation of a pulse water gun will become possible only if there is a significant effect on turbulence in a barrel channel. A search for such a technique, in fact, is the main task of the study. Experimental verification of the methodology is a complex process, so we cannot perform it at the development stage. Therefore, the criterion for the validity of the methodology will be a thorough analysis of its correspondence to existing concepts of turbulence. It is also necessary to analyze principles of operation of a number of fountains to understand physical processes in them and their connection with turbulence. Finally, based on a new technique, to offer a schematic diagram of a water gun, which we will be able to generate a stable jet with a large kinetic energy.

A flow of water from a nozzle will undoubtedly occur at a speed greater than full speed of a laminar flow. The Reynolds criterion determines a flow mode. The Reynolds criterion is the number that characterizes the ratio of inertia force and viscosity force. We can determine it by the following expression

$$Re = \frac{uL}{\nu}, \tag{1}$$

where u is the characteristic flow rate, L is the characteristic flow size, for example, a pipe diameter, ν is the kinematic viscosity coefficient, which is determined as a ratio η/ρ of a dynamic viscosity coefficient η to a density ρ .

At flowing in a circular tube, transition from a laminar flow to a turbulent mode begins at a critical value of Re_{cr} , which is approximately 2,300; it can have a transition interval. Studies on turbulent flows in wind tunnels detected the main regularities of the turbulent flow. In a flow of a water gun, we expect large values of Re in comparison with wind tunnels due to the lower kinematic viscosity of water ($\sim 10^{-2} \text{ cm}^2 \text{ s}^{-1}$) compared to the kinematic viscosity of ($\sim 1.5 \cdot 10^{-1} \text{ cm}^2 \text{ s}^{-1}$).

Traditional hydrodynamic approaches do not give possibility to affect the turbulence in a flow channel significantly and to inhibit the destruction of a jet. However, based of modern concepts of the nature of turbulence, it is possible to prevent development of strong turbulence by means of artificially created small-scale (SS) turbulence. Paper [9] considers its importance for provision of stabilization of a jet.

The special properties of SS turbulence follow from theoretical models [10–13] of the so-called developed turbulence with Re , the Reynolds number, greater than 10^5 . It is enough to confine ourselves to the Kolmogorov fundamental model [11] of locally isotropic turbulence in the framework of the problem. The basic concepts of the model are the concepts

of two types of turbulent fluctuations – large-scale (LS) ones and small-scale (SS) ones. Linear scales l_k of them form a singularity of an interval of the corresponding values of wave numbers $k=2\pi/l_k$. Turbulence generating begins with LS formations (vortices) which play a role of energy accumulators from a flow. Vortices turn into SS fluctuations due to the Richardson cascade process of energy transition. Fig. 1 presents the process schematically. The process ends with vanishingly small turbulent fluctuations with dissipation of kinetic energy into heat.

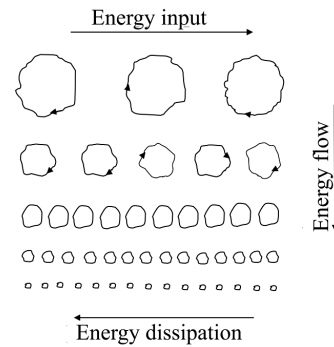


Fig. 1. Scheme of the Richardson cascade process of vortex evolution

The possibility of a use of the developed turbulent flow in the presented technique follows from the singularity of the spectral energy density $E(k)$ of pulsations of a longitudinal velocity component inside a fluctuation. A graph on Fig. 2 demonstrates this feature by $E(k)$ dependence. The graph corresponds to energy changes, which occur in the Richardson cascade. In fact, the nature of $E(k)$ spectral dependence explains the existence of a flow of turbulent energy. It has three intervals separated by vertical dashed lines in the figure. The initial interval of the spectrum with small k refers to the processes of LS turbulence formation due to the energy of a main flow. The maximum value of energy corresponds to k_0 wave number. Then spectral values of energy decrease, and an energy flow to turbulent structures of a smaller scale occurs. The final transformation of kinetic energy into heat occurs with ϵ average energy dissipation speed in the range of values greater than k_η . According to the Kolmogorov model, there is the so-called “5/3 law” in the $k_0 \leq k_i \leq k_\eta$ of wave numbers of the energy spectrum:

$$E(k) \approx \epsilon^{2/3} \cdot k^{-5/3}. \tag{2}$$

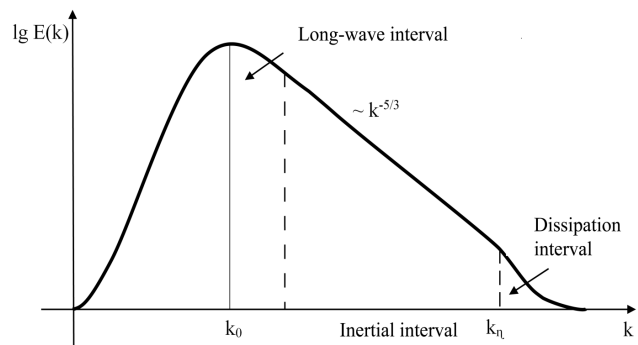


Fig. 2. Dependence of $E(k)$ spectral energy density on k wave numbers in the logarithmic scale. k_0 – wave number at the energy maximum and k_η – at the beginning of the energy dissipation process

The presence of only one characteristic value of the process, an energy of dissipation ϵ , in the expression (2) means that transition of energy by SS turbulent fluctuations does not depend on frictional forces. Inertia forces determine it solely. The interval of k_i values at which the “5/3” law takes place is called an inertial interval of $E(k)$ spectrum. Its width is the greater, the larger the Reynolds number is.

Thus, it follows from the theoretical model that LS turbulent structures cannot arise in a hypothetical flow, which consists of fluctuations with $k_i \gg k_0$ wave numbers. This conclusion is a basis for the proposed method of stability of a jet.

Numerous experimental studies confirmed the existence of the “5/3” law. So, they strengthened the reality of representation of locally isotropic turbulence. Naturally, there is a temptation of practical use of properties of the array of SS fluctuations in a developed turbulent flow with large Reynolds numbers for provision of stability of a jet and achievement of its larger range.

Of course, we cannot expect that a developed turbulent flow will consist of fluctuations with wave numbers of an inertial interval only. We should assume a presence of a laminar flow in a flow taking into account that turbulent fluctuations are non-linear waves. Recent studies on a structure of developed turbulence showed [14] that its real composition and local characteristics differ from the considered simplified model. There is a non-equilibrium turbulence found in [15], and the law of non-equilibrium dissipation coexists with the ordinary law of equilibrium dissipation in different regions of the same flow. These refinements are important for the theory, but, perhaps, do not affect possibility of practical application of turbulent flow for this problem. However, complexity of the nature of turbulence does not give possibility to predict conditions for production of intense SS turbulence, its qualitative composition and localization in a flow reliably. Therefore, an assessment of wave characteristics of SS turbulent excitations in a real flow remains beyond the scope of an experimental art of operation of turbulent flows.

Thus, we should proceed to consideration of a scheme for creation of an artificial flow with SS to release its jet. We assume that vortex formation will not occur in the process of turbulence attenuation.

5. Creation of a flow with small-scale turbulence

A base of a procedure for creation of SS turbulence is the known Richardson cascade process of energy transition. We use a flow, which passed through the active stage of turbulence and is in a state of turbulent fluctuations with k_i values of wave numbers in the inertial interval of the energy spectrum. We introduce necessary turbulent energy into a flow by artificial creation of vortices by means of a lattice installed in the flow path. A photograph of the known Album of flows of liquids and gases fixed a picture of evolution of turbulent vortices after a lattice [16].

Large vortices decrease with a distance and disappear in the process of turbulence attenuation. They turn into invisible SS fluctuations. This flow region with apparent absence of turbulence became a subject of interest in numerous studies. Researchers established that “turbulence behind a lattice at distances exceeding $30 \div 40$ (where M is a lattice cell size) is close to homogeneous turbulence and isotropic turbulence in many of its characteristics” [12, 13] at an early stage of the studies with simple lattices already.

Now, there are studies on a region of disintegration of turbulence with application of various methods and with a help of various lattices. Lattices, which represent spatial systems of fractal squares, create SS turbulence the most efficiently [17, 18]. It is established fact that there is homogeneous isotropic turbulence with unusually high Reynolds numbers observed in the region of disintegration of lattice turbulence. Investigations clarified the nature of a dependence of $E(k)$ energy spectrum density, it keeps the exponential form of $k^{-5/3}$, but it has a more complex coefficient [18].

The most important for the design of a water gun is information on distribution of intensity of homogeneous isotropic turbulence along a flow [17]. The intensity reaches a maximum value at x_{peak} distance from a lattice, and then decreases exponentially. Accordingly, we can describe u component of a mean-square turbulent speed along a flow by the expression

$$u'^2 = u_{\text{peak}}'^2 \exp[-(x - x_{\text{peak}}) / l_{\text{turb}}]. \quad (3)$$

We use the determined [17] nature of the distribution of localization of intensity of the lattice turbulence for the procedure of isolation of a region of SS turbulence in a flow in a channel of a water gun barrel. Of course, the problem is not simple, since characteristics of the lattice turbulence and x_{peak} value itself are derivatives of a flow speed and lattice parameters.

Since excitations of an inertial interval of the spectrum have small energy, it is important to obtain a higher intensity of SS turbulence so that it remains active in a state of attenuation. An experience presented in paper [19] can be useful for this problem. Authors of paper [19] created a large intensity of turbulence with application of a spatial fractal generator.

6. Conditions for the formation of a jet with small-scale turbulence

The process of jet formation should ensure transition of energy from the established region of maximum intensity of turbulent fluctuations to a jet. The total energy in this region depends on the integral energy over the entire set of wave numbers of the inertial interval provided by flow conditions (conditions of a turbulent flow must realize them), and on time scales of fluctuations. The width of the inertial interval of the spectrum for large Reynolds numbers covers 2–3 orders of magnitude with a significant set of time scales. It is necessary to take into account continuity of acts of appearance of turbulent fluctuations. As a result, in the flow region near x_{peak} , there is a local array of fluctuations with a resource of turbulent kinetic energy, in which only the dissipative process takes place. Thus, this flow region is a continuous generator of SS turbulent energy.

A part of the array withdrawn into a jet will prevent formation of strong turbulence in it until exhaustion of turbulent energy in a water portion. It is important to have an idea of duration of the process of its attenuation in this problem. Optimism in this issue creates information [20] on the average lifetime of τ pulse of SS turbulence. We can note that τ as a function of the Reynolds number Re increases remarkably rapidly, almost as $\ln \tau \sim Re$. A refinement of this dependence showed that it is stronger – with a double exponent $\tau \sim \exp(\exp(Re))$ [21]. As we already noted, a flow in a water gun will have large Reynolds numbers, so the discov-

ered [20] property of stability of a turbulent pulse makes us expect the presence of an array of SS turbulent fluctuations in a jet for some time.

Stability is an important feature of a flow with SS turbulence. The turbulent mechanism of pulse transition makes possible to consider a turbulent flow as a special medium. Boussinesq (1897) introduced the concept of turbulent viscosity for the description of its motion. A representation of the Reynolds number as the ratio of corresponding viscosity coefficients reflects a symbiosis of turbulent mechanism and molecular mechanism of pulse transition during flow. Accordingly, a reaction of a flow with SS turbulence to an external action is different from a laminar flow reaction. A local fluctuation immediately breaks an order in some nearest region in an ordered field of laminar flow speeds; and there is no order in the case of locally isotropic homogeneous turbulence. We can consider a medium of SS turbulent fluctuations as a finely structured elastic continuum. Authors of work [22] use a name “turbulent liquid” for it [22]. A much more stress than in other flows is necessary for formation of long-range order and appearance of a vortex in its field of speeds. In addition, speeds of turbulent transition and mixing are orders of magnitude higher than speeds of molecular transition of a pulse, heat, and matter, so relaxation of arising stresses will occur faster than in a laminar flow, for example, on wall roughness. As a result, turbulent liquid flows along a boundary layer. Flow resistance decreases at boundary layer turbulization, and we observe a *resistance crisis*, when a resistance coefficient drops sharply several times [10], in the region of Reynolds numbers $Re \sim 10^5$.

However, the stability mechanism of SS turbulence acts up to some critical stress, after which vortices begin to form. Authors of paper [23] studied these vortices precisely in fully developed turbulent flow in channels with projections. This paper did not investigate a voltage threshold for the formation of vortices; it investigated the process of their evolution and attenuation only. A vortex disappeared in the form of a trace, which also agrees with the stated property of stability of flow with SS turbulence.

Impossibility of spontaneous formation of LS structures in the developed turbulent flow and its resistance to external influences are the basic criteria for the technique of jet preservation in a pulse water gun. In particular, turbulent stability will ensure preservation of a flow structure at a change of a flow mode in a water gun channel and at transition to a nozzle and further into a jet.

7. Stabilizing role of SS turbulence in fountains

The unexpected manifestation, apparently, of properties of SS turbulence showed itself in the analysis of operation of fountains with a jumping jet, known as Jumping Jet or Laminar Water Jet. They create a continuous transparent jet with a small kinetic energy, but its length seems too large for a laminar flow, which is assumed in fountains. The principle of operation and design of branded fountains are copyright, but available technical characteristics and visual parameters of jets give some understanding about them. For example, the Reynolds number of a flow at an exit from a nozzle turned out to be more than $1 \cdot 10^5$, which does not correspond to a laminar mode. Apparently, a long length of a continuous jet exists due to the presence of lattice turbulence in it, possibly

even in the form of SS turbulence. Here are the most obvious facts in support of such conclusion.

The analysis of the design of industrial fountains within the limits of available possibilities showed that a shape of a flow channel and a profile of a nozzle not only do not provide laminar flow conditions, but cause turbulence undoubtedly. Moreover, there are grids or lattices with small cells that create lattice turbulence in flow channels. In this case, we can observe a stable jet despite ignoring conditions for obtaining of a laminar flow. These contradictory facts are consistent in the case of the presence of SS turbulence, which provides the stability of a flow, only.

There are designs of amateur fountains with a transparent jet on the Internet. They use one principle scheme, to produce laminar flow apparently. It is necessary to fill a cavity of an injector of a cylindrical shape with straws for drinking or other material with narrow channels densely. However, the butt end of a set of straws forms a kind of lattice, which leads to mixing of individual jets and a turbulent flow.

Light effects demonstrated by the jets also indicate the presence of SS lattice turbulence in them. For example, a pure laminar jet should not scatter illumination light like a lightguide, and the observed luminescence of jets indicates light scattering on small-scale turbulent fluctuations. A work [9] considers a more complex demonstration light effect, which is also caused by SS turbulence.

Engineers found a way for the creation of a continuous jet in fountains such as Jumping Jet by an empirical method, and technical solutions used in them deserve the highest evaluation, but they do not make possible to obtain a jet in the pulse mode. Fountains use a continuous flow, the pulse mode needs overlapping of a jet with a flap.

We can obtain a direct evidence of the presence of developed turbulence in fountains flow with a help of special studies only. However, such studies are inexpedient because of their complexity. There was a numerical modeling of flow characteristics in a model of one amateur fountain device carried out with a use of Computational Hydrodynamics Ansys Icem CFD software package. The nozzle of the device was a cylindrical chamber, an inlet branch pipe was in the lower butt end, and there was a nozzle in the form of a cylindrical tube in the upper butt end. There were 6 lattices in the form of perforated sheets installed right at the entrance to the cell. Two lattices were with a large perforation, they provided alignment of a flow in the direction, apparently. And four lattices were with fine perforation; they extinguished flow pulsation, and, probably, created turbulence. Most of the chamber in front of the nozzle was free, and, apparently, served to calm a flow. At the same time, the chamber can be a space where the lattice turbulence attenuates with the formation of an array of SS fluctuations.

In the experiment, we assumed the outflow speed from the nozzle equal to 10 m/s, which corresponded to the real value. Fig. 3, 4 show the visualization profiles of the turbulence intensity obtained in the experiment in different sections of the chamber. We can see on Fig. 3 that the turbulence is high enough near the grids and reaches 60 % in some places. And it follows from Fig. 4 that the intensity is about 30 % in the middle of a free space of the chamber and it is almost uniform throughout the section.

Fig. 5 shows that the intensity of turbulence decreases closer to the nozzle, as it is up to 35 % at the edge of the nozzle cross-section and up to 5–10 % in the center.

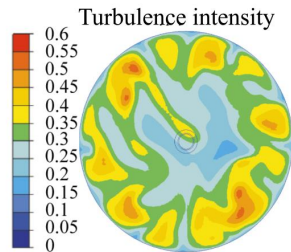


Fig. 3. Profile of distribution of the turbulence intensity in the section of the chamber of the injector near the grids

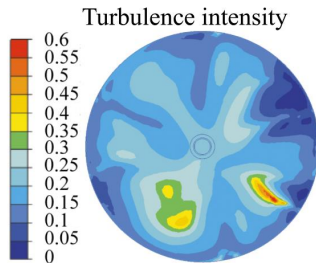


Fig. 4. Profile of distribution of the turbulence intensity in the section of the chamber of the injector in the middle of a free space

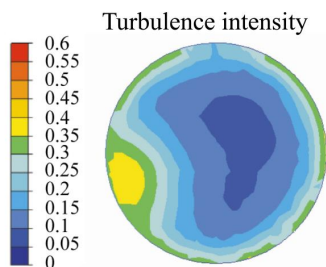


Fig. 5. Profile of distribution of the turbulence intensity in the section at the nozzle cut

We can consider results of the modeling as a proof of absence of turbulence at the outlet from the nozzle into a jet and presence of a laminar flow. Designers of fountains came to the same conclusion, apparently. They, of course, conducted computer modeling of a flow. However, in reality, the obtained results indicate absence of LS turbulence only. SS turbulence is not available for a numerical modeling of a usual level. The pattern of a change in the turbulence intensity after the grids observed in the computer experiment corresponds to the classical process of evolution of lattice turbulence completely. In addition, only presence of SS turbulence explains possibility to neglect smoothness of transition from the chamber to the nozzle in fountain devices.

8. Design fundamentals of a pulse water gun

The results of the analysis of properties of SS turbulence, as well as its established presence in fountains with a transparent jet, make possible to use this kind of a turbulent flow in a water gun. However, the pulse mode of a flow will create difficulties in obtaining of SS turbulence due to instability of a flow at the initial portion of a pulse. It is apparently impossible to determine a region of localization of SS turbulence in a flow due to high flow speeds and to investigate

its characteristics in the pulse mode. We can proceed to the pulse mode and establish an optimum length of a continuous jet only after working off the methods for obtaining of SS turbulence in a continuous flow mode with the initial parameters, which include a diameter of a water projectile and flow speed of a jet. There is also a difficulty associated with a gradual increase of flow speed in a barrel channel at the pulse flow. The initial part of a jet will be “spoiled” because of unstable outflow. The non-equilibrium process of outflow will end with the speed of sound after a complete opening of the nozzle, and the subsequent part of a jet will be created in an equilibrium mode. It is clear that a length of the “good” jet should be much greater than a length of the “spoiled” jet, hence the requirement for a short time of activation of the nozzle shutter, no more than 20 ms. A minimum length of the barrel must correspond to the condition for containing of the volume of liquid in a full jet of one pulse. We should increase a length of the barrel multiply to ensure a firing rate.

Fig. 6 represents the idea of the principle of action of a water gun. A size of structural elements in the figure do not correspond to the actual dimensions.

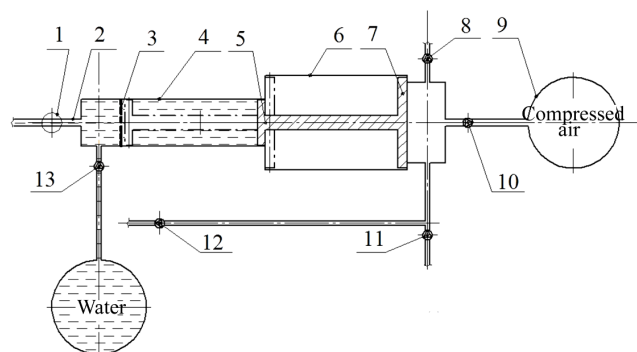


Fig. 6. Schematic diagram of the pulse water gun: 1 – nozzle shutter, 2 – nozzle, 3 – grids, 4 – barrel, 5 – piston of a barrel, 6 – pneumatic cylinder, 7 – piston of pneumatics, 8 – pressure relief valve, 9 – receiver, 10 – valve of a receiver, 11 – reducer of high pressure, 12 – valve of shutter pneumatic, 13 – water supply valve

The pneumatic method for release of water gives possibility to obtain different flow speeds by changing the air pressure. A double piston of different cross-section creates high pressure on water in the barrel channel at a relatively low pressure in the air cavity of the water gun. One part of the piston is 5, it is smaller cross-section, it moves in the channel of barrel 4, another part – 7, it is larger cross-section, it moves into pneumatic cylinder 6. The piston is in preparation for a shot in Fig. 8. The pressure on water is greater than the air pressure by the ratio of the area of the pistons S_7/S_5 . Receiver 9 maintain a constant pressure during the outflow of a jet. The water gun uses electromechanical valves, except the shutter of the nozzle. The shutter must withstand high pressure in addition to the speed of operation. There are no industrial products of this type. It is necessary to manufacture it independently, possibly in the form of a gate valve with a pneumatic drive. Other elements of the water gun scheme do not require an explanation in the framework of this study.

We listed only a part of the obvious technical problems, which will arise at construction of a water gun. Their solution is available to the professional team with the necessary

technical support only. The expected breakthrough in jet technologies and creation of a water gun with a long range of action itself will justify efforts and resources expended.

9. Discussion of prospects for the concept of creating a pulse water gun

We considered a rather urgent problem in the study. We tried to solve the problem of obtaining of a stable water jet with a large kinetic energy on the example of creation of a water gun with a long range of action. A successful solution of the mentioned problem will give us possibility to apply the technique of obtaining of a stable jet in all jet technologies, where there is a need to increase power and range of a jet. In particular, actions of the police in mass riots will be more effective with the use of the proposed water gun than with the use of existing water guns.

The principle of operation of the pulse water gun differs radically from all known techniques for obtaining of jets by creation of artificial small-scale turbulence in a barrel channel. Its properties are studied thoroughly, which gives us possibility to use turbulence in a water gun confidently. The property of stability inherent in turbulent flow should ensure wholeness of a jet. This study differs from traditional studies on turbulent flows in its focus on a use of turbulence as a tool against stronger turbulence – vortex formation.

We have to solve a number of non-trivial tasks on the way to implementation of the idea despite its thorough substantiation. Even the use of the known technique for obtaining of SS turbulence will become problematic at high flow speeds. We have also completely unexplored tasks of manipulation of an array of SS fluctuations and its behavior in a jet. It is necessary to solve these tasks during tests by selection of necessary speeds and grids, using known methods for diagnosing SS turbulence. It makes no sense to estimate any parameters of turbulent disturbances before necessary tests, since their collection depends on specific flow conditions. A type of $E(k)$ energy spectral density shown in Fig. 2 depends on a coefficient in (2), which is skipped in this expression because we should determine it experimentally. The only significant and determinable value is l_η linear scale of structures that are still involved in the viscous dissipation process. But we also need the experimental value of energy dissipation speed to evaluate this value.

The existence of lattice turbulence in fountains with a transparent jet is a reasonable assumption, but not a proven fact. Despite the seeming commonality of solutions for ob-

taining of a stable jet in fountains and in the author's version, they differ in a scope of application, validity of a technique and parameters of jets.

The proposed design of a water gun gives an idea of a possible product only, but it shows the reality of achievement of the ultimate goal of the study even in this form. Creation of a water gun is a rather complex technical project, which requires special consideration after a series of preliminary studies.

10. Conclusions

1. A base of the concept of creation of a water jet is the pulse method of release of a portion of water without a shell. That makes it possible to obtain a large kinetic energy of a water projectile, which will ensure a greater range of its flight. The traditional use of continuous jets is not effective either from the point of view of water consumption or by the results of its use. The apparent simplicity of the method loses its advantages in the overall evaluation of a jet process. Technical complexity constrains the development of pulse methodology, so the proposed version of the methodology can provoke progress in this area.

2. We proposed using the turbulence itself in a state of attenuation as a preventive tool from the turbulent mechanism of jet destruction. To do this, it is necessary to create a small-scale turbulence in a channel of a water gun flow with the help of a grid, in which vortex formation is impossible. This turbulent structure withdrawn into a jet will have the property of stability of a turbulent flow, which will slow down destruction of a jet. We based the proposed idea on the known properties of developed turbulence and the procedure for obtaining it.

3. We presented a schematic diagram of the design of a pneumatic pulse water gun. We realized the technique of using turbulence in the state of attenuation in it. A characteristic feature of a pulse water gun is the presence of grids in a barrel channel. The combination of this feature with the pulse flow mode leads to a number of problems, which require solutions, in the course of the experimental development of a water gun.

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