**КОМИТЕТ ПО ЧРЕЗВЫЧАЙНЫМ СИТУАЦИЯМ
МВД РЕСПУБЛИКИ КАЗАХСТАН**

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

In present paper showed the methodology, grounded, evaluated, illustrated and described by formulas influence of manufacturing precision of the fire barrel outlet hole diameter of which do not meets the regulatory and established requirements in varying degrees 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 barrel 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.

Keywords: fire safety, fire barrel, jet, manufacturing precision.

Introduction. Geometric parameters of trajectory of water jet from a manual fire nozzle (MFN) depends on diameter of its outlet hole. In approximate calculations of these parameters are used the nominal value of the diameter [1 – 5], which is conditional and characterized by a certain normative established (GOST 9923-93) value of the precision [6, 7]. However, as practice shows, on combat duty of subdivisions of the State Emergency Service of Ukraine there is some number of MFN that do not meet the standards for manufacturing precision, in particular the outlet hole diameter. Moreover, such deviations have value within ±5 % from both tolerance field limits. Therefore, study of the impact of MFN real manufacturing precision on the geometric parameters of its water jet from 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 real, which differs from normative established, values of MFN output hole size deviation in the calculation of its water jet trajectory geometric characteristics (in particular its flight length and lifting height) 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 real manufacturing precision as a mass-produced product on the object of study.

In study [8] evaluated influence of the of MFN RS-50A outlet hole diameter Δd_0 (in mm), which meets requirements of GOST 9923-93 [6] and GOST 25347-2013 [7] (i.e. for its manufacturing precision), on absolute and relative value determination error of MFN water jet geometric characteristics (its flight length Δl (in m) and lifting height Δh (in m)). In these case using the data of study [9] was choused the basic MFN outlet hole geometric characteristic – its diameter d_0 (in m). In study [8] was used the method of approximate estimation (i.e. excluding air resistance) of

MFN water jet geometric characteristics (its flight length l (in m) and lifting height h (in m)) from [3, 5] in function of influencing factors changes – diameter d_0 and MFN axis to horizon inclination angle Θ_0 (in degrees). Also in that study was used the method for errors determination (manufacturing, measuring, estimation) choused influencing factor (Δd_0) on determination errors water jet geometric characteristics (Δl and Δh) from references [2, 3, 5], where the following partial derivatives are used: $\partial\omega_0/\partial d_0$ (in m), $\partial V_0/\partial\omega_0$ (in $(m\cdot s)^{-1}$), $\partial l/\partial V_0$ (in s), $\partial h/\partial V_0$ (in s), where ω_0 – MFN outlet hole area (in mm^2).

The above described evaluation was performed on the assumption that on the values of Δl and Δh affect only the values Δd_0 (changes discretely from one MFN unit to another) and Θ_0 (changes continuously in the firefighting process). Other influencing factors (average initial velocity of water flow motion through life cross section which coinciding with MFN outlet hole V_0 (in m/s), height of MFN outlet hole center placement relative to an arbitrary horizontal plane h_0 (in m), volumetric water flow rate through any MFN normal cross section Q_0 (in m^3/s)) are not independent (according to continuity of fluid flow low $V_0 \sim \omega_0 \sim d_0^2$ at Q_0 = const) or changes unpredictable (in significant range, for example Q_0 depending on the extinguishing fluid properties, on pump and a hose line parameters), or randomly (in insignificant range, for example h_0 both for manual and lafet fire nozzle) and therefore assumed constant (h_0 = const, Q_0 = const).

In GOST 9923-93 [6] 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 GOST 25347-2013 [7], means that d_0 = [13.00… …13.11] mm, d_{0n} are minimum allowable value of d_0 and the diameter indicated the drawings as Ø13H11 или Ø13$^{+0,11}$. That is, the parameter is changed by the regulatory requirements by the amount Δd_{0r} = +0.84 % relative to value $d_{0n} = d_0$.

Results of the study [8], carried out for nozzle RS-50A with maximum available within GOST 9923-93 requirements limits d_0 value and the typical case 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), shows that partial derivatives have the following values: $\partial\omega_0/\partial d_0$ = const = 0.0204 m, $\partial V_0/\partial\omega_0$ = const = $= -1.507\cdot10^{-5}$ $(m\cdot s)^{-1}$, $\partial l/\partial V_0$ and $\partial h/\partial V_0$ are functions of Θ_0 (see Table 1).

But nozzles RS-50A with which are equipped two research installations of hydraulic laboratory of Applied Mechanics Dept. of Technogenic and Ecologic Safety Faculty of National University of Civil Defense of Ukraine characterized by the d_0 values which differs from normative established. For them the d_0 values were determined by averaging the results of eight times direct measurement using vernier caliper ShTs-I-150-0.02. Thus for the first one d_0 =12.6 mm and for the second d_0 = 13.7 mm that differs from the nominal value of d_0 on Δd_0 = –0.40 mm and +0,70 mm or Δd_{0r} = –3.1 % and +5.4 % respectively. For comparison was chosen the nominal value of d_0 because it is used for MFN water jet trajectory calculation. Thus, from the practice of study it becomes clear that in exploitation are certain number of MFN items which for various reasons do not comply with GOST requirements for d_0

value. Exact number of such MFN items is difficult to evaluate, as noted in introduction.

Results of that study are also summarized in Table 1 and presented on Fig. 1. Dependences of the absolute changes of flight length Δl and lifting height Δh values (both in m) of water jet from nozzle RS-50A with varying degrees of compliance with GOST 9923-93 from the value of inclination angle of its axis to the horizon Θ_0 (in degrees) is shown on Fig. 1, a, b. Same dependences for the relative values (Δl_r and Δh_r, both in %) is shown on Fig. 1, c, d.

As we can see from the data of Table 1 and Fig. 1 (where also presented results of study [8] for comparison) for nozzle RS-50A with outlet hole having a maximum possible value of diameter within the these requirements values of l, $\partial l/\partial V_0$ and Δl reaching maximums (41.751 m, 4.08 s и –1.381 m respectively) at Θ_0 = 45°, than l = [40,370…41,751] m or $l = 41.751_{-1.381}$ m, Δl_r = 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 (13.055 mm). 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 %. The values of h, $\partial h/\partial V_0$, Δh и Δh_r reaching maximums at Θ_0 = 90° (21.387 m, 2.04 s, –0.690 m and –3.23 % accordingly) and therefore $h = 21.387_{-0.69}$ m, or $2.0697 \leq h \leq 21.387$ 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 Θ_0 = 0° the values of $\partial h/\partial V_0$, Δh и Δh_r are equal to zero and $h = h_0$ [8].

Also from the data of Table 1 and Fig. 1 we can see, that the values of l, $\partial l/\partial V_0$, h and $\partial h/\partial V_0$ for all three investigated cases are not different from the case of MFN with nominal value of diameter d_0 from the study [8].

Results of such evaluation for the first one of MFN with Δd_0 = –0.40 mm are following. Absolute values of Δl and Δh reaching maximums (5.021 m and 2.509 m respectively) when Θ_0 = 45° and 90°. Than l = [41.751…46.772] m or $l = 41.751^{+5.021}$ m. Relative values of Δl_r и Δh_r reaching maximums (+12.162 % и +11.732 %) when Θ_0 = 90°. Than $h = 21.387^{+2.509}$ m or h = [21.387…23.896] m. Should be noted that when Θ_0 = 0° Δl = +0.556 m, Δl_r = +6.154 %, Δh = 0 m.

Results of such evaluation for the first one of MFN with Δd_0 = +0,70 мм are following. Absolute values of Δl and Δh reaching maximums (–8.787 m and –4,391 m respectively) when Θ_0 = 45° and 90°. Than l = [32.964…41.751] m or $l = 41.751_{-8.787}$ m. Relative values of Δl_r и Δh_r reaching maximums (–21.284 % and –20.531 %) when Θ_0 = 90°. Than $h = 21.387_{-4.391}$ m or h =[16.996…21.387] m. Should be noted that when Θ_0 = 0° Δl = –0.973 m, Δl_r= –10.769 %, Δh = 0m.

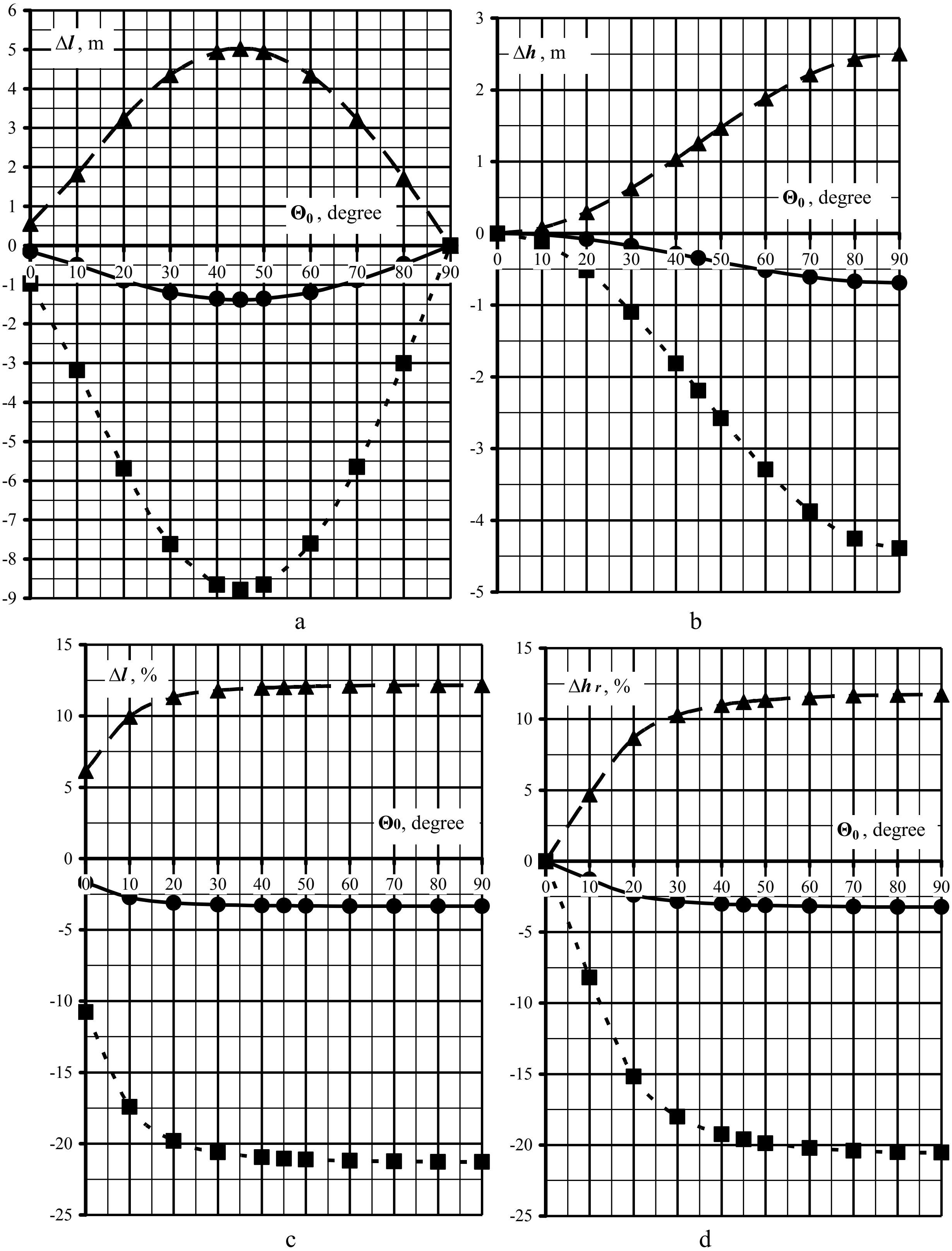

Figure 1 – Dependences of the absolute (a, b) and relative (c, d) changes of flight length (a, c) and lifting height (b, d) of water jet from nozzle RS-50A with different degrees of compliance with GOST 9923-93 from the value of inclination angle of its axis to the horizon:
■ – Δd_0 = +0.70 mm; ▲ – Δd_0 = –0.40 mm; ● – Δd_0 = +0.11 mm

Table 1 – Parameters of the water jet trajectory from fire manual nozzle RS-50A, with different degrees of compliance with GOST 9923-93, 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 = 0.0 mm (nominal value)										
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
$\partial h/\partial V_0$	s	0.000	0.061	0.238	0.510	0.842	1.019	1.196	1.529	1.800	1.977	2.039
		Δd_0 = +0.11 mm (within the requirements of GOST)										
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
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
		Δd_0 = –0.40 mm (deviation from the GOST requirements in the smaller side)										
Δl	m	0.556	1.818	3.251	4.355	4.946	5.021	4.944	4.347	3.226	1.717	0.000
Δl_r	%	6.154	9.951	11.319	11.780	11.972	12.026	12.066	12.116	12.144	12.158	12.162
Δh	m	0.000	0.076	0.294	0.627	1.037	1.255	1.472	1.882	2.216	2.434	2.509
Δh_r	%	0.000	4.686	8.672	10.289	11.002	11.208	11.358	11.552	11.660	11.715	11.732
		Δd_0 = +0.70 mm (deviation from the GOST requirements in the greater side)										
Δl	m	-0.973	-3.182	-5.689	-7.621	-8.656	-8.787	-8.652	-7.608	-5.646	-3.004	0.000
Δl_r	%	-10.769	-17.414	-19.809	-20.616	-20.951	-21.046	-21.115	-21.203	-21.251	-21.276	-21.284
Δh	m	0.000	-0.132	-0.514	-1.098	-1.814	-2.196	-2.577	-3.293	-3.877	-4.259	-4.391
Δh_r	%	0.000	-8.200	-15.175	-18.006	-19.253	-19.614	-19.877	-20.216	-20.405	-20.502	-20.531

Thus, from the data of Table 1 and Fig. 1 are follows that the values of Δl_r and Δh_r significantly changing when the value of Θ_0 vary in limits 0…45°. After Θ_0 reaching values of 45° and down to the 90° they "go on the shelf", asymptotically approaching the value of +12.5 % for the first one manual fire nozzle with Δd_0 = –0.40 mm and –22.0 % for the second MFN with Δd_0 = +0.70 mm. At the same time influence factor (d_0) changed at a much lower value Δd_{0r} (–3.1 % and +5.4 % respectively) being in inverse correlation with the desired values. The above described is presented in Fig. 2.

On Fig. 2 are showed influence of absolute (Δd_0 in mm) and relative (Δd_{0r} in %) values of nozzle RS-50A outlet hole diameter (d_0) changing on absolute (Δl and Δh in m) and relative (Δl_r and Δh_r in %) values of flight length (l) and lifting height (h) of its water jet in all possible combinations.

As follows from the analysis of data contained in Fig. 2, these dependencies are linear, influencing factor and the desired effect are inversely correlated for the absolute values of Δl and Δh and also these dependencies on Δd_0 and Δd_{0r} are different (see Fig. 3, a, b), and for the relative values Δl_r и Δh_r they are identical (see Fig. 3, b, c). Linearity of these relationships follows from the analysis of the formulas (13) – (19) in study [8] with constant values of Θ_0. They described by the method of least squares (for all dependencies R^2 = 1,0) and can be represented by the formulas (1) – (6).

$$\Delta l = -12{,}553 \cdot \Delta d_0 \text{, m;} \tag{1}$$

$$\Delta h = -6{,}273 \cdot \Delta d_0 \text{, m;} \tag{2}$$

$$\Delta l_r = \Delta h_r = -3{,}953 \cdot \Delta d_{0r} \text{, \%;} \tag{3}$$

$$\Delta l = -1{,}6319 \cdot \Delta d_{0r} \text{, m;} \tag{4}$$

$$\Delta h = -0{,}8155 \cdot \Delta d_0 \text{, m;} \tag{5}$$

$$\Delta l_r = \Delta h_r = -30{,}4063 \cdot \Delta d_{0r} \text{, \%.} \tag{6}$$

So, from the above evaluation results analysis it follows that the nozzle RS-50A outlet hole diameter value deviation, going beyond the tolerance field according to GOST 9923-93 in both directions, has a significant impact on its water jets motion trajectory geometric parameters under otherwise equal conditions. In practice, the magnitude of such influence would not be as significant due to the influence of unaccounted factors. This is the following factors: water jet motion air resistance, deviation from roundness (deviation of the surface shape) of the MFN outlet hole and distribution of this deviation on hole perimeter (beating of the radius), changes of parameters of the pump and hose lines, presence of lateral wind and (or) headwind, varying the type and composition of the fire-extinguishing liquid, changes of resistance, velocity and flow rate coefficients of MFN as a conical converging nozzle, environmental parameters (temperature, pressure, humidity) etc.

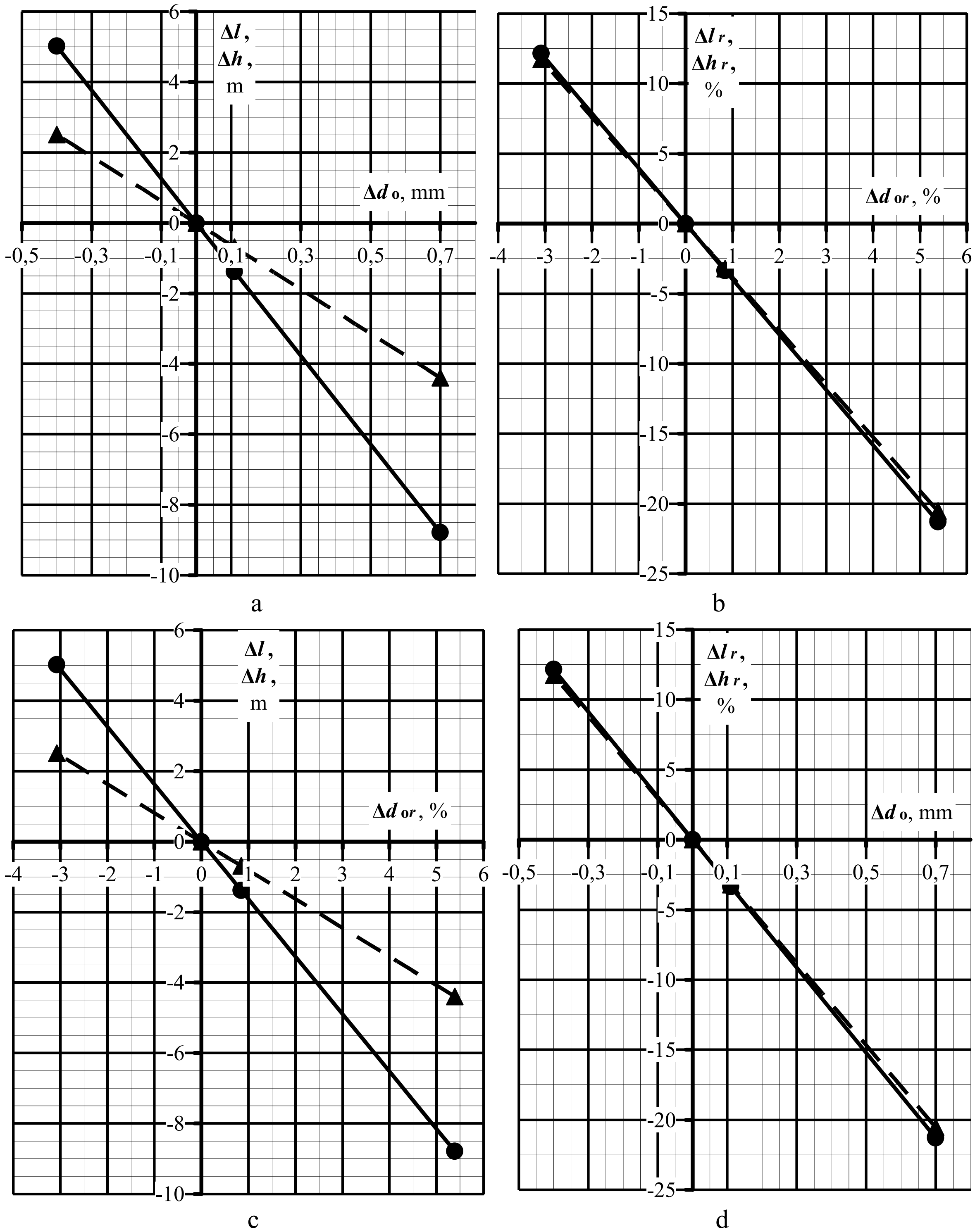

Figure 2 – Dependences of the maximum values of absolute (a, b) and relative (c, d) changes of flight length (a, c) and lifting height (b, d) of water jet from nozzle RS-50A with different degrees of compliance with GOST 9923-93 from the absolute (a, d) and relative (b, d) value of change of its outlet hole diameter:

● – Δl (при $\Theta_0 = 45°$) и Δl_r (при $\Theta_0 = 90°$); ▲ – Δh и Δh_r (при $\Theta_0 = 90°$)

The above as well as the results of studies [8 – 11], 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 in case when condition of precise description empirical distribution of such physical value by the normal law [10].

Conclusions. Thus, this study includes the methodology, substantiated, estimated, described by formulas and illustrated by graphs the impact of manufacturing precision of manual fire nozzle diameter outlet hole, which does not meet the regulatory established requirements of GOST 9923-93 in varying degrees, 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 under certain assumptions, and other conditions being equal 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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ҚОЛ ӨРТ ОҚПАНЫНЫҢ НАҚТЫ ӘЗІРЛЕУ ДӘЛДІГІНІҢ ЖӘНЕ ОДАН ШЫҒАТЫН СУ АҒЫНЫНЫҢ ГЕОМЕТРИЯЛЫҚ СИПАТТАМАСЫНЫҢ ӨЗАРА БАЙЛАНЫСЫ

Өзара әсер етудің бейсызықты екенін ескере осы көлемдерді сипаттау үшін бета-үлестіруді қолдану орынды екендігі негізделді. Әртүрлі деңгейдегі бекітілген нормативті талаптарға жауап бермейтін шығыс диаметрі саңылауының, олардан шығатын су ағыны траекториясының геометриялық параметрлеріне, атап йатқанда оның жету ұзындығы мен көтерілу биіктігіне, абсолютті және қатысты өлшемдердегі оқпан өсінің горизонтқа иілу бұрышының әртүрлі мәндеріне қол өрт оқпанының әзірлеу дәлдігінің әсер етуі әртүрлі формулалармен көрсетілді, суреттелді, бағаланды, негізделді және әдістемесі жүргізілді.

Негізгі түсініктер: өрт қауіпсіздігі, қол өрт саңылаулары, струя, дәлдігі өндірістік.

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

Приведена методика, обосновано, оценено, проиллюстрировано и описано формулами влияние точности изготовления ручных пожарных стволов, диаметр выходного отверстия которых не отвечает нормативно установленным требованиям в разной степени, на геометрические параметры траектории струи воды из них, 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, точность изготовления.

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