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СИНТЕЗ СИСТЕМЫ УПРАВЛЕНИЯ ПРОЦЕССОМ ФОРМИРОВАНИЯ УГЛЕРОДНЫХ ИЗДЕЛИЙ

Предложена новая система управления, которая предусматривает управление с итеративным обучением (УИО) процессом формирования продавливанием электродной массы через мундштук соответствующей формы в гидравлическом прессе. Предложен соответствующий УИО-алгоритм. Данное исследование подтвердило, что УИО-алгоритм обеспечивает высокое качество управления в условиях отсутствия начальных неопределенностей и внешних возмущений.

Ключевые слова: углеродные изделия, управления с итеративным обучением (УИО), система управления, УИО-алгоритм.

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EXPERIMENTAL RESEARCH OF WEAR INTENSITIVITY OF 9 mm PISTOL BARREL WITH THE USE OF LONG-TERM STORAGE AMMUNITION

Спрогнозовано вплив використання боєприпасів тривалих термінів зберігання на інтенсивність зносу ствола 9 мм пістолета. Дана оцінка інтенсивності вичерпання ресурсу ствола пістолета при використанні таких боєприпасів. Отримано залежності зміни початкової швидкості кулі і зносу каналу ствола від кількості пострілів. Встановлено термін зберігання боєприпасів, при стрільбі якими знос ствола пістолета не дозволяє повністю використати закладений в нього ресурс.

Ключові слова: *9 мм пістолети, знос каналу ствола, боєприпаси довгострокового терміну зберігання.*

1. Introduction

The task of providing reliable and safe operation of weapons and ammunition at any time was and is one of the priority tasks. Today, in conditions of anti-terrorist operation that continues for more than one year in the eastern regions of Ukraine, the tasks of guaranteeing effective, trouble-free and safe combat use of weapons are more urgent than ever [1, 2].

In this situation, used weapons in themselves meet the requirements of the relevant operational documentation. It was either not used before (it was stored in warehouses, bases and arsenals), or major repairs or upgrades, or a new (Ukrainian or foreign manufacturer). This ratio can be represented as a percentage, as 50 % by 25 % and by 25 %, respectively. That is, 75 % of weapons mainly use ammunition for long or post-warranty periods of storage and only 25 % goes to the armament of the Ukrainian armed forces, complete with new ammunition.

At the same time, scientific, theoretical and experimental studies of the impact of the use of such ammunition were carried out separately and only on individual samples of weapons.

Based on this, it can be argued that scientific research, experiments and forecasts in this direction continue to be important and extremely necessary.

2. The object of research and its technological audit

The object of research is the process of changing the condition of the pistol barrel bore due to its wear when using long-term storage ammunition.

The subject of research is the ballistic characteristics of the pistol when using long-term storage ammunition.

The process of deteriorating the ballistic characteristics of any barrel weapons in general and pistols in particular is directly proportional to barrel bore wear process. Let's consider the operation of the weapon sample with the exception of violations of the frequency and the procedure for its maintenance, and its storage and use – in strict accordance with the requirements of technical documentation. In this case, the main factor that affects the barrel bore wear is the shooting process. Namely, such basic parameters of internal ballistics as the maximum pressure of powder gases (P_{max}), temperature (T), burning rate (u), etc. Neglect of an increase in the intensity of such wear is unacceptable both in performing training firing and in performing a service- combat and combat missions, especially in the territory of the anti-terrorist operation in the conditions of direct and constant fire contact with the enemy.

The study used:

– 9 mm Makarov pistols (PM) – 6 pcs. (3 of 1988 and 1990 year of issue, respectively);
– 9 mm pistol cartridges with a steel core bullet (57-H-181C), 1969, 1986 and 2002 year of issue;
– digital chronometer ProChrono Digital CEI-3800 (USA);
– borescope Hawkeye® Pro Slim (USA);
– calipers;
– level;
– go gage and no-go gage caliber of 9 mm pistol PM (Fig. 1).

a

b

Fig. 1. Caliber for 9 mm pistol PM: *a* – go gage; *b* – no-go gage

When selecting weapons and ammunition samples, the recommendations of previous works were taken into account [3, 4].

The experiment was conducted during 2016 in open and closed shooting galleries on the territory and using the material and technical base of the military units of the National Guard of Ukraine.

3. The aim and objectives of research

The aim of research is experimentally determination of the influence of ballistic characteristics on the use of long-term storage ammunition for increasing the wear intensity of the 9 mm pistol barrel.

To achieve this aim, it is necessary to solve the following tasks:

1. To carry out an experimental study of the effect of the use of long-term storage ammunition on the wear rate of the 9 mm pistol barrel.
2. To estimate the intensity of the change in the resource of the pistol barrel when using of long-term storage ammunition on the basis of a comparative analysis of the theoretical and experimental obtained data.
3. To predict the impact of the use of long-term storage ammunition on the wear rate of the 9 mm pistol barrel.
4. To obtain the dependence of the change in the initial bullet velocity and PM barrel bore wear when firing using long-term storage ammunition from the value of these terms.
5. To identify the patterns between the initial bullet velocity and the barrel bore wear channel when using long-term storage ammunition

4. Research of existing solution of the problem

To date, there are a large number of scientific papers on this subject on small arms and artillery armament. It can be singled out the works in which the effect of the use of long-term storage ammunition on the ballistic characteristics of weapons [5–7] and the wear rate of the barrel bore [3, 8–10] is investigated. There are also a number of works in which the effect of the use of long-term storage ammunition on the obtained results is not taken into account at all [11–13].

Separately it is worth noting a series of scientific papers [4, 14–16], in which these studies are concretized on different 9 mm pistols. They describe the theoretical and experimental scientific research associated with changing the ballistic characteristics when firing long-term storage cartridges.

The effect of the use of such ammunition on the barrel bore wear of the 9 mm pistol in the above and other similar works is not disclosed. At the same time, it is impossible to apply appropriate techniques and models to pistols developed for other types of rifle (automatic, machine gun, sniper rifle) and even more artillery weapons. The main reason for this is the serious constructive differences between them.

Consequently, an experimental study of the wear intensity of 9 mm pistol barrel with the use of long-term storage ammunition appears to be a logical extension of a whole series of scientific works. It can also become a «reliable bridgehead» for further research activities.

5. Methods of research

Taking into account the technique of the previous work [4], the selected pistols are divided into 3 groups of 2 pistols each for experimental shooting with 9 mm pistol cartridges with a steel core bullet (57-H-181C) for only one particular year of production [15]:

I experimental group – cartridges of the batch 38-69, 1969 year of issue, 47-year storage period (T_1).

II experimental group – cartridges of the batch 38-86, 1986 year of issue, 30-year storage period (T_2).

III control group – cartridges of the batch 270-02, 2002 year of issue, 14-year storage period (T_3).

At the beginning of the experiment, the control of the barrel bore wear (L_{e0}) of each pistol was carried out by no-go gage caliber [17]. To do this, the pistol is fixed with the muzzle of the trunk vertically upwards. The no-gage caliber is lowered into the barrel (without effort, under the influence of its weight). The depth at which the caliber falls into the pistol barrel is measured by a caliper (Fig. 2). The measurements are repeated 10 times

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in a row, after which, according to the obtained results, the average value of wear is determined, which is recorded in Table 1. Subsequent wear values (L_{e1}, L_{e2}, L_{e3} and L_{e4}) are determined and recorded in Table 1 after every subsequent thousand shots respectively and similarly. In parallel with this, a visual inspection of the condition of the pistol barrels is carried out with the help of a borescope.

At similar stages of the experiment (0, 1, 2, 3, and 4 thousand shots), control shooting is conducted by cartridges of the control group to determine the initial velocity of the bullet flight (V_{e0}, V_{e1}, V_{e2}, V_{e3} and V_{e4}) using the procedure [4]. The results are listed in Table 2. Based on the obtained results (V_{e0}), the initial bullet velocity of these cartridges (V_{pr4}) is predicted at the end of the experiment (at the end of 4000 shots), as decreased by 5 % (V_{e0}) [4].

a *b* *c*

Fig. 2. Measurement of the barrel bore wear:
a – installing and fixing the pistol on the platform using a level;
b – checking the barrel wear using no-go gage caliber; *c* – measurement of wear using a caliper

Table 1

Experimental results of measurement of the barrel bore wear of 9 mm pistols

Groups	Pistols	Barrel bore wear, m								
		0	1000		2000		3000		4000	
		L_{e0}	L_{e1}–L_{e0}	L_{e1}	L_{e2}–L_{e1}	L_{e2}	L_{e3}–L_{e2}	L_{e3}	L_{e4}–L_{e3}	L_{e4}
I group 47 years	PM № 1 88	0.0001	0.0007	0.0008	0.002	0.0028	0.0039	0.007	0.0054	0.0121
	PM № 2 90	0.0001	0.0011	0.0012	0.0019	0.0031	0.0044	0.008	0.0057	0.0132
	Average	0.0001	0.0009	0.001	0.002	0.003	0.0042	0.007	0.0056	0.0127
II group 30 years	PM № 3 88	0.0001	0.0005	0.0006	0.0012	0.0018	0.0014	0.003	0.0046	0.0078
	PM № 4 90	0.0001	0.0007	0.0008	0.0006	0.0014	0.0012	0.003	0.0041	0.0067
	Average	0.0001	0.0006	0.0007	0.0009	0.0016	0.0013	0.003	0.0044	0.0073
III group 14 years	PM № 5 88	0.0001	0	0.0001	0.0005	0.0006	0.0005	0.001	0.0012	0.0023
	PM № 6 90	0.0001	0.0004	0.0005	0.0003	0.0008	0.0007	0.002	0.001	0.0025
	Average	0.0001	0.0002	0.0003	0.0004	0.0007	0.0006	0.001	0.0011	0.0024

Table 2

Experimental results of measurement of initial bullet velocity of 9 mm pistols

Groups	Pistols	Initial bullet velocity, m/s									
		0	1000		2000		3000		4000		
		V_{e0}	V_{e0}–V_{e1}	V_{e1}	V_{e1}–V_{e2}	V_{e2}	V_{e2}–V_{e3}	V_{e3}	V_{e3}–V_{e4}	V_{e4}	V_{pr4}
I group 47 years	PM № 1 88	318.30	1.10	317.20	3.14	314.06	7.90	306.16	23.28	282.88	302.39
	PM № 2 90	317.50	1.40	316.10	2.96	313.14	9.55	303.59	25.60	277.99	301.63
	Average	317.90	1.25	316.65	3.05	313.60	8.73	304.88	24.44	280.44	302.01
II group 30 years	PM № 3 88	316.90	0.90	316.00	1.70	314.30	4.25	310.05	12.41	297.64	301.06
	PM № 4 90	318.70	0.65	318.05	1.20	316.85	3.32	313.53	13.24	300.29	302.77
	Average	317.80	0.77	317.03	1.45	315.58	3.79	311.79	12.83	298.97	301.91
III group 14 years	PM № 5 88	318.60	0.72	317.88	1.10	316.78	1.19	315.59	3.61	311.98	302.67
	PM № 6 90	317.10	0.54	316.56	0.55	316.01	1.53	314.48	3.26	311.22	301.25
	Average	317.85	0.63	317.22	0.83	316.40	1.36	315.04	3.44	311.60	301.96

On the basis of the experimental data of the corresponding values of each of the pistols of one group, let's find the average value of this quantity and record it in Tables 1, 2.

In the intervals between the control firing using the selected pistols, scheduled firing is carried out in the same time and weather conditions, with identical volume and periodicity of maintenance. After that, a visual inspection of the barrel bore condition is carried out with the help of a borescope for its erosion [18] and other defects.

6. Research results

Based on the results of experimental studies, the corresponding graphs are constructed and two groups of regularities are established:

The first is an increase in barrel bore wear on the number of shots (Fig. 3). These patterns describe the functions $L(N)$, which are calculated in the Excel 2016 program as polynomial trend lines of the third degree [19] and are represented in the form (1).

$$L(N)_{Igr} = 0.3\cdot10^{-13}\cdot N^3+0.6\cdot10^{-9}\cdot N^2+0.9\cdot10^{-7}\cdot N+0.1\cdot10^{-3},$$
$$L(N)_{IIgr} = 0.2\cdot10^{-12}\cdot N^3-0.8\cdot10^{-9}\cdot N^2+0.1\cdot10^{-5}\cdot N+0.6\cdot10^{-4}, \quad (1)$$
$$L(N)_{IIIgr} = 0.2\cdot10^{-13}\cdot N^3-0.7\cdot10^{-11}\cdot N^2+0.2\cdot10^{-6}\cdot N+0.1\cdot10^{-3}.$$

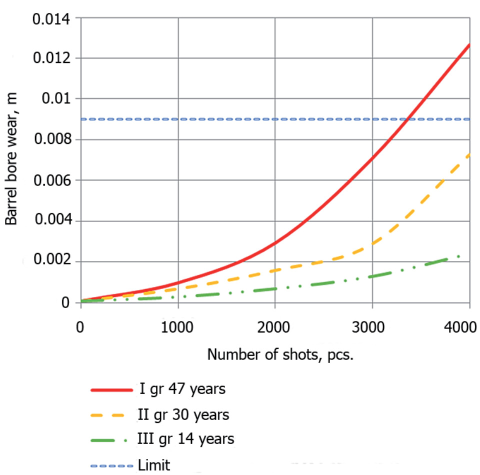

Fig. 3. Dependence of the change in the barrel bore wear on the number of shots

The second is decrease in the initial bullet velocity on the number of shots (Fig. 4). These patterns describe functions $V(N)$, which are similarly calculated in the Excel 2016 program as polynomial trend lines of the third degree [19] and are represented in the form (2).

$$V(N)_{Igr} = -0.2\cdot10^{-9}\cdot N^3+0.5\cdot10^{-6}\cdot N^2-0.0011\cdot N+317.87,$$
$$V(N)_{IIgr} = -0.7\cdot10^{-9}\cdot N^3+0.2\cdot10^{-5}\cdot N^2-0.0027\cdot N+317.87, \quad (2)$$
$$V(N)_{IIIgr} = -0.1\cdot10^{-8}\cdot N^3+0.3\cdot10^{-5}\cdot N^2-0.0038\cdot N+317.99.$$

Comparative analysis of the corresponding predicted (V_{pr4}) and experimental (V_{e4}) values of the initial bullet velocities (Table 2) shows that for the I and II experimental groups the inequality $V_{e4}<V_{pr4}$ is fulfilled, and for the II experimental group it is vice versa: $V_{e4}>V_{pr4}$. Consequently, the method used for this forecast does not justify its effectiveness.

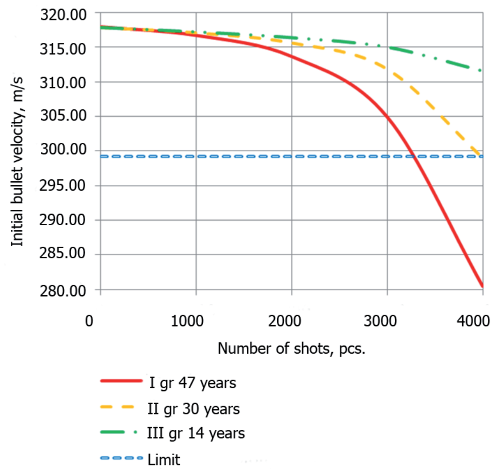

Fig. 4. Dependence of the change in initial bullet velocity on the number of shots

Based on the average values of the barrel bore wear (L_{e4}) for the cartridges of the respective storage period (T_1, T_2 and T_3), a graph is constructed (Fig. 5). Dependence (3) of the increase of this wear on the ammunition storage period used for firing is established. This dependence is described by the function $L(T)$, which is calculated by the above method and is represented as:

$$L(T) = -0.9\cdot10^{-7}\cdot T^3+0.9\cdot10^{-5}\cdot T^2+ \\ +0.6\cdot10^{-4}\cdot T+0.1\cdot10^{-3}. \quad (3)$$

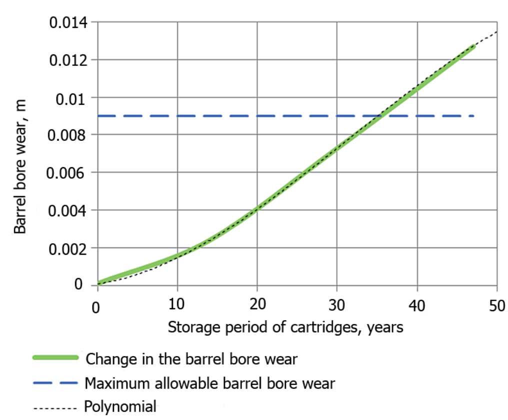

Fig. 5. Dependence of the change in the barrel bore wear on the ammunition storage period

Based on the obtained average values of the initial bullet velocity (V_{e4}) for the cartridges with the storage period (T_1, T_2 and T_3), a graph is constructed and the dependence (4) of decrease in bullet velocity on the ammunition storage period is established (Fig. 6). This function is described by the function $V(T)$. It is calculated similarly to the above, with the only addition that the value of the total average initial bullet velocity (V_0) is taken as the average value

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of the average initial velocities of all three groups of pistols ($V_{e0\mathrm{Igr}}$, $V_{e0\mathrm{IIgr}}$, and $V_{e0\mathrm{IIIgr}}$). The dependence is presented as:

$$V(T)=0.5\cdot 10^{-4}\cdot T^{3}-0.0136\cdot T^{2}-0.2656\cdot T+317.85. \quad (4)$$

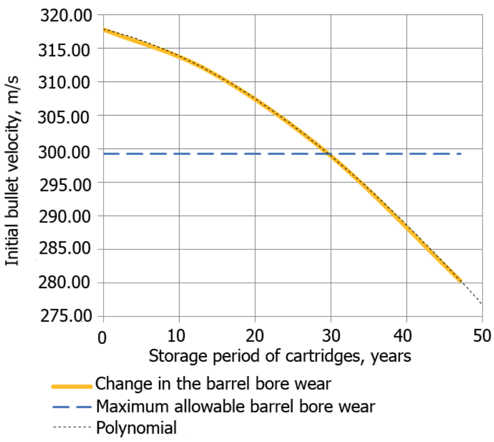

Fig. 6. Dependence of the change in the initial bullet velocity on the ammunition storage period

Based on the above graphs (Fig. 3, 5), the maximum ammunition storage period is predicted. It is 33.97 years. When using such ammunition, the maximum allowable barrel bore wear (0.009 m) will not be exceeded within the limits of the resource in it (4000 shots).

Similarly, Fig. 4, 6 predicted a maximum ammunition storage period. It is 28.92 years. The use of this ammunition does not lead to decrease in the minimum allowable initial bullet velocity (299.25 m/s) within the above resource.

In the obtained dependencies (3), (4) of the ammunition storage period has already been laid as a parameter. From the graphs (Fig. 3, 4), it is evident that the decrease in the initial bullet velocity comes faster than the corresponding barrel wear. Therefore, as a determining factor, one should take not the barrel wear (Fig. 3), namely, decrease in the initial velocity. This is confirmed by the fact that it is the decrease in velocity determines the achievement of the boundary-permissible value by the number of shots (Fig. 4) for ammunition with a storage period of 30 years.

As for the error, during the experiment intensive (high-speed) shooting and, accordingly, overheating of the barrel are not allowed, although it is impossible to completely exclude such impact. So for the units of the National Guard of Ukraine, the majority of training exercises in small arms in general and 50 % of pistol exercises in particular include shooting in a limited time [20]. This in turn leads to overheating of the barrel and its additional wear. The scientific task to study the effect of shooting intensity with long-term storage ammunition is not set in this work, and therefore its solution can become the basis for additional scientific research.

In the same work, the overheating of pistols, both during shooting and under the action of direct sunlight, can be taken into account as a 5 % error in the obtained results.

In addition, it is necessary to take into account the error associated, both with accuracy of the powder charge, and its initial qualitative state. And adding the inaccurate production of the bullets themselves, which leads primarily to the unequal action of the frictional force during the firing, we obtain another error in the experimental results of about 5 %.

If take into account changes in the intensity of depletion of powder charges under the influence of changes in ambient temperature, daily, monthly and seasonal temperature fluctuations [16], then the total error can grow by another 15.2 %. As a result, the total error of this and similar studies can be up to 25.2 %.

Taking into account such errors, the maximum storage period for ammunition can be reduced from 28.92 to 21.63 and from 33.97 to 25.41 years, respectively. And then: under condition of neglect of the others conditionally not taken into account, but possibly admitted, errors. Consequently, for ammunition with a storage period of more than 21.63 years, the barrel wear may not allow the full use of the resource in it for 4000 shots.

Control measurements of the initial bullet velocity when firing directly with experimental ammunition after every thousand shots are carried out, but they are not given or taken into account in this article. This is done to exclude the influence of the physicochemical processes that occur in powders during their aging, and, consequently, the factor of the influence of internal ballistics of long-term storage ammunition on the obtained results. At the same time, these data can be used for further research on similar topics.

Also during the experiment there is a tendency to increase the number of both delays (chucking of the cartridge into the chamber, not throwing the cartridge case out of the shutter, etc.), as well as breakages (breakage of the fighting and return springs, wear of the sear, etc.). The trend is intensified not only with the increase in the shooting from these pistols, but also with the firing of older ammunition in relation to shooting newer ones. The study of the impact of the use of long-term storage ammunition on the technical condition and the trouble-free operation of 9 mm pistols is not included in the objectives and tasks of this scientific work. Therefore, generalization of such information isn't carried out during the experiment. Nevertheless, such processes can become the object of subsequent experimental studies and other scientific papers.

7. SWOT analysis of research results

Strengths. Strengths of research:

– dependences of the decrease in the initial bullet velocity and increase in the PM barrel wear during the shooting of long-term storage ammunitions from the values of these terms are established;

– PM barrel bore wear is predicted when firing ammunition with storage time up to 50 years;

– the maximum ammunition storage period is predicted, the excess of which can lead to a decrease in the minimum allowable initial bullet velocity within the resource of PM barrel;

– it is proved that the decrease in the initial bullet velocity is the determining factor in the effect of the use of long-term storage ammunition on the wear rate of the barrel bore;

– a number of dependencies are obtained that can be applied in similar studies not only of other pistols, but also of other types of small arms.

Weaknesses. Weaknesses of this research:

– an increase in the error by 15.2 %, which is due to the lack of information on the method of ammunition storage;

– an estimated 5 % error, which is due to the lack of scientific work with studies of the effect of overheating of the pistol during shooting, on its ballistic characteristics.

Opportunities. Opportunities of research:

– application of the obtained patterns for other short-barreled systems;

– revision of both the terms of guarantee storage of ammunition and the resources of weapons in general, and their parts and mechanisms – in particular;

– conducting studies on the impact of the use of long-term storage ammunition on the technical state of weapons;

– conducting a study of the effect of shooting intensity on wear and armament life;

– study of the expediency of using long-term storage ammunition from the economic point of view, which leads to a premature exhaustion of the resource of PM barrel and, consequently, to its repair or disposition;

– continuation of a number of studies related to the use of long-term storage ammunition in general and 9 mm pistol cartridges in particular.

Threats. Threats of research:

– complete or partial exhaustion of the barrel resource in particular and weapons in general when carrying out similar experimental work with the use of long-term storage ammunition;

– because of possible delays and breakdowns during firing with such ammunition, the probability of disruption, delay or failure to perform not only training firing, but also service and combat missions, increases.

8. Conclusions

1. The functions obtained in the course of the experimental investigation can serve to predict the barrel bore wear of 9 mm PM pistol barrel when using ammunition with a storage period of up to 50 years.

2. The dependence of the wear rate of the barrel bore and the initial bullet velocity on the number of shots with long-term storage ammunitions for various such terms is experimentally obtained.

3. The maximum ammunition storage period in 28.92 (taking into account possible errors – 21.63) years is predicted, the excess of which can lead to a decrease in the minimum allowable initial bullet velocity within the above-mentioned resource.

4. Dependences of the change in the initial bullet velocity and PM barrel bore wear from the ammunition storage period are obtained.

5. In the course of the experimental study the following regularities are revealed:

– decrease in the initial bullet velocity on the number of shots is faster than the increase in barrel bore wear for the same number of shots;

– intensity of decrease in the initial bullet velocity is inversely proportional to the increase in the ammunition storage period;

– intensity of the increase in the barrel bore wear is directly proportional to the increase in the ammunition storage period.

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ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ИНТЕНСИВНОСТИ ИЗНОСА СТВОЛА 9 ММ ПИСТОЛЕТА ПРИ ИСПОЛЬЗОВАНИИ БОЕПРИПАСОВ ДЛИТЕЛЬНЫХ СРОКОВ ХРАНЕНИЯ

Спрогнозировано влияние использования боеприпасов длительных сроков хранения на интенсивность износа ствола 9 мм пистолета. Дана оценка интенсивности исчерпания ресурса ствола пистолета при использовании таких боеприпасов. Получены зависимости изменения начальной скорости пули и износа канала ствола от количества выстрелов. Установлен срок хранения боеприпасов, при стрельбе которыми износ ствола пистолета не позволяет полностью использовать заложенный в него ресурс.

Ключевые слова: 9 мм пистолеты, износ канала ствола, боеприпасы длительного срока хранения.

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