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ОБЕСПЕЧЕНИЕ ПОЖАРНОЙ И ПРОМЫШЛЕННОЙ БЕЗОПАСНОСТИ

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RELATIONSHIP BETWEEN REGULATORY MANUFACTURING PRECISION OF FIRE NOZZLE AND ITS WATER JET TRAJECTORY GEOMETRIC CHARACTERISTICS

In present paper showed the methodology, grounded, evaluated, illustrated and analytically described by formulas influence of manufacturing precision of the fire nozzle outlet hole diameter of which meets the regulatory and established requirements on its water jet trajectory geometric characteristics, namely the distance of the flight and height of lifting, for various values of inclination angle of the nozzle axis to the horizon, both in absolute and in relative terms. Expedience of beta distribution using for describe these variables taking into account the non-linearity of their dependence on each other was grounded.

Key words: fire safety, fire nozzle, water jet, manufacturing precision.

Introduction. From the main provisions of the hydraulics is known that the geometric parameters of trajectory of water jet from a convergent conical nozzle, what is the manual fire nozzle (MFN), depends on diameter of its outlet hole [1 – 5]. In approximate calculations of these water jet parameters are used the nominal value of the MFN outlet hole diameter [3 – 5]. However, this parameter is conditional and characterized by a certain value of the precision [6, 7]. Analysis and evaluation of the accuracy of manufacture of fire fighting equipment components, as well as any technical object, is the subject of research of metrology [1, 2]. Since the MFN is the product of mass production, the basic requirements to it are reflected in GOST 9923-93 [6] and other normative legal acts, which are set including the precision requirements of its manufacturing. From the main provisions of hydraulics are also known, and other factors affecting the geometric characteristics of the water jet from the nozzle of this type, as the MFN [3 – 5]. Therefore, study of the impact of MFN regulatory manufacturing precision on the geometric parameters of a water jet from it are allocated a significant scientific and practical interest.

Statement of the problem and its solution. The purpose of study is justification for the need to consider the regulatory established values of MFN output hole size deviation in the calculation of its water jet trajectory geometric characteristics and the calculated estimation the value of this impact. The object of study is the geometric characteristics of the trajectory of MFN water jet. The subject of study is the influence of MFN regulatory manufacturing precision as a mass-produced product on the object of study.

From described in [8] the list of geometric characteristics of the outlet opening MFN the most simple (basic) is its diameter d_0. To describe the effect of the value d_0 on the geometric characteristics of the trajectory of the water jet from MFN is possible to use the method of approximate calculation of these characteristics from [3, 5]. Also we can use the assessment methodology of influencing factors measurement errors on the MFN jet trajectory geometric characteristics from [2, 3, 5]. The main geometric characteristics of the MFN water jet trajectory are its flight length l and lifting height h. In the approximate calculation (i.e. without taking into account air resistance), these values are determined by the formulas (1) and (2) in meters [2, 3, 5].

$$l = \left(V_0^2 \cdot \cos\theta_0 / g\right) \cdot \left(\sin\theta_0 + \sqrt{\sin^2\theta_0 + 2 \cdot g \cdot h_0 / V_0^2}\right),, \quad (1)$$

$$h = V_0^2 \cdot \sin^2\theta_0 / (2 \cdot g) + h_0,, \quad (2)$$

where V_0 – average initial velocity of water flow in a living cross section matching with the MFN outlet hole, m/s; g – acceleration of gravity, m/s^2; h_0 – height of MFN outlet hole center placement relative to an arbitrary horizontal plane, which is directed along the x axis, m; Θ_0 – inclination angle of MFN axis to the horizon, degree.

The trajectory of MFN water jet and its geometric characteristics and also the factors influencing on it are illustrated in Fig. 1. [3, 5].

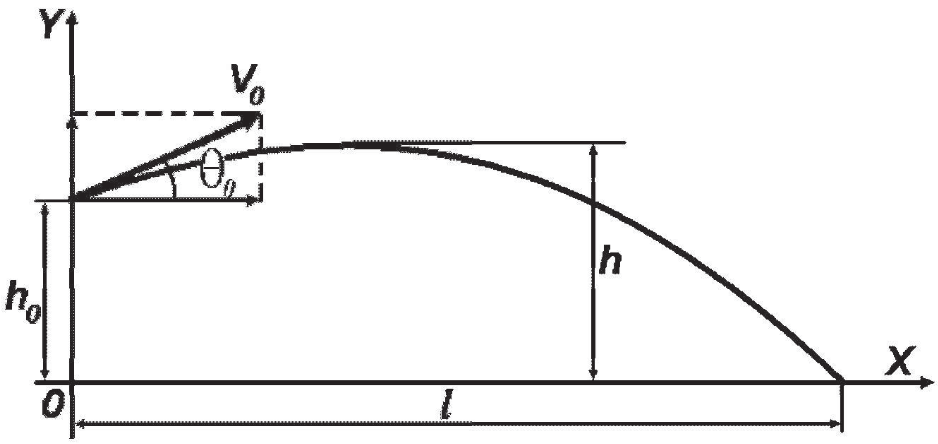

Figure 1 – Motion trajectory of water jet from MFN [3, 5]

In the such problem statement on the value of l and h is influenced only following factors: V_0, h_0, Θ_0, of which with MFN outlet hole geometric characteristics is directly related value of V_0 only. Moreover, this relationship can be described by the continuity equation of fluid flow from the formula which binds the volumetric water flow rate through any MFN normal cross section Q_0 (in m^3/s) and the area of its outlet hole ω_0 (in m^2) by the formulas (4) and (4).

$$V_0 = Q_0 / \omega_0, \quad (3)$$

$$\omega_0 = \pi \cdot d_0^2 / 4. \quad (4)$$

The value h_0 we will conventionally assumed to be constant both for case of nozzle placed in rescuer hands, and for case of its fixed on carriage. Accordingly, the setting and accounting the precision level of determination of this values in such problem statement does not make sense. Accounting of precision of Θ_0 value in such problem statement is also meaningless, since during the fire extinguishing MFN axis inclination angle dynamically and randomly changing personally by rescuer for adjusting of jet impact point on the burning object, that is, Θ_0 = 0 ... 90°. The same applies to the Q_0 value, which depends on the unpredictable changes in the parameters of the pump and hose lines. Then the value of l in this problem statement is a function of one independent variable – V_0. Because the task of setting of absolutely exact value of V_0 is impossible in principle, the impact of error of its determination ΔV_0 on jet length error value Δl may be described by the formulas (5) and (6) from references [3, 5] (since there is only one influence factor in these formulas, it is possible to use of partial derivatives algebraic values), adding them by formulas (7) – (12).

$$\Delta l \approx \left|\partial l / \partial V_0\right| \cdot \Delta V_0, \quad (5)$$

$$\Delta h \approx \left|\partial h / \partial V_0\right| \cdot \Delta V_0, \quad (6)$$

$$\frac{\partial l}{\partial V_0} = \frac{1}{g}\left(\sin(2\theta_0)\cdot V_0 + 2\cdot\cos\theta_0 \frac{V_0^2\cdot\sin^2\theta_0 + g\cdot h_0}{\sqrt{V_0^2\cdot\sin^2\theta_0 + 2\cdot g\cdot h_0}}\right), \quad (7)$$

$$\partial h / \partial V_0 = \sin^2\theta_0 \cdot V_0 / g, \quad (8)$$

$$\Delta V_0 \approx \left(\partial V_0 / \partial\omega_0\right)\cdot\Delta\omega_0, \quad (9)$$

$$\partial V_0 / \partial\omega_0 = -Q / \omega_0^2, \quad (10)$$

$$\Delta\omega_0 \approx \left(\partial\omega_0 / \partial d_0\right)\cdot\Delta d_0, \quad (11)$$

$$\partial\omega_0 / \partial d_0 = \pi\cdot d_0 / 2. \quad (12)$$

In the normative documents (for example, GOST 9923-93 [6]) and in the specialized literature (for example, [3, 5]) established a series of MFN outlet hole nominal diameters d_{0n} and precision qualitet and type of tolerance field for this parameter. Thus, for the nozzle RS-50A with d_{0n} = 13 mm set accuracy of H11, that according to the data given in [7], means that the value of this parameter should be in the range 13.00...13.11 mm, and the diameter indicated the drawings as Ø13H11 или Ø$13^{+0,11}$. That is, the parameter is changed by the regulatory requirements by the amount Δd_{0r} = +0,84 % relative to values $d_{0n} = d_0$.

For the nozzle RS-50A with outlet hole having a maximum possible value of diameter within the these requirements, and typical case described in [3, 5], h_0 = 1 m (when MFN placed in the rescuer hands), and V_0 = 20 m/s (a value close to the maximum possible for these conditions). Then we have the following results of the application the formulas (9) – (12): $\partial\omega_0/\partial d_0$ = 0,0204 m, $\Delta\omega_0 = 2{,}246\cdot10^{-6}$ m^2, $\partial V_0/\partial\omega_0 = -1{,}507\cdot10^{-5}$ (m·s)$^{-1}$, ΔV_0 = –0,338 m/s (ΔV_{0r} = –1,692 %). For different Θ_0 values have the following results of formulas (1) – (8) application, they are shown in Table. 1 and Fig. 2 – Fig. 4. Dependences of the values of l and h (in m) from the Θ_0 value are shown in Fig. 2. Dependences of the absolute Δl (in m) and relative Δl_r (in %) values of l from value of Θ_0 are shown in Fig. 3. Dependences of the absolute Δh (in m) and relative Δh_r (in %) values of l from value of Θ_0 are shown in Fig. 4.

As can be seen from Table. 1 and Fig. 3 at Θ_0 = 45° the value of l, $\partial l/\partial V_0$ and Δl reaching maximums: 41.751 m, 4.08 s and –1.381 m accordingly, and therefore $l = = 41.751_{-1.381}$ m, or $40.370 \le l \le 41.751$ m, the value Δl_r amounts to –3.31 %, and the actual value of l in this case is determined with an accuracy of ±0.691 m or ±1.66% relative to the value corresponding to the influencing parameter middle of the tolerance field. The value of Δl_r reaching its maximum equal to –3.345 % at Θ_0 = 90°. It should be noted that when Θ_0 = 0°, these values are not equal to zero: l = 9.030 m, $\partial l/\partial V_0$ = 0.452 s and Δl = –0.153 m, $\Delta\ l_r$ = –1.692 %.

Table 1 – Parameters of the water jet trajectory from fire manual nozzle RS-50A, which are in compliance with regulatory requirements, depending on the inclination angle of its axis to the horizon

Parameter	**Unit**	**Value of parameter at h_0 = 1 m, V_0 = 20 m/s, d_0 = 13.0 mm, Δd_0 = +0.11 mm, ΔV_0 = –0.338 m/s**										
Θ_0	degree	0	10	20	30	40	45	50	60	70	80	90
l	m	9.030	18.274	28.717	36.967	41.314	41.751	40.977	35.880	26.568	14.120	0.000
h	m	1.000	1.615	3.385	6.097	9.424	11.194	12.964	16.291	19.003	20.773	21.387
$\partial l/\partial V_0$	s	0.452	1.477	2.641	3.538	4.019	4.080	4.017	3.532	2.621	1.395	0.000
Δl	m	-0.153	-0.500	-0.894	-1.198	-1.360	-1.381	-1.360	-1.195	-0.887	-0.472	0.000
Δl_r	%	-1.692	-2.736	-3.113	-3.240	-3.292	-3.307	-3.318	-3.332	-3.339	-3.343	-3.345
$\partial h/\partial V_0$	s	0.000	0.061	0.238	0.510	0.842	1.019	1.196	1.529	1.800	1.977	2.039
Δh	m	0.000	-0.021	-0.081	-0.173	-0.285	-0.345	-0.405	-0.518	-0.609	-0.669	-0.690
Δh_r	%	0.000	-1.289	-2.385	-2.829	-3.025	-3.082	-3.124	-3.177	-3.207	-3.222	-3.226

In contrast to the flight length of MFN water jet as is seen from Table. 1 and Fig. 4, the values of h, $\partial h/\partial V_0$, Δh и Δh_r reaching maximums at Θ_0 = 90° – accordingly: 21.387 m, 2.04 s, –0.690 m and –3.23 % and therefore $h = 21.387_{-0.69}$ m, or $2.0697 \le h \le 21.387$ m, and the actual value of h in this case is determined with an accuracy of ±0.691 м или ±1.66 % relative to the value corresponding to the influencing parameter middle of the tolerance field. When $\Theta_0 = 0°$ the values of $\partial h/\partial V_0$, Δh и Δh_r are equal to zero and $h = h_0$.

Also from the data shown in Fig. 2 and 3 and Table. 1 implies that the values of the relative errors in determining the values of l and h (Δl_r and Δh_r) significantly modified by changing the value of Θ_0 between 0 and 45°. After reaching values of Θ_0 45° and down to the 90° they "go on the shelf", asymptotically approaching the value of –3.5 %. At the same time influence factor (d_0) changed only by the amount of $\Delta\, d_{0r} = +0{,}846$ %, being in inverse correlation with the desired values.

Let us get dependences describing research results analytically. Dependences for the absolute values of Δl and Δh, received by transforming the formulas (5), (6) taking into account the formulas (3), (4), (7) – (12) (in m) have the following form:

$$\Delta l = -\frac{\sqrt{A} \cdot ctg\Theta_0 \cdot \Delta d_{0r} \cdot \left(\sqrt{A} + \sqrt{B}\right)^2}{50 \cdot g \cdot \sqrt{B}}, \quad (13)$$

$$\Delta h = -\frac{A \cdot \Delta d_{0r}}{50 \cdot g}. \quad (14)$$

where $\Delta d_0 r$ – relative change of diameter value d0, %; A and B – substitution values for facilitate the calculation, determined by the following formulas:

$$\Delta d_{0r} = \Delta d_0 / d_0 \cdot 100; \quad (15)$$

$$A = V_0^2 \cdot \sin^2 \theta_0; \quad (16)$$

$$B = A + 2 \cdot g \cdot h_0. \quad (17)$$

Dependences for the relative values of Δl_r and Δh_r, obtained by ratio of formulas (13) and (14) with formulas (1) and (2) (in %):

$$\Delta l_r = \frac{\Delta l}{l} \cdot 100 = -\frac{2 \cdot \Delta d_{0r} \cdot \left(\sqrt{A} + \sqrt{B}\right)}{\sqrt{B}}, \quad (18)$$

$$\Delta h_r = \frac{\Delta h}{h} \cdot 100 = -\frac{4 \cdot \Delta d_{0r} \cdot A}{B}. \quad (19)$$

Thus, from the analysis of the above results of performed estimation it follows that impact of changes of MFN of the model RS-50A outlet hole diameter, located within the regulatory established tolerance field, has a significant impact on the geometric parameters of its water jet motion trajectory, in particular on its flight length and lifting height.

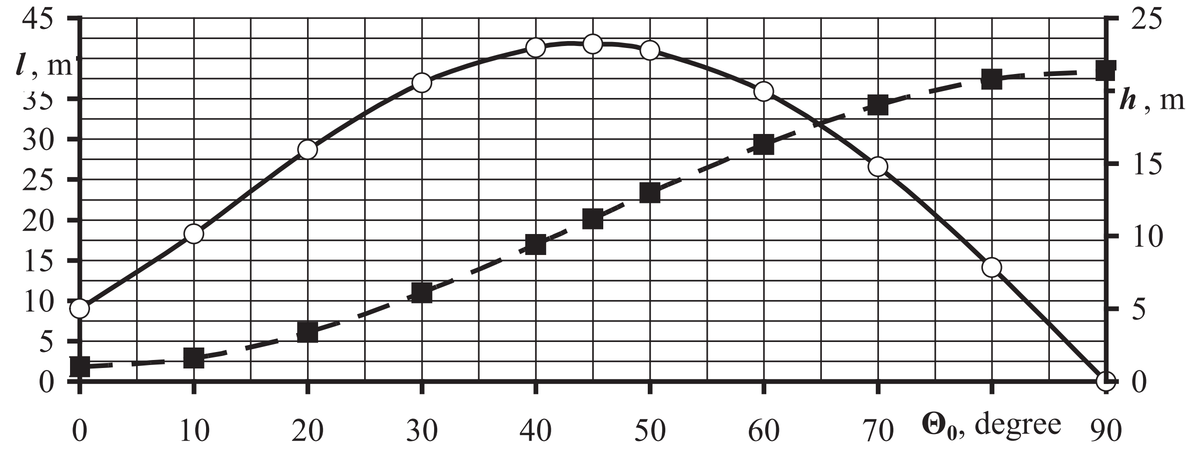

Figure 2 – Dependences of the values of MFN water jet flight length and lifting height from the value of inclination angle of its axis to the horizon: ○ – l, m; ■ – h, m

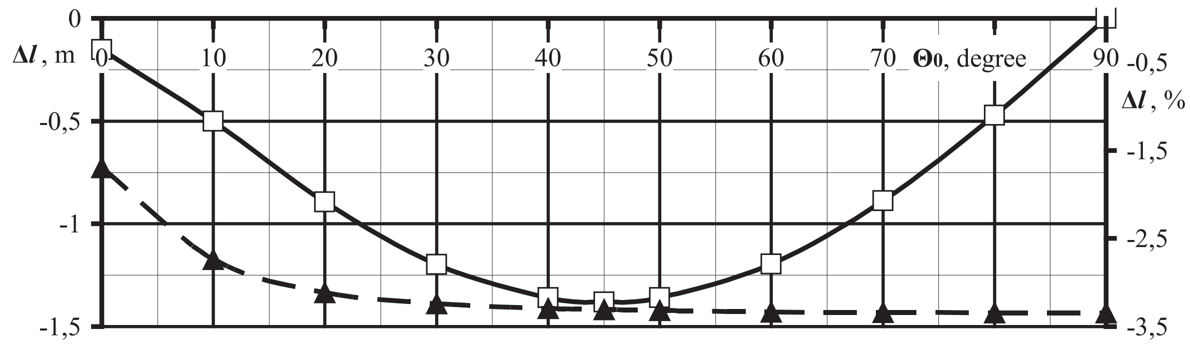

Figure 3 – Dependences of the absolute and relative changes of flight length of water jet from MFN which corresponding to the requirements of GOST from the value of inclination angle of its axis to the horizon: □ – Δl, m; ▲ – Δl_r, %

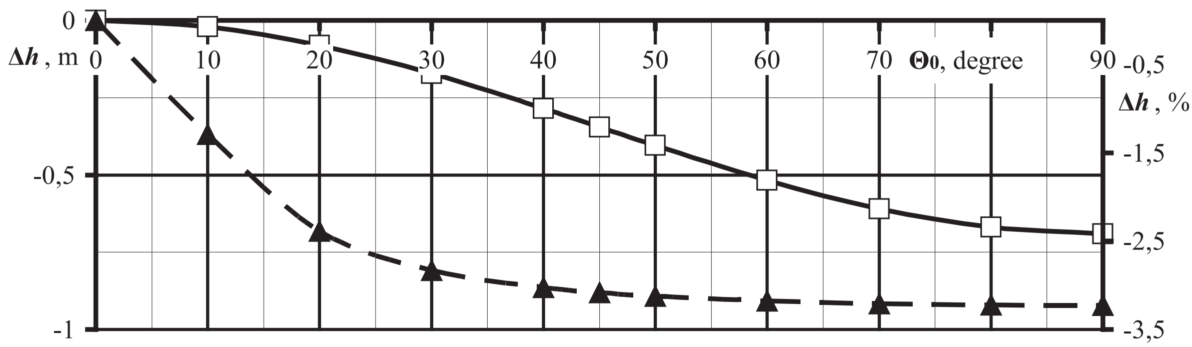

Figure 3 – Dependences of the absolute and relative changes of lifting height of water jet from MFN which corresponding to the requirements of GOST from the value of inclination angle of its axis to the horizon: □ – Δh, m; ▲ – Δh_r, %

The above confirms and illustrates the feasibility of using the mathematical apparatus of the beta distribution to describe distribution law of physical value having a non-linear effect on the other physical values, even if the condition of precise description empirical distribution of such physical value by the normal law [8, 9]. In this case, such an influence quantity is d_0, which is a mathematical expression for: ω_0 at 2nd degree (see formula (4)), V_0 at –2 degree (see formula (3)), l and h at –2 and –4 degrees (see formulas (1) and (2)).

Conclusions. Thus, this study shows the methodology, substantiated, estimated, illustrated and described by analytical formulas the impact of manufacturing precision of manual fire nozzle diameter outlet hole, which corresponds with regulatory established requirements, on the trajectory geometric parameters of water jet from it, in particular its flight length and lifting height, for various values of nozzle axis inclination angle to the of the horizon, in both absolute and relative terms. It found that such an impact is significant.

Also in the study was substantiated the expediency of using the beta distribution for description of these variables taking into account non-linearity of their mutual influence.

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ӨРТ СӨНДІРУ ҚОЛ ОҚПАНЫН ӨНДІРУДІҢ НОРМАТИВТІК ДӘЛДІГІ МЕН ОДАН ШЫҒАТЫН СУ АҒЫСЫНЫҢ ГЕОМЕТРИЯЛЫҚ СИПАТТАМАЛАРЫ АРАСЫНДАҒЫ ӨЗАРА БАЙЛАНЫС

Шығу тесігінің диаметрі нормативті түрде бекітілген талаптарға сәйкес келетін өрт сөндіру қол оқпанын өндірудің нормативтік дәлдігінің одан шығатын су ағысының геометриялық сипаттамаларына әсері аналитикалық формулаларымен бейнеленіп, суреттеліп, баға беріліп, негізделіп, әдістемесі келтірілген. Атап айтар болсақ, оқпан білігінің деңгейжиекке қарасты иілуі бұрышының түрлі көрсеткіштеріндегі су ағысының ұшу қашықтығы, көтерілу биіктігі абсолюттік және салыстырмалы мөлшеррлерде өлшелген. Осы мөлшерлердің бір-біріне әсерінің сызықтық еместігін есепке ала отыра, оларды сипаттау үшін бета-таратқышты қолданудың лайықтығы дәлелденген.

Негізгі түсініктер: өрт қауіпсіздігі, өрт сөндіру қол оқпаны, су ағысы, өндіріс дәлдігі.

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ВЗАИМОСВЯЗЬ НОРМАТИВНОЙ ТОЧНОСТИ ИЗГОТОВЛЕНИЯ РУЧНОГО ПОЖАРНОГО СТВОЛА И ГЕОМЕТРИЧЕСКИХ ХАРАКТЕРИСТИК ВЫХОДЯЩЕЙ ИЗ НЕГО СТРУИ ВОДЫ

Приведена методика, обосновано, оценено, проиллюстрировано и описано аналитически формулами влияние точности изготовления ручного пожарного ствола, диаметр выходного отверстия которого отвечает нормативно установленным требованиям, на геометрические параметры траектории струи воды из него, в частности ее дальность полета и высоту подъема, для различных значений угла наклона оси ствола к горизонту, как в абсолютных, так и в относительных величинах. Обоснована целесообразность использования бета-распределения для описания этих величин с учетом нелинейности их взаимного влияния.

Ключевые слова: пожарная безопасность, ручной пожарный ствол, струя воды, точность изготовления.

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ОБЕСПЕЧЕНИЕ ПОЖАРНОЙ И ПРОМЫШЛЕННОЙ БЕЗОПАСНОСТИ

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