

DEVELOPMENT OF A METHOD FOR PREDICTING BARREL WEAR RESISTANCE WHEN USING AMMUNITION WITH A LONG STORAGE LIFE

Oleg Anipko

Department of Aviation Engineering¹

Dmitro Baulin

*Scientific and Research Center of Service and Military Activities
National Guard of Ukraine²*

Stanislav Horielyshev

*Scientific and Research Center of Service and Military Activities
National Guard of Ukraine²*

Igor Boikov✉

*Department of Armoured Vehicles²
biv543@ukr.net*

Mykhailo Medvid

*Deputy Head of the Kyiv Institute
of the National Guard of Ukraine for Educational and Methodological Work
Kyiv Institute of the National Guard of Ukraine
9 Zakhysnykiv of Kyiv str., Kyiv, Ukraine, 03179*

Yurii Babkov

Department of Operational Art²

Aleksandr Nakonechnyi

Department of Armament of Air Defense of Ground Forces¹

Oleksandr Kolomiitsev

*Forensic Research Laboratory
National Scientific Center Bokarius Forensic Science Institute
8a Zolochivska str., Kharkiv, Ukraine, 61177*

Natalia Gleizer

*Department of Physics
H. S. Skovoroda Kharkiv National Pedagogical University
2 Valentynivska str., Kharkiv, Ukraine, 61168*

*¹Ivan Kozhedub Kharkiv National Air Force University
77/79 Symska str., Kharkiv, Ukraine, 61023*

*²National Academy of the National Guard of Ukraine
3 Zakhysnykiv Ukrainy sq., Kharkiv, Ukraine, 61001*

✉ Corresponding author

Abstract

Despite the fact that a large amount of small arms ammunition has been used up over the past two years, their stocks in warehouses and arsenals in various countries are quite large. And their shelf life is 20 years or more. In addition, over time, the number of such ammunition will increase.

Among the large number of requirements for modern small arms, one can highlight the provision of the necessary survivability of its parts and mechanisms. The problem of barrel survivability is especially important.

One of the factors affecting barrel survivability is changes in internal ballistics parameters. In turn, these parameters change when using ammunition whose service life exceeds the warranty.

In this regard, the task of studying the survivability indicators of small arms barrels when using post-warranty ammunition seems relevant.

The requirements for barrel systems and factors affecting the wear of the barrel bore of powder charges during long-term storage have been determined.

An analysis of changes in the ballistic characteristics of powder charges was carried out, which allows to state increased wear of barrels when using ammunition with long storage periods.

The dependencies for determining the limit number of shots from a weapon sample are analyzed.

A method for predicting barrel survivability when using long-term storage ammunition is proposed.

Data are presented on an experimental study to determine changes in barrel survivability as a result of the use of long-term storage ammunition by estimating changes in the initial velocity of the projectile.

Based on the results obtained, ways for further research are proposed in the direction of expanding the range of ammunition and weapons.

Keywords: barrel survivability, long-term storage ammunition, forecasting, limit number of shots.

DOI: 10.21303/2461-4262.2024.003298

1. Introduction

The effectiveness and safety of combat use of weapons significantly depend on the degree of wear of the barrels and the quality of the ammunition used. Therefore, for the armed forces of any state, the problem of establishing patterns of influence of the state of the ammunition used on the survivability of the barrels of the barrel systems is of an interspecific nature in its scale.

Despite the fact that over the past two years a large amount of ammunition for small arms has been transferred to Ukraine by NATO countries (USA, Germany, France, etc.), their existing stocks are quite large. However, their shelf life is close to 20 years or more [1–7]. In addition, over time, the number of such ammunition will increase. The negative aspects of storing ammunition with post-warranty service life are known [3–9]. The main ones are their inconsistency with the ballistic characteristics of the weapon, the danger of unauthorized fire and explosion, the likelihood of causing damage to personnel, weapons and equipment during their further use.

During long-term storage, powder charges used in small arms ammunition undergo various physical and chemical changes. These changes negatively affect the ballistic properties of gunpowder, which can change so much that the use of ammunition for its intended purpose becomes dangerous and impractical.

Analysis of studies [10–12] allows to predict the deterioration in the survivability of small arms barrels when using ammunition with long storage periods. Studies of the main dependencies of the internal ballistics of small arms show that the values of the powder burning rate and the maximum pressure of the powder gases are most sensitive to physico-chemical changes in the powder charge. The results of independent studies in different countries [1, 11, 13–15] indicate that the intra-ballistic characteristics accompanying the shot of ammunition with a calendar shelf life of more than 15 years differ significantly from the tabulated ones.

Due to long-term storage of ammunition, gunpowder loses some of its energetic properties as fuel. This manifests itself in the form of an increase in the maximum pressure of the powder gases and the burning rate of the powder in the barrel, which leads to a decrease in the initial velocity of the projectile. In addition, an increase in maximum pressure affects the temperature increase, and this, in turn, affects the thermal state of the barrel bore. Erosion processes occur, and the thermophysical properties of the barrel material change [16–18]. There is also a shift in the coordinates of the point of maximum pressure towards the breech end of the barrel. Analysis of these changes allows to state increased wear of barrels when using ammunition with long storage periods.

In works [9, 13, 19, 20], researchers provide various formulas for calculating the limit number of shots from a weapon. However, each of these formulas is focused on taking into account the influence of individual parameters.

Thus, Orlov's formula [9, 13, 19] considers only high-power barrel systems and is not applicable to small arms:

$$N = \frac{K_T}{C_q^x \cdot V_0^y \cdot d^z}, \quad (1)$$

where N – the number of shots; K_T – thermomechanical coefficient, determined depending on the calorie content of the gunpowder and the mechanical characteristics of the barrel steel; C_q – relative weight of an artillery shell; V_0 – initial velocity of the projectile; d – gun caliber; x, y, z – empirical coefficients.

In the Linte formula [9, 13, 19], the survivability criterion is determined only for artillery barrels:

$$N = 700 \cdot \frac{n_0}{n} \cdot \frac{d^2 \delta g}{\sigma q V_0}, \quad (2)$$

where n – fire rate; σ – elastic limit of the projectile material; g – free fall acceleration; δ – resistance of the barrel material; q – projectile weight.

Formulas (1), (2) cannot be used to predict the survivability of small arms barrels, since they do not take into account the differences in the ongoing processes of internal ballistics in an artillery barrel and in the barrel of a small arms (assault rifle).

The Gabo-Slukhotsky expression [9, 13, 19] allows to determine changes in the survivability indicator of barrels of many barrel systems, including small arms, but has a large number of variables:

$$N = K \cdot \frac{(d_0^2 - d_1^2) \cdot (1 + \Delta_d) \cdot e^{-n_1 \cdot t_0}}{e^{2.8 \cdot n_1 p_0 + n_2 \cdot T} \cdot \omega \cdot V_0^2} \cdot \left[\Delta_d \cdot \left(\frac{V_1}{V_d} \right)^2 + \left(\frac{0.64}{1 + \chi_n \cdot \Delta_d} \cdot \frac{1}{V_0} \right)^2 \cdot 2 \cdot g \cdot \frac{1 + \Theta}{2 + \Theta} \cdot \frac{p_d}{\gamma_d} \right], \quad (3)$$

where K – coefficient that depends on the caliber, depth and steepness of the rifling; d_0 – rifling caliber; d_1 – field caliber; $\Delta_d = W_d/W_0$ – number of volumes of gas expansion in the barrel channel; $W_d = S \cdot l_d$ – total volume of the barrel bore; S – cross-sectional area of the barrel channel; l_d – full path of the bullet (projectile); W_0 – volume of the charging chamber; ω – charge mass; $n_1 = k \cdot (1 - \lambda_1)$, $k, \lambda_1, n_2 = k \cdot \lambda_1$ – coefficients [13]; p_0 – boost pressure; T – powder combustion temperature; t_0 – temperature of the surface layer of the barrel at the beginning of the bullet cutting into the rifling; V_1/V_d – coefficient from table [13]; $\chi_n = \frac{1}{1/\chi + 0.75 \cdot d/l_0}$ – coefficient [13]; χ – expansion coefficient; l_0 – reduced chamber length; Θ – characteristic; p_d – muzzle pressure; $\gamma_d = \frac{\Delta}{(1 + \Delta_d) \cdot 1000}$ – coefficient; Δ – charging density.

In addition, formula (3) does not take into account the maximum pressure of powder gases, which has a significant impact on the survivability of the barrel.

Yustrov's dependence [20], in terms of the quantities included in it, is most closely suited for application to small arms. However, the expression includes an initial velocity indicator (in the numerator, squared), which is assumed to be constant (tabular), which is incorrect when using ammunition with long shelf life:

$$N = \frac{xy}{d} \cdot \frac{C_q V_0^2}{\lambda} \cdot \frac{\delta \varepsilon}{\mu k_l}, \quad (4)$$

where x, y – special functions; ε – relative deformation of the barrel walls; k_l – temporary resistance of the driving belt (shell); μ – friction coefficient of the driving belt (shell).

All given dependencies are suitable only for comparative calculations or analysis of the influence of individual parameters.

However, expression (4), taking into account changes in the initial velocity depending on the storage period of ammunition, and due to its ease of use, is most suitable for determining changes in the barrel survivability indicator.

Gerontological changes in the properties of gunpowder charges affect not only the issues of survivability of weapons. Also, one cannot underestimate the economic component of the impact of using ammunition beyond the warranty period on preserving the quality of the barrel and the weapon as a whole. The barrel is an expensive element of the barrel system, moreover, it determines its suitability for use, and the ammunition itself is a consumable item.

Thus, the problem of survivability of small arms barrels is an urgent scientific problem, since it is not fully considered in the available sources and therefore there is a need to create a forecasting methodology that covers the main parameters of intra-ballistic processes, which is what this study consists of.

The aim of research is to develop a method for predicting the survivability of small arms barrels when using long-term storage ammunition by determining the dependence of barrel survivability on various parameters of intra-ballistic processes.

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

1. Develop a theoretical method for predicting the survivability of small arms barrels depending on the storage period of ammunition.
2. Conduct experimental studies to verify the adequacy and confirm the reliability of the developed method.

2. Materials and methods of research

The object of the experimental study is the process of changing the survivability of small arms barrels when using post-warranty ammunition.

During the study, the main hypothesis was put forward, which is that when using ammunition with long storage periods, the survivability of the barrel, as the main part of the weapon, decreases. This research hypothesis was tested experimentally by conducting a series of physical experiments.

Thus, the study consisted of determining the decrease in the survivability of a weapon barrel when using ammunition with long storage periods as a result of a change in the initial velocity of the projectile. The experimental research program for determining the initial velocity of the projectile and the experimental methodology are given in [21–24].

The pilot study was conducted in 2021. The study used six new 5.45 mm assault rifles AK74 and ammunition of various years of manufacture – 1995, 2011, which corresponds to 26 and 10 years of storage. Two assault rifles were used with ammunition manufactured in 2011. Four assault rifles with ammunition manufactured in 1995.

The firing mode is uniform, in short bursts, without overheating the barrels.

When 4000, 6000, 8000, 10000 shots were fired from each barrel, a series of determinations of the initial velocity of the projectile were carried out. In this case, ammunition with a shelf life of 10 years was used in order to eliminate the influence of the gerontological changes of the powder charge on the initial velocity.

In each series, 30 measurements of the initial velocity of the projectile of each weapon sample were carried out.

The initial velocity of the projectile was determined using a certified optoelectronic measuring complex «ИБХ-731.4», designed to measure the velocity and energy of a small arms bullet, metrologically verified, with a maximum relative error of velocity measurement of 0.5 %.

Processing of data from experimental studies was carried out according to the method of statistical processing of empirical data [25]: checking for the presence of outlier observations, reproducibility of experiments, and adequacy of the model.

The main simplifications and assumptions used when conducting the experiment and processing experimental data:

1. Based on the purpose of the experiment, it was not the absolute value of velocity that was considered more important, but its change after the use of long-term storage ammunition.

2. The ratio of the initial velocity of an ammunition projectile with a long shelf life V_0^τ to the tabulated velocity V_0^{tab} corresponds to the ratio of the number of shots when using such ammunition N^τ to the tabulated number of shots $N^\tau \cdot V_0^\tau / V_0^{tab} = N^\tau / N^{tab}$.

3. Changes in weather conditions are insignificant and were considered the same for all series of the experiment.

4. The storage conditions for all ammunition used are the same before the experiment.

5. The initial projectile velocities at the beginning of the experiment correspond to the tabulated data due to the fact that the weapons used are new, from the same manufacturer, with the same ballistic characteristics.

3. Results and discussion

3.1. Method for predicting barrel survivability

The survivability of a weapon model is determined by the possible number of shots fired before a significant change in its tactical and technical characteristics. They are determined by the deterioration of the accuracy of the fire, the occurrence of cases of the projectile falling off the rifling, leading to its incorrect flight. With a general survivability of weapons up to $N = 100,000$ rounds, the survivability of the barrels is only up to $N = 25,000$ rounds (**Table 1**) [26].

The proposed method for predicting barrel survivability structurally consists of two stages:

– the first stage – determining the change in the initial velocity of the striking element depending on the storage period of the ammunition;

– the second stage – determining the possible limit number of shots from a weapon model.

Let's consider the first stage of the method.

One of the most important performance characteristics of a weapon type is the initial velocity of the projectile. The works [4, 8, 13, 21, 27] show that with an increase in the storage period of ammunition, the initial velocity decreases.

Experimental studies [13, 21, 27–30] confirm the negative effect of ammunition storage time on muzzle velocity. The authors of this study obtained the dependence of the change in the relative value of the initial velocity of the projectile on the storage life of ammunition at $10 \leq \tau \leq 50$ years, in the form of a second-degree polynomial [4]:

$$\frac{V_0^\tau}{V_0^{tab}} = 5 \cdot 10^{-5} \cdot \tau^2 - 5.2 \cdot 10^{-3} \cdot \tau + 1.06, \quad (5)$$

where V_0^τ – initial projectile velocity with a certain shelf life; V_0^{tab} – initial projectile velocity of new ammunition in accordance with the tactical and technical characteristics; τ – ammunition storage period.

Table 1

Technical resource of weapon barrels

No.	Type of weapon	Number of shots
1	9 mm PM	4000
2	9 mm APS	8000
3	5.45 mm PSM	3000
4	7.62 mm SVD	6000
5	7.62 mm AKM and its modifications	10000
6	5.45 mm AK74 and its modifications	10000
7	7.62 mm PKM and its modifications	25000
8	7.62 mm RPK and its modifications	20000
9	5.45 mm RPK74 and its modifications	20000
10	12.7 mm NSV	10000
11	14.5 mm KPVT	12000
12	14.5 mm KPVT	6000
13	30 mm 2A72	6000

The graph of this function is shown in **Fig. 1**.

According to regulatory documents, if the initial velocity decreases by more than 5 % from the table value, the weapon model is considered unsuitable for combat use.

Knowing the nature of the physical and chemical processes in powder charges, it is possible to predict the guaranteed time period for the use of ammunition without deteriorating the ballistic characteristics of the weapon [13]. **Fig. 1** shows that the guaranteed storage life of ammunition without deteriorating the ballistic characteristics of the weapon is ≈ 26 years.

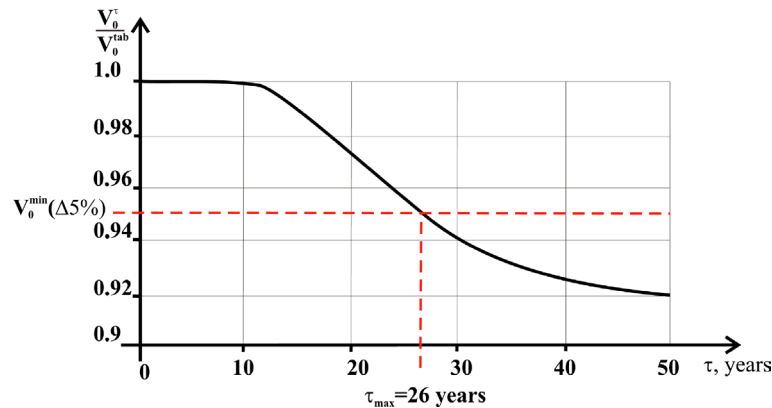


Fig. 1. Dependence of changes in the relative value of the initial velocity of the projectile on the storage period of ammunition

The second stage of the method is based on monitoring parameters corresponding to the internal ballistics of «fresh» ammunition, i.e. with a calendar shelf life not exceeding its warranty period (10 years). However, as stated above, one of the main indicators of deterioration in barrel survivability is a decrease in the initial velocity of the projectile, caused by the duration of storage of ammunition. Taking this into account, having analyzed the above dependencies (1–4), the authors decided to use Yustrov's expression (4) to check the change in the value of barrel survivability, but with the need to take into account the change in the initial velocity of the projectile (V_0).

In the developed method, instead of V_0 , the function $V(\tau)$ (5) is used. Substituting formula (5) into (4) it is possible to obtain an expression for assessing the survivability of the barrel, which satisfies the conditions of the study and makes it possible to obtain the most accurate values. After this, Yustrov's expression is presented as:

$$N = \frac{xy}{d} \frac{C_q (5 \cdot 10^{-5} \cdot \tau^2 - 5.2 \cdot 10^{-3} \cdot \tau + 1.06)^2}{\lambda} \frac{\delta \varepsilon}{\mu k_l}. \quad (6)$$

Parametric studies of this formula suggest that it makes it possible to most accurately determine the parameter under study for different storage periods of ammunition.

3. 2. Checking the adequacy and confirming the reliability of the developed method

3. 2. 1. Theoretical forecasting of changes in the survivability index for ammunition of various storage periods

The reliability of the method was checked using experimental data for the 5.45 mm assault rifles AK74 and ammunition with a shelf life of 20, 30, 40, 50 years. Using expressions (6), the change in barrel survivability index for ammunition of different storage periods was predicted. The forecast results are presented in **Table 2** and in **Fig. 2**.

The study determined not absolute, but relative values of barrel survivability indicators depending on gerontological changes in the characteristics of the powder charge for their comparison.

Fig. 2 shows that the graph of changes in the barrel survivability indicator also crosses the barrel rejection line when using ammunition ≈ 26 –27 years of storage. The use of ammunition

beyond this storage period is impractical due to the unsatisfactory condition of the barrel and the impossibility of using the weapon for its intended purpose. As it is possible to see, the data obtained using the proposed method correlates with the obtained dependence of the change in the relative value of the initial velocity of the projectile on the storage period of the ammunition (Fig. 1).

Table 2

Barrel survivability indicators when using ammunition of various storage periods

Relative survivability index	Ammunition shelf life				
	10	20	30	40	50
N^τ/N^{tab}	0.998	0.997	0.929	0.869	0.799

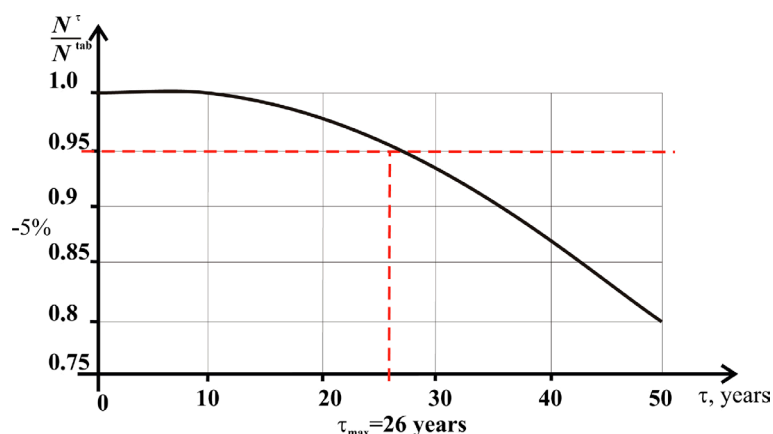


Fig. 2. Dependence of changes in the relative indicator of barrel survivability on the storage period of ammunition

These results were compared with experimental data on changes in the initial velocity of the projectile presented below.

3. 2. 2. Results of experimental studies to determine changes in barrel survivability indicators

The experimental studies consisted of determining the relative values and nature of changes in the initial velocities of bullets from the 5.45 mm assault rifles AK74.

According to **Table 1**, the survivability of the 5.45 mm assault rifles AK74 barrel is determined at 10,000 rounds.

However, these values are valid under the following conditions:

- firing mode – medium, without obvious overheating of the barrel;
- ammunition with guaranteed service life (internal ballistics parameters – tabular).

When using post-warranty ammunition, the maximum pressure in the barrel increases, the coordinate of the maximum pressure shifts towards the chamber, the burning rate of the gunpowder increases, and the force of the gunpowder decreases [4, 8, 13, 21].

Taking into account these changes, it is assumed that the survivability of the barrel will change due to changes in the parameters of the intra-ballistic process.

The condition of weapon barrels was monitored by measuring the initial velocity of the bullet [4, 13, 21, 27].

The results obtained during the experiment are summarized in the form of dimensionless values of the relative values of the initial velocities of bullets V_0^τ/V_0^{tab} and the dependence of their changes on the service life of the barrels in the shots.

Table 3 shows the results of one series of experiments, which were carried out when $N = 10,000$ shots were fired from each weapon barrel. **Table 4** and in **Fig. 3** show the average relative values obtained in the experimental series with different barrel firings.

Analysis of the data obtained shows: line 10 shows the maximum permissible reduction in the initial velocity of the projectile by 5 % from the table value. According to [26], one of the reasons for barrel rejection is a decrease in the initial velocity below this value.

From the data in **Table 4** and **Fig. 3** it can be seen that changes in the initial velocity of all six assault rifles practically coincide at the point equal to $N \sim 2000$ shots. This part of the graph differs from the normal operation of the barrel with normal ammunition by an amount not exceeding 0.4 %.

Table 3

Relative values of the initial bullet velocity obtained in one series of experiments when the firing rate reached 10,000 shots

Shot number	Weapon numbers and relative values of initial velocities, V_0^z / V_0^{tab} at $N = 10000$					
	1	2	3	4	5	6
1	0.9479	0.9488	0.941	0.9399	0.9422	0.93
2	0.9478	0.9485	0.9412	0.9399	0.9418	0.9298
3	0.9479	0.9483	0.941	0.9398	0.942	0.9304
4	0.9482	0.9488	0.9409	0.9402	0.9421	0.9299
5	0.9479	0.9483	0.941	0.9403	0.9421	0.9304
6	0.9476	0.9487	0.9409	0.9402	0.9419	0.9302
7	0.9481	0.9488	0.9407	0.9397	0.9419	0.9301
8	0.9476	0.9486	0.9412	0.9399	0.9418	0.9304
9	0.9478	0.9488	0.9411	0.9401	0.942	0.9299
10	0.9482	0.9489	0.941	0.9399	0.9421	0.9301
11	0.9482	0.9489	0.9412	0.94	0.9418	0.93
12	0.9477	0.9486	0.9412	0.9402	0.9418	0.93
13	0.9479	0.9485	0.941	0.9398	0.9416	0.9302
14	0.9482	0.9488	0.9412	0.9399	0.942	0.9303
15	0.9481	0.9487	0.9411	0.9398	0.9419	0.9302
16	0.9477	0.9488	0.9408	0.9398	0.942	0.93
17	0.9477	0.9483	0.9407	0.9398	0.942	0.93
18	0.9479	0.9484	0.9409	0.9399	0.9421	0.9304
19	0.9479	0.9485	0.9409	0.9398	0.9421	0.9301
20	0.948	0.9485	0.9408	0.9401	0.9418	0.9301
21	0.9478	0.9485	0.9409	0.9399	0.942	0.9302
22	0.9478	0.9485	0.9412	0.94	0.9421	0.93
23	0.9477	0.9487	0.9409	0.9401	0.9422	0.9301
24	0.9477	0.9486	0.941	0.9401	0.9416	0.9301
25	0.9481	0.9486	0.9409	0.9399	0.9419	0.9301
26	0.9481	0.9488	0.9407	0.9402	0.9417	0.9303
27	0.9476	0.9484	0.9407	0.94	0.9418	0.9301
28	0.9481	0.9483	0.9413	0.9397	0.942	0.9298
29	0.948	0.9484	0.941	0.9402	0.9418	0.9298
30	0.9478	0.9486	0.9411	0.9398	0.9422	0.9299

Table 4
Averaged experimental data

Shot number, N	Weapon numbers and average relative values of initial velocities, V_0^r/V_0^{tab}					
	1	2	3	4	5	6
0	1	1	1	1	1	1
4000	0.993	0.993	0.99	0.989	0.991	0.985
6000	0.971	0.971	0.9655	0.965	0.967	0.96
8000	0.9555	0.956	0.9489	0.948	0.95	0.94
10000	0.9479	0.9486	0.941	0.94	0.9419	0.9301

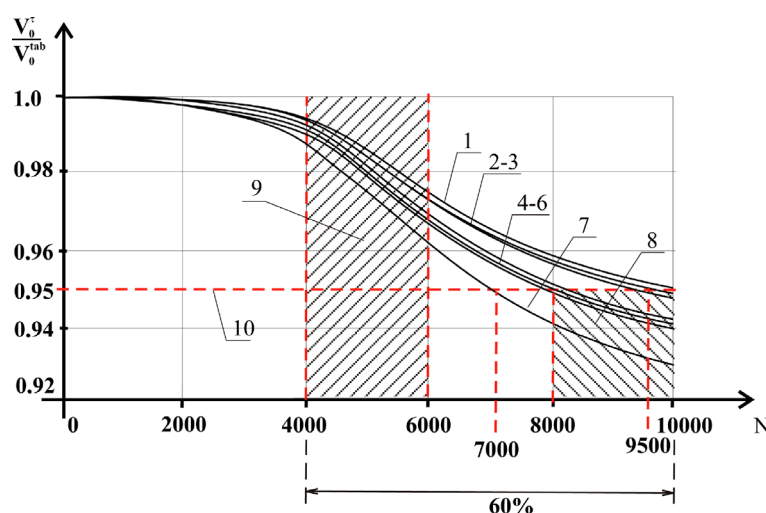


Fig. 3. Change in the relative values of the initial velocity depending on the resource of the barrels: 1 – theoretically obtained graph of the change in V_0 ; 2, 3 – graphs of changes in V_0 of assault rifles (No. 1, 2); 4, 5, 6 – graphs of changes in V_0 of assault rifles (No. 3–5); 7 – graph of changes in V_0 of the assault rifle (No. 6); 8 – difficult to predict barrel wear interval; 9 – area of the beginning of a more intense change in V_0 ; 10 – line of the maximum permissible drop value V_0

Lines 2, 3 are graphs of changes in the initial velocities of bullets of two assault rifles, which were operated with ammunition of guaranteed shelf life and practically do not differ from line 1 – the theoretically obtained graph of changes in V_0 .

When using post-warranty ammunition, the best result is lines 4, 5, 6 – three assault rifles, the values of the initial bullet velocities of which actually decrease by 5 % after 8000 rounds. This is 80 % of the resource. One sample (line 7) crosses the barrel rejection line with ~30 % of the resource being «underdeveloped».

The characteristic point on the graph is the coordinate $N = 4000$ shots. Considering the discrete nature of the control of the initial velocity during the experiment, it can be assumed that the beginning of a more intense change in the initial velocity lies in the range of ~3000...4000 shots. The point of 4000 shots is 40 % of the resource, that is, at the remaining 60 % of the barrel life, more significant deviations in the initial velocity begin and the intensity of barrel wear increases. At the same time, it can be assumed that with a more intense firing mode, the coordinate of the point where the intense drop in initial velocity begins will shift up to 3000 shots – 30 % of the barrel's life.

The experimental data are correlated with the data obtained theoretically based on the developed methodology. Thus, the theoretical results are confirmed experimentally, and formula (6) allows one to determine with sufficient accuracy the survivability of the barrel when using ammunition of a certain shelf life.

Also, during experimental studies of the survivability of the barrels of 5.45 mm assault rifles AK74, not only the barrels were examined, but also other parts of the weapon, such as elements of the mechanical system. As a result, burnout of the gas tube was detected in all tested samples. This observation is especially important due to the fact that this structural element is not included in the range of spare tools and accessories (SPA).

Thus, it has been found that not only the barrel, but also other structural elements are affected by the factors of using long-term storage ammunition. The study of deformations and the state of the surface layer of automation elements has not been carried out and requires additional research.

4. Conclusions

Predicting changes in barrel survivability is one of the tasks associated with the problem of ammunition operation. At different storage times, the most important indicator of changes in the properties of a powder charge is the initial velocity of the projectile.

A method has been proposed for predicting barrel survivability depending on the shelf life of the ammunition used, which makes it possible to determine this indicator with sufficient accuracy and justify the feasibility of their use.

Using the developed method, it has been found that the guaranteed time period for using ammunition without deteriorating the ballistic characteristics of the weapon is approximately 26 years.

The adequacy and reliability of the developed method were checked by comparing the obtained theoretical results with the results of experimental studies.

The main result of experimental studies of both small arms and artillery systems should be considered the identification of a pattern of changes in the initial velocity of a bullet associated with intense wear of the barrel (its firing and wear), as well as wear of automation elements. The reason is the use of ammunition with post-warranty storage periods and the influence of modified internal ballistics factors. Thus, the problems of ensuring the required service life of barrels when operating weapons with ammunition with post-warranty (long) storage periods can be solved on the basis of the obtained patterns of barrel survivability depending on the number of shots.

It has been experimentally shown that as a result of the use of ammunition with long storage periods, the intensity of barrel resource exhaustion increases and, under the influence of factors caused by this, the indicators and characteristics of the barrel system as a whole change. It has been found that when using such ammunition, the barrel survivability indicator decreases by 20–30 % of the table value. It can be predicted that with an increase in the intensity of fire, this indicator will worsen by ~40 %.

In addition, the detected damage to the gas tube seems practically important, especially considering that this element is not included in any spare parts. The obtained experimental effect requires further research in the direction of expanding the range of ammunition and weapons, as well as research into the structural elements of the barrel system.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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Received date 22.12.2023

Accepted date 22.02.2024

Published date 29.03.2024

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How to cite: Anipko, O., Baulin, D., Horielyshev, S., Boikov, I., Medvid, M., Babkov, Y., Nakonechnyi, A., Kolomiitsev, O., Gleizer, N. (2024). Development of a method for predicting barrel wear resistance when using ammunition with a long storage life. *EUREKA: Physics and Engineering*, 2, 119–130. <https://doi.org/10.21303/2461-4262.2024.003298>