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EVALUATION OF THE EFFECTIVENESS OF TECHNICAL DIAGNOSTIC TOOLS FOR FIREARMS BARREL CHANNELS

A methodical approach to quantitative assessment of the effectiveness of means of technical diagnostics of firearms barrel channels is proposed. The expediency of introducing operational technical diagnostics of barrel channels into the general system of measures aimed at establishing the technical condition of weapons samples is substantiated. The group of properties of technical diagnostic tools to be evaluated is determined, and expressions for the corresponding performance indicators are synthesised. A quantitative assessment of the effectiveness of known and promising technical diagnostic means of domestic and foreign production is carried out.

Keywords: *barrel channel, effectiveness of diagnostic tools, technical diagnostics, technical condition, barrel channel defect.*

Statement of the problem. In the conditions of active hostilities, the susceptibility of firearms barrels to destruction increases due to temperature effects, the functioning of weapons in conditions of mud and moisture, lack of timely maintenance, a significant excess of the resource (firing) and other negative factors [1]. Important factor that adversely affects the technical condition (TC) of barrel channels (BC) is the use of a wide variety of ammunition with different chemical and physical characteristics, which is due to differences in the technological processes of their manufacture in different countries of the world, as well as cases of storage in uncontrolled conditions. The complex of these factors causes premature damage (degradation) to the surface of the TC and their critical wear, as a result of which the weapon no longer meets the requirements set out in the technical documentation, and its service life is prematurely exhausted [2]. At the same time, cases of discrepancy between the actual residual life and the one specified in the form for the weapon sample are not excluded.

Damage to the TC leads to changes in the ballistic characteristics of the weapon, for example, to a drop-in muzzle velocity of the projectile, a decrease in the accuracy of firing (an increase in the dispersion of the hit points relative to the aiming point), and even to a sudden failure of the weapon [3]. All of this creates conditions for an unpredictable decline in the quality of fire mission performance [4].

This situation prompts the adoption of organisational and technical measures to improve the process of technical diagnostics (TD) of the TC for the timely detection of weapons failures and their prevention. In particular, [5] proposes the introduction of a new type of TD – operational. This type of TD can be implemented in addition to the known types of TD established by the standard [6], for example, in the case of preliminary pre-repair diagnostics (defect) [7], technical inspection of weapons by officials [8], etc. Operational MT is carried out without interrupting the process of operation of the weapon sample, i.e. directly during its intended use or maintenance, which provides certain advantages. The process of TS can be carried out in the field (if the weapon sample is located in the area of combat operations – at or close to the positions, without the need to withdraw to rear points), which eliminates the transportation of weapons to stationary places of control and significantly increases its efficiency. This will make it possible to make timely decisions on the feasibility of repairing and rejecting weapons samples, which, turn, will increase the readiness of weapons for use and, accordingly, increase the likelihood of performing a combat (fire) mission.

In most cases, it is advisable to focus operational TS on weapons with limited resources, increased requirements for accuracy, and high procurement and maintenance costs. Such weapons include modern artillery and sniper weapons, which require concealment, restrictions on movement, and always being in good working order to ensure that they hit the target on the first shot.

Thus, the concept of operational TD provides for the rapid acquisition of a significant amount of data (measurement information) on the TS of the diagnosed weapon sample, which places increased demands on diagnostic tools. At present, there are known means of TD, which can be conditionally attributed to traditional (measuring gauges, gauges, borescopes, etc. [9, 10]) and promising (for example, based on a laser triangulation means of measuring the geometric characteristics of the CS [5]). The latter determines a set of values of CS radii for certain angular and axial orientations of the laser probing beam. The obtained data are tabulated and can be further used to determine the characteristics of defects, to visualise the results in the form of a three-dimensional model of the CS surface, etc.

From the above analysis, it follows that the creation of a set of tools for the implementation of operational TS is an urgent need in practice, and this necessitates the solution of a number of important scientific and technical problems. One of these tasks is to substantiate the principle of operation and composition of the complex of diagnostic tools. At the same time, deciding on the feasibility of using a particular diagnostic tool or their combination as part of a diagnostic complex requires a comprehensive analysis of the potentially achievable effect during the implementation of operational testing. In particular, to select and evaluate the suitability of diagnostic tools, their comparative analysis should be performed according to certain performance indicators.

However, despite the fairly wide coverage in the literature of the issues of evaluating the effectiveness of military technical systems, the problem of forming a unified methodological approach to creating a list and quantifying the performance indicators of the means of operational technical systems of firearms remains unresolved.

Analysis of recent research and publications. Indicators, criteria and methods for assessing the effectiveness of technical systems are described in a number of domestic and foreign scientific papers, but the approaches they present differ depending on the purpose of these technical systems.

Article [11] proposes a method for assessing the efficiency of technical systems using graphical analytical diagrams of partial and integral indicators of system efficiency, but this method has limited accuracy and scope due to the ability to consider only a certain number of partial performance indicators.

Methods for evaluating full and partial performance indicators are analysed in [12], but the approaches outlined give preference to reliability indicators and at the same time do not consider indicators that reflect the properties associated with the time spent on the implementation of processes.

Partial indicators and criteria for the effectiveness of metrological support of communication facilities are proposed and discussed in [13]. In it, the authors substantiated the expediency of using partial performance indicators – indicators of information content, efficiency, economy and mobility, but their evaluation and optimisation consider only the organisational component of the work of metrological support units. The influence of the characteristics of measuring instruments on the effectiveness of metrological support measures is not considered in the article.

An analysis of sources [14–17] shows the difference in global approaches to assessing the effectiveness of technical systems depending on their application. Thus, for military technical systems, efficiency in [14] is considered in the context of the ability to perform the task with maximum efficiency and technical reliability without considering resource costs. The effectiveness of technical systems for production purposes in [15, 16] is proposed to be assessed using the OEE (*Overall Equipment Effectiveness*) indicator, which is an integrated performance indicator consisting of partial indicators of availability, productivity and quality. The effectiveness of non-military technical systems is defined in [17] as the degree of satisfaction of the end user's needs with minimal resource costs.

Thus, as the analysis shows, the known sources of information lack a systematic presentation of the methodological basis for assessing the effectiveness of military technical systems in general and the effectiveness of firearms technical systems in particular.

The purpose of the article is to substantiate a methodological approach to the formation of a list, synthesis of expressions and quantitative assessment of performance indicators of the means of operational technical diagnostics of firearms barrel channels.

Summary of the main material. As noted above, in the current conditions of combat operations, there is a need for the CU CMC to quickly determine the types of weapons of units performing combat operations without removing them from the area of operations. It should also be added that due to the significant upgrade of weapon systems with the latest models, the requirements for the quality of the TD have also increased. Taking these factors into account, it is possible to formulate and list the tasks that should be solved with the help of a set of operational TA tools.

1. Monitoring the technical condition and establishing the category of a weapon sample, i.e. its conditional accounting characteristic, depending on the current technical condition, technical resource reserve and the need for repair.
2. Obtaining reliable information about the location and cause of the malfunction (if any).
3. Determination of the residual life of the object of diagnosis and/or vehicle prognostication for a certain time interval in the future.

The TD process is an operation, i.e. a system of purposeful actions united by a common goal. The study of an operation involves a joint consideration of its three defining aspects: operation management activities; active means of the operation (technical systems); other means that interact with active means (objects of influence, enemy personnel and weapons, etc.). In the course of the implementation of the CSA, the diagnostic tool (diagnostic complex) acts as an active means of achieving the goal, and in this case, the concept of operation effectiveness is identified with the concept of the effectiveness of the CSA tool.

Comparison of diagnostic tools is based on the definition and quantification of performance indicators that characterise the degree to which the results of a TD meet the requirements for it. The result of a TD depends on the properties of the TD tool, which affect the useful effect, as well as the resources and time spent. Let us define these properties as informativeness, efficiency and cost-effectiveness of the CS TA tool.

Informativeness characterises the completeness and reliability of the data obtained from the results of the TD. In the case of determining the category of the barrel, this data is information on the deviation of the geometric dimensions of the determined sections of the CS from the ranges of permissible values established for each category. In the case of determining the location and nature of the fault, these data provide information on the presence and quantification of the characteristics of the CS defects. It is worth noting that common defects of CCW include diametric wear (abrasion) of CCW, elongation of the charging chamber, barrel swelling, presence of shells, cracks, wear (abrasion, crumbling) of the combat edges of the rifling, etc.

Let us consider the information content indicators for the cases of establishing the category of the barrel and determining the location and nature of the malfunction separately. It should be noted that in order to ensure the comparability and clarity of performance indicators, when synthesising the relevant expressions for quantification, we should try to ensure that they are in the range of possible values [0; 1] for any combination of means and conditions of technical investigation. At the same time, we assume that in the case of increasing efficiency, the value of the indicator will increase.

When establishing the category of the barrel, the indicator of informativeness I_K should be defined as the probability P_B of making a correct conclusion about the category number of the barrel by its TS based on the measurement information about the deviation of the geometric parameters of the sections of the CS from the tolerances established for them. The reliability of P_B depends on the probability of making an incorrect conclusion about the CS TS, which, in turn, consists of the probabilities of false and undetected out-of-tolerance of the controlled parameter for this category of the barrel by the TS (hereinafter – the probabilities of false and undetected failures) [18]:

$$\mathrm{P_{CC}} = 1 - \mathrm{P_{IC}} = 1 - (\mathrm{P_{UF}} + \mathrm{P_{FR}}), \qquad (1)$$

where P_{IC} is the probability of an incorrect conclusion; P_{UF} is the probability of an undetected failure; P_{FR} is the probability of a false failure.

We accept the following notation: x is the true value of the controlled CS parameter, which is a random variable for a set of similar products; φ_X is the probability density of the values of x; Δ is the absolute measurement error of the controlled CS parameter using a diagnostic tool, which is also a random variable; φ_Δ is the probability density of the values of Δ; $b - a = 2\delta$ is the width of the tolerance field (here δ is the permissible deviation of the controlled parameter from the middle of the tolerance field or the nominal value of the parameter).

Then the expressions used to calculate the components of P_{UF} and P_{FR} can be presented as follows [19]:

$$P_{FR} = \int_{0}^{b-a} (\int_{b-\Delta}^{b} \varphi_x dx)\varphi_\Delta d\Delta + \int_{-(b-a)}^{0} (\int_{a}^{a-\Delta} \varphi_x dx)\varphi_\Delta d\Delta, \quad (2)$$

$$P_{UF} = \int_{0}^{b-a} (\int_{a-\Delta}^{a} \varphi_x dx)\varphi_\Delta d\Delta + \int_{-(b-a)}^{0} (\int_{b}^{b-\Delta} \varphi_x dx)\varphi_\Delta d\Delta. \quad (3)$$

Finding P_{UF} and P_{FR} by expressions (2) and (3) is quite cumbersome and inconvenient, so in practice it is advisable to use a graph-analytical method of determining these values [18].

It should be noted that the distribution of the controlled parameter (e.g., the diameter wear of the CS or the elongation of the charging chamber) over the tolerance field usually follows a uniform distribution law, since the process of degradation of the CS surface during abrasion cannot be of a familiar variable nature and occurs due to one dominant factor. The error of the TD tool is distributed according to the normal law, since it is the result of the action of several factors of commensurate scale of influence.

The input data for finding P_{UF} and P_{FR} using graph analytics are:

– is the value of the limit of permissible measurement error of the controlled parameter Δ;

– is the permissible deviation of the controlled parameter δ;

– the value of the standard deviation (SD) σ_x of the controlled parameter or the value of the confidence probability P_d for the confidence interval $\Delta x_{\max}$ of the controlled parameter.

To find P_{UF} and P_{FR} using the graph-analytical method, it is necessary to use the nomograms of dependencies $P_{UF}(\frac{\delta}{\sigma_x}, \frac{\delta}{\Delta})$, $P_{FR}(\frac{\delta}{\sigma_x}, \frac{\delta}{\Delta})$ to distribute the controlled parameter according to a uniform distribution, and its measurement error according to a normal law. Such nomograms (Figure 1) are given in specialised literature sources describing the graph-analytical method of assessing the reliability of measurement control of parameters, for example [19].

The value of σ_x can be determined based on the results of the analysis of the parameters of a certain set of weapons of this type. If it is difficult to obtain such information, then as a first approximation, it can be assumed that the confidence interval $\Delta x_{\max}$ of the controlled parameter is commensurate with the tolerance value δ, and proceed from the known relationship between $\Delta x_{\max}$ and σ_x for a uniform distribution law of a random variable [18]:

$$\sigma_x = \Delta x_{\max} / t_p, \quad (4)$$

$$\Delta x_{\max} \cong \delta, \quad (5)$$

where t_p is the confidence (quantile) coefficient tabulated for different distribution laws (in particular, in [19]).

From expressions (4) and (5) we have:

$$\frac{\delta}{\sigma_x} = \frac{\Delta x_{\max}}{\Delta x_{\max} / t_p} = t_p. \quad (6)$$

For example, for a uniform distribution law of a controlled parameter, if the confidence level of $P_d = 0.9$, then the value of $t_p = 1.56$. There fore, if we use nomograms, we will assume that $\frac{\delta}{\sigma_x} \cong 1.6$.

Based on the results of calculating the values of $|\delta| / \sigma_x$ and $R = \Delta / \delta$, it is necessary to enter the nomograms: the value $|\delta| / \sigma_x$ is plotted along the abscissa axis of each of the nomograms, after which the curves corresponding to the previously calculated *R* values are selected. According to the nomograms, the points of intersection of the abscissa $|\delta| / \sigma_x$ with the *R* curves are determined, the ordinates of which give the desired values of P_{FR} and P_{UF}. The value of the informativeness indicator I_K is calculated by expression (1).

In the case of the implementation of TD, in order to determine the location and nature of the malfunction for the synthesis of the indicator of informativeness I_H of the TD tool, it is advisable to take into account the presence or absence of its ability to identify a certain significant defect of the CS from the list defined above (or established by the manufacturer of the weapon sample).

One of the rather simple, but quite reasonable approaches to the synthesis of the informativeness indicator I_H is to accept the agreement to quantify the ability to identify a CS defect by the number 1, and the absence of this ability by the number 0.

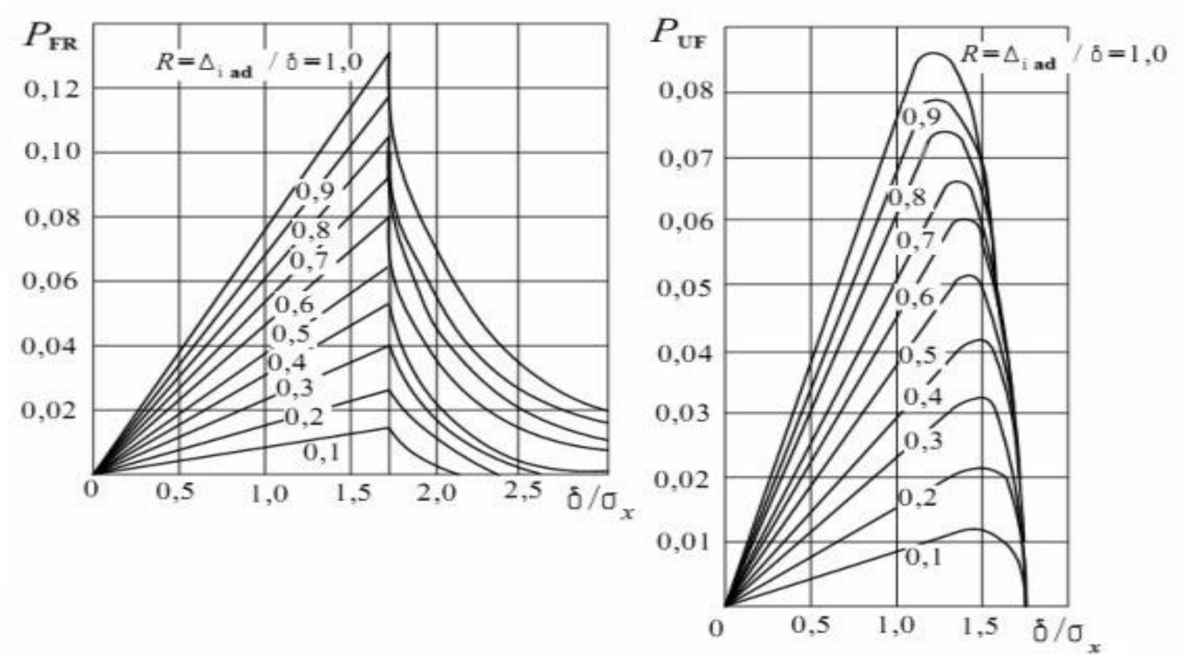

Figure 1 – Nomograms for the distribution of the controlled parameter uniform, and its measurement errors follow the normal law

Considering that the entire list of possible significant CS defects consists of *n* known types of damage, the formula for determining the informativeness indicator of the CS TD tool takes the

$$I_H = \frac{1}{n}\sum_{i=1}^{n} F_i\,, \qquad (7)$$

where I_H is the informativeness indicator; F_i is the assessment of the ability to identify the CS defect; n is the number of significant CS defects considered during TD.

Another, more complex approach would be to give separate scores to this indicator both for the ability to establish the fact of a particular defect and for the ability to quantify the degree of its manifestation (for example, for the ability to determine the depth of damage and the area of its base). Thus, each of the estimates F_i will be determined by the sum of its components, $F_i'\,F_i''$ F_i'''. In this case, F_i' can take the value 0 (in the absence of the ability to identify i the damage to the CS) or 0.33 (if such an ability is available); F_i'' takes the value 0 (in the absence of the ability to determine the depth of i the damage) or 0.33 (if such an ability is available); F_i''' also takes the value 0 (in the absence of the ability to determine the area of the base of i the damage) or 0.33 (if such an ability is available). According to this approach, the information content indicator will be determined by the expression

$$I_H = \frac{1}{n}\sum_{i=1}^{n}\left(F_i' + F_i'' + F_i''' \right). \qquad (8)$$

The efficiency of the TS means characterises the speed of the TS process implemented with its help, or the time spent on the TS process. The efficiency indicator should consider both the specified limit (desired) time for performing TS of the CS and the actual labour intensity (labour costs) of diagnostic operations using the selected means, technical characteristics of the TS means and operator competence. The time spent on the CS technical inspection is the sum of the time intervals spent on individual operations. These operations include:

– preparing the vehicle for operation;

– diagnostic operations (measurements, vehicle control, intermediate calculations, etc.);

– analysis of the results of the TA;

– performing regulated work with the TA product after completion of its intended use.

Based on the above approach, the expression for the indicator of efficiency *O* of the means of TD CS can be presented in the following form

$$O=\frac{T_{des}}{\sum_{j=1}^{m}T_j}, \qquad (9)$$

where T_{des} is the set (desired) time for conducting the TD; m is the number of TD stages; T_j is the time spent on performing operations of the j stage of the TD.

The cost-effectiveness of a vehicle is characterised by the amount of resources required for its procurement (creation, manufacture) and the costs of its operation and subsequent disposal. The operation of a technical means includes the stages of storage, transportation, intended use, and maintenance of readiness (maintenance, possible repairs or upgrades). It is also advisable to consider the costs of training (education) of the relevant specialists in the operation of technical means (operators). Therefore, the cost-effectiveness indicator should consider such costs:

– for the creation or purchase (e.g., the market value of a set of TD tools);

– for the intended use (the cost of material assets required to ensure the functioning of the vehicle, such as electricity, operating fluids, etc.);

– maintenance and repair (the cost of calibration, adjustment, adjustment, restoration of performance, consumables and components to be replaced in case of repair, as well as the cost of the relevant logistics support);

– storage and transport costs (cost of material resources and maintenance of premises required for storage of TDs, cost of transport containers, etc.);

– education and training of operators (the cost of services provided by the manufacturer or other institution that provides personnel training services);

– disposal costs (the cost of paying for services to companies that dispose of technical equipment that have exhausted the service life specified in the technical documentation or have become unsuitable for use and restoration).

The expression for determining the cost-effectiveness of E can be represented as follows:

$$E=\frac{C_{des}}{C_{fact}} \text{ at, } C_{fact}=\sum_{i=1}^{k}\sum_{j=1}^{h}C_{i,j}, \qquad (10)$$

where C_{des} is the set (desired) amount of costs for a set of technical means; C_{fact} is the actual value of costs for a set of technical means; k is the number of measuring instruments included in such a set; h is the number of stages of the life cycle of technical means at which costs are expected (production or purchase, maintenance, storage, etc.); $C_{i,j}$ is the cost of an operation performed with the help of the i technical means and the j stage of the life cycle.

The result of applying the above methodological approach will be a set of values of three separate performance indicators – *I*, *O*, *E*. It should be noted that the expediency of further scalarisation of these three indicators (combining them into one generalised one) should be determined by a specialist, considering the specifics and purpose of a particular study. Further, the quantitative assessment of *I*, *O*, *E* and the analysis of its results will be carried out provided that the independent significance of each of these indicators is preserved, i.e., the generalised indicator will actually be presented in a vector form.

We will quantify these performance indicators for the cases of using such means of TD.

1. Domestic diagnostic complex consisting of a charging chamber length measuring device (CLD), a device for measuring the diameter wear of the CCP and a mechanical star (MS) and an endoscope [20]. It should be noted that to ensure the possibility of TD of various weapons systems, the diagnostic complex should include several sets of PKI and MZM, which will provide measurements in the ranges of calibres and geometric dimensions of common weapons samples (namely, PKI-10, PKI-17, PKI-19, PKI-20, PKI-26, as well as sets 1, 11, 12, 13 of MZM), which will affect the calculations for assessing performance indicators.

2. Foreign diagnostic complex *Zistos Measuring Kit* [21].

3. A promising diagnostic tool based on a laser triangulation tool for measuring the geometric characteristics of CS [5].

The assessment of the information content of I_K was carried out considering the information on the limits of permissible measurement errors of the above-mentioned technical means [9, 10, 20]. The calculations were performed for the example of categorising a 125-mm tank gun of the D-81 type, with the limits of the ranges of values of the diameter wear of the CS for transferring from category I to II, from category II to III, and from category III to V established in [21].

The results of the quantitative assessment of I_K are shown in Figure 2.

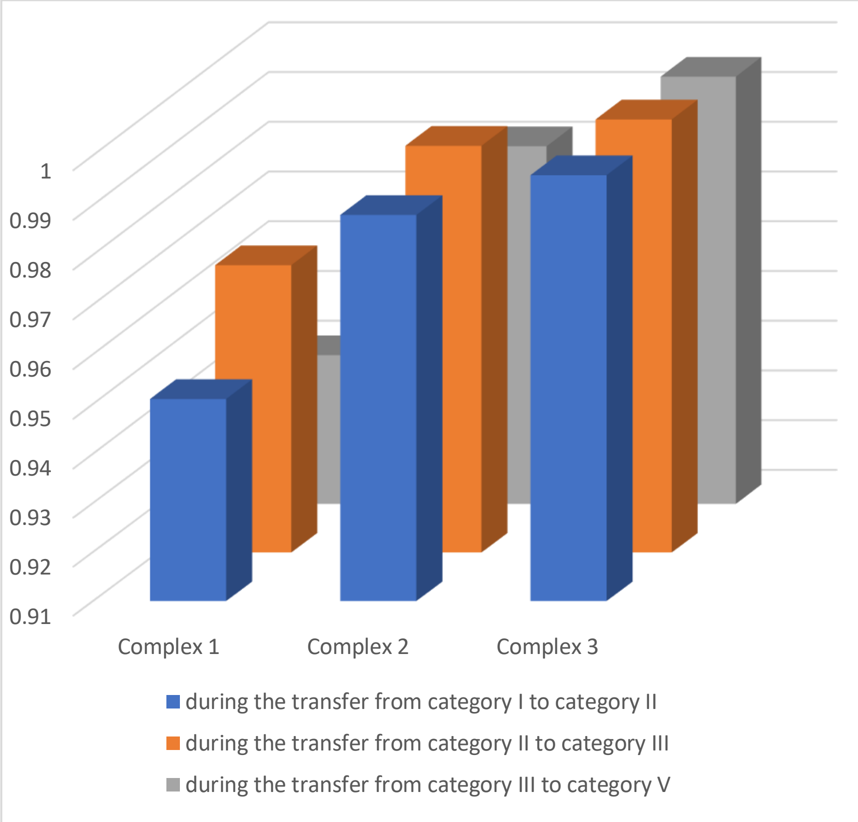

Figure 2 – Results of the quantitative assessment of the information content indicator I_K

It should be noted that all three diagnostic complexes under consideration provide relatively high and quite acceptable values of the I_K indicator, with a certain advantage being given by the use of a promising diagnostic tool based on a laser triangulation tool for measuring the geometric characteristics of the CS.

The I_H informativeness indicator was assessed for a typical list of significant defects [diametric wear, charging chamber elongation, crack, field puncture, wear of the leading (combat) edge of the cut, sink, swelling of the CS] with a score of n =7. In this case, according to expression (8), separate points were given to both the ability to establish the fact of a particular defect and the ability to determine the depth of damage and the area of its base. The results of the quantitative assessment of I_H are shown in Figure 3.

As can be seen in Figure 3, the first of the complexes of TD tools is significantly inferior to the second and third and is characterised by a relatively low value of the efficiency indicator. The third complex (a promising diagnostic tool based on a laser triangulation tool for measuring the geometric characteristics of the CS) provides the highest of the three obtained values of the indicator I_H .

To quantify the performance of O, we assume that T_{back} is equal to the time allocated to maintain an artillery system (e.g., 152 calibre or 155 mm) during a park day. In turn, time spent on j operations of the TD stage (9) is taken from observations, assuming equal training of the personnel using the TD means. The results of the quantitative assessment of O are shown in Figure 4.

As can be seen in Figure 4, a promising diagnostic tool based on a laser triangulation tool for measuring the geometric characteristics of a CS has significant advantages in terms of efficiency compared to other sets of tools, which can be a decisive factor in the implementation of operational TD of CS.

Quantifying the cost-effectiveness indicator is a rather difficult task due to the dynamics of changes in the cost of products and services and (partly) the lack of publicly available data due to the terms of contracts concluded between military authorities and industrial enterprises. In view of this, the study uses approximate price (cost) indicators as of the beginning of 2025 as the average values of the price ranges of commercial offers of manufacturing and trading enterprises specialising in the sale of civilian measuring instruments and whose products have characteristics that are close to their military counterparts.

To quantify the cost-effectiveness of E, we will take C_{back} at the level that corresponds to the minimum purchase price of one set of TD equipment from all three complexes considered in this article. The results of the quantitative assessment of E are shown in Figure 5.

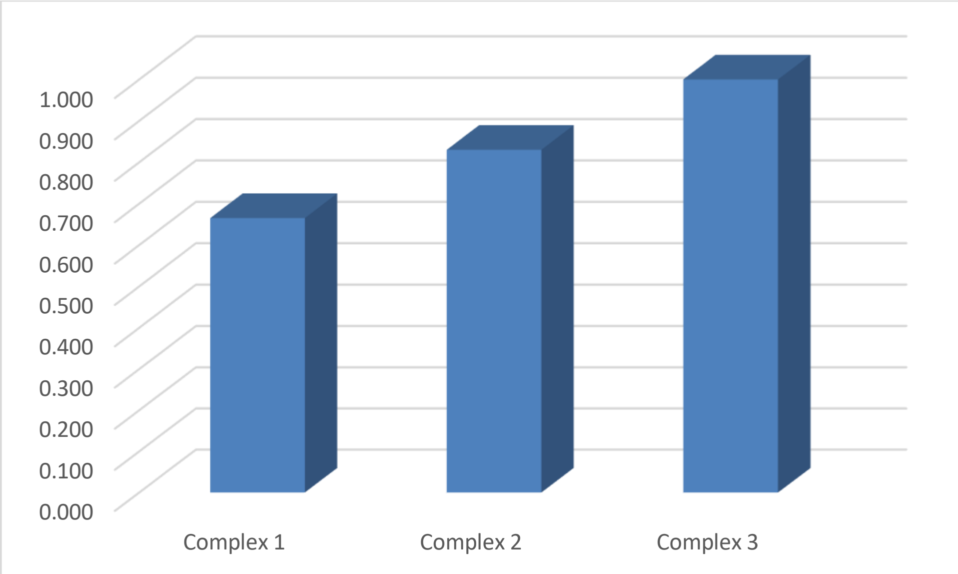

Figure 3 – Results of the quantitative assessment of the information content indicator I_H

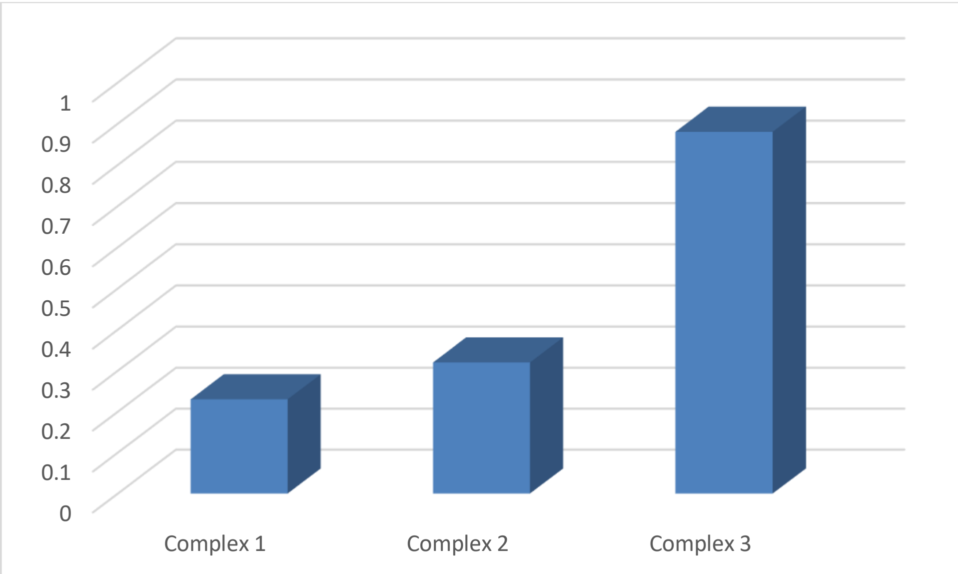

Figure 4 – Results of quantitative assessment of the efficiency indicator O

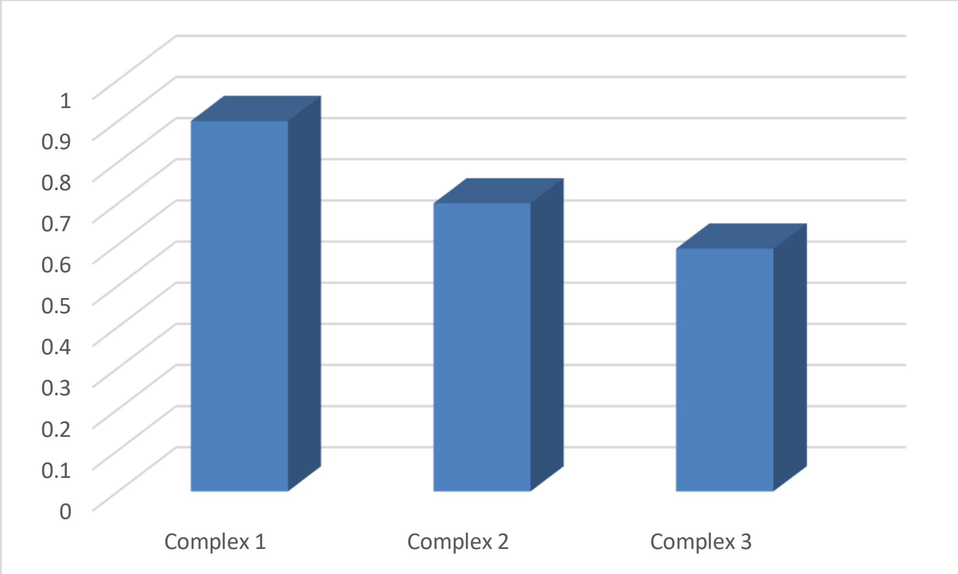

Figure 5 – Results of the quantitative assessment of the cost-effectiveness indicator E

The analysis of Figure 5 shows that the first complex has a significant (though not critical) advantage over the other two, which have comparable values of the cost-effectiveness indicator. However, when creating and using a complex of means of the technical means of the CS (as well as other technical systems of military purpose), the indicator of efficiency can be considered as auxiliary (secondary) in relation to the indicators of information and efficiency, and the costs (for procurement, operation, maintenance, etc.) can be considered acceptable if they are within the limits of the specified restrictions.

To summarise the results of the quantitative assessment of the performance indicators of the means of TD CS, we will present them in the form of a petal diagram. The values of the indicators of informativeness, efficiency and cost-effectiveness are plotted on the corresponding three axes, the angle between which is 120º (Figure 6).

The diagram above shows that the diagnostic complex based on a laser triangulation tool for measuring the geometric characteristics of the CS is characterized by a significant advantage over other complexes, as evidenced by the maximum values of the indicators of information and efficiency among the possible values, and the maximum area of the corresponding triangle, the vertices of which are the values of the three indicators plotted on the axes I, O, E (the area of the figure, the vertices of which correspond to the values of the indicators on the axes of the petal diagram, can be considered as a scalar).

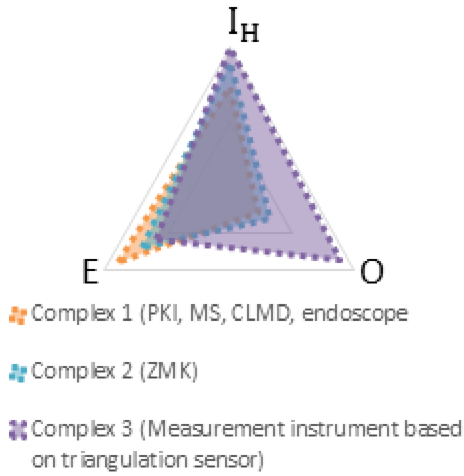

Figure 6 – Presentation of the results of quantitative assessment of performance indicators in the form of a radar chart during the implementation of technical diagnostics to determine the location and nature of the fault

This makes it possible to conclude that the use of a laser triangulation tool for measuring the geometric characteristics of barrel channels is promising in the process of creating a diagnostic complex for the implementation of operational technical diagnostics of firearms barrel channels.

Conclusions

The article considers a methodological approach to the formation of a list and quantitative assessment of performance indicators of means of operational technical diagnostics of firearms barrel channels. It is proposed to evaluate the effectiveness on the basis of the study of such properties of the means of technical diagnostics of barrel channels as informativeness, efficiency and cost-effectiveness.

On the basis of the basic provisions of the theory of mass maintenance, expressions for evaluating the indicator of informativeness of technical diagnostic tools during the operation of controlling the technical condition of barrel channels are proposed. Such an indicator is defined as the probability of making a correct conclusion about the technical condition of the barrel channels based on the results of control. Taking into consideration the inconvenience of using the relevant integral equations, the expediency of using a graph-analytical method of determining the informativeness with the help of special nomograms is noted. In the case of implementation of technical diagnostics to determine the location and nature of the malfunction, it is proposed to determine the informativeness indicator considering the ability of diagnostic tools to identify certain significant defects in barrel channels from the list established by the manufacturer of the weapon sample. At the same time, separate points are given to the informativeness indicator both for the ability to establish the very fact of the presence of a certain defect and for the ability to determine the quantitative assessment of the degree of its manifestation.

An expression for the efficiency indicator has been proposed, which considers the specified time limit for performing technical diagnostics of barrel channels, real labour costs for diagnostic operations, technical characteristics of technical diagnostic tools and operator competence.

An expression for the indicator of efficiency of a technical diagnostic tool has been obtained, which characterises the amount of resources required for its purchase and the costs of its operation and subsequent disposal. When synthesising the expression for the indicator of efficiency, the number of measuring instruments that can be included in the complex of diagnostic tools is considered, as well as the costs at all stages of the life cycle of such tools are considered.

To ensure the comparability and visibility of performance indicators, the expressions for quantitative assessment ensure that they are in the range of possible values [0; 1] for any combination of means and conditions of technical diagnostics, while the value of the indicator increases with increasing efficiency.

A quantitative assessment of the indicators of informativeness, efficiency and cost-effectiveness of three means of technical diagnostics of wellbore channels was carried out, in particular, a complex based on the devices of the CCD, PCI (MZ) and endoscope, a foreign diagnostic complex *Zistos Measuring Kit* and a promising diagnostic complex based on a laser triangulation tool for measuring the geometric characteristics of wellbore channels.

It has been established that the diagnostic complex based on a laser triangulation tool for measuring the geometric characteristics of barrel channels has significant advantages over other complexes, as evidenced by the maximum values of its indicators of information content and efficiency among the compared ones the case of insignificant lagging behind in terms of efficiency.

Thus, the advantages and prospects of using a laser triangulation tool for measuring the geometric characteristics of barrel channels in the process of creating a diagnostic complex for the implementation of operational technical diagnostics of firearms barrel channels have been proved.

Further research should be aimed at improving methodological approaches to the processing of measurement information on the geometric characteristics of barrel channels, which can be obtained using a promising technical diagnostic tool based on a laser triangulation measuring device.

References

1. Mulenko O. O., Ziuban M. I., Bondarenko S. V. (2023). *Zalezhnist zhyvuchosti stvoliv striletskoi zbroi vid zastosuvannia patroniv pisliaharantiinykh terminiv* [The survivability of rifle gun barrels during the drying of cartridges is preserved after warranty terms]. *Molodui vchenyi*, no. 2 (114), pp. 1–4. DOI: https://dx.doi.org/10.32839/2304-5809/2023-2-114-1 [in Ukrainian].

2. Kriukov O. M., Melnikov R. S., Muzychuk V. A. (2018). *Metod diahnostuvannia tekhnichnoho stanu kanaliv stvoliv ta boieprypasiv na osnovi identyfikatsii kharakterystyk balistychnykh elementiv postrilu* [Method for diagnosing the technical condition of barrel bores and ammunition based on identification of characteristics of ballistic elements of a shot]. *Zbirnyk naukovykh prats Natsionalnoi akademii Natsionalnoi hvardii Ukrainy.* Kharkiv : NA NGU, vol. 2 (32), pp. 5–11 [in Ukrainian].

3. Kriukov O. M., Mudryk V. H. (2013). *Perspektyvy eksperymentalnoho vyznachennia balistychnykh elementiv postrilu* [Prospects for

experimental determination of ballistic elements of a shot]. *Zbirnyk naukovykh prats Akademii vnutrishnikh viisk MVS Ukrainy*. Kharkiv : Akad. VV MVS Ukrainy, vol. 1 (21), pp. 21–24 [in Ukrainian].

4. Kriukov O. M., Aleksandrov O. A. (2009). *Shliakh pidvyshchennia tochnosti modeliuvannia vnutrishnobalistychnykh protsesiv* [Ways to improve the accuracy of modeling intraballistic processes]. *Zbirnyk naukovykh prats Akademii vnutrishnikh viisk MVS Ukrainy*. Kharkiv : Akad. VV MVS Ukrainy, vol. 1, pp. 11–14 [in Ukrainian].

5. Kriukov O. M., Mihura O. O. (2023). *Metod tekhnichnoho diahnostuvannia kanaliv stvoliv vohnepalnoi zbroi na osnovi vyznachennia ikh heometrychnykh kharakterystyk* [A method of technical diagnostics of firearm barrel channels based on determining their geometric characteristics]. *Chest i zakon*, no. 3 (86), pp. 101–109. DOI: https://doi.org/10.33405/2078-7480/2023/3/86/287124 [in Ukrainian].

6. *DSTU 2389:1994. Tekhnichne diahnostuvannia ta control tekhnichnoho stanu. Terminy ta vyznachennia* [Technical diagnostics and technical condition monitoring. Terms and definitions]. (1995, January 1). Kyiv : Derzhstandart Ukrainy [in Ukrainian].

7. *DSTU V 15.602:2022. Systema rozroblennia i postavlennia na vyrobnytstvo ozbroiennia ta viiskovoi tekhniky. Remont ozbroiennia ta viiskovoi tekhniky. Osnovni polozhennia. Klasyfikatsiia* [System of development and delivery of weapons and military equipment. Repair of weapons and military equipment. Basic provisions. Classification]. (2023, October 1). Kyiv : Derzhstandart Ukrainy [in Ukrainian].

8. Chernichenko Yu. M. (2016). *Osnovy orhanizatsii remontu striletskoi zbroi ta zasobiv blyzhnoho boiu* [Basics of organizing the repair of small arms and close combat weapons]. Kharkiv : NA NGU, part 1 [in Ukrainian].

9. Liapa M. M., Trofymenko P. Ye., Latin S. P. et al. (2013). *Dovidnyk ofitsera artyleriiskoho pidrozdilu* [Artillery Unit Officer's Handbook]. Sumy : SumDU [in Ukrainian].

10. Large Gun Video Borescope – Zistos Portable Video Systems. Retrieved from: https://zistos.com/large-bore-inspection/gbc/ (accessed 16 November 2024) [in English].

11. Borovyk O. V., Traskovetska L. M., Borovyk L. V. (2013). *Osoblyvosti otsinky efektyvnosti tekhnichnykh system za dopomohoiu hrafoanalitychnykh diahram* [Features of assessing the efficiency of technical systems using graph-analytical diagrams]. *Zbirnyk naukovykh prats Viiskovoho instytutu Kyivskoho natsionalnoho universytetu im. Tarasa Shevchenka*. Kyiv : VI KNU, vol. 43, pp. 10–16 [in Ukrainian].

12. Rahulin S. V., Syroizhka I. O. (2019). *Analiz pokaznykiv ta kryteriiv efektyvnosti systemy tekhnichnoi ekspluatatsii radioelektronnykh navihatsiinykh system* [Analysis of indicators and efficiency criteria of the technical operation system of radio electronic navigation systems]. *Systemy upravlinnia, navihatsii ta zviazku*. Poltava : NU "Poltavska politekhnika imeni Yuriia Kondratiuka", is. 5, no. 57, pp. 3–6 [in Ukrainian].

13. Yakovlev M. Y., Ryzhov Y. V., & Kravchenko T. A. (2012). *Utochnenyi kompleks pokaznykiv efektyvnosti metrolohichnoho obsluhovuvannia zasobiv zviazku Sukhoputnykh viisk* [The set of indicators of the effectiveness of metrological maintenance of communications equipment of the Ground Forces has been refined]. *Viiskovo-tekhnichnyi zbirnyk*, vol. 7, pp. 125–133. DOI:https://doi.org/10.33577/23124458.7.2012.125-133 [in Ukrainian].

14. Andersson K., Bang M., Marcus C., Persson B., Sturesson P. (2015). Military utility: A proposed concept to support decision-making. *Technology in society*, no. 43, pp. 23–32. DOI: https://doi.org/10.1016/j.techsoc.2015.07.001 [in English].

15. Facchinetti T., Citterio G. (2022). Application of the Overall Equipment Effectiveness to a Service Company. *IEEE Access*, no. 10, pp. 106613–106640. DOI: https://doi.org/10.1109/ACCESS.2022.3211266 [in English].

16. Lisbeth del Carmen Ng Corrales, María Pilar Lambán, Mario Enrique Hernandez Korner, Jesús Royo (2020). Overall Equipment Effectiveness: Systematic Literature Review and Overview of Different Approaches. *Applied Sciences*, no. 10 (18):6469, pp. 1–20. DOI: https://doi.org/10.3390/app10186469 [in English].

17. Understanding Effectiveness Evaluation: Definition, Benefits, and Best Practices. Retrieved from: http://surl.li/wdqipc (accessed 15 January 2025) [in English].

18. Kriukov O. M., Florin O. P. (2010). *Osnovy metrolohichnoho zabezpechennia* [Fundamentals of metrological support]. Kharkiv : KhNADU [in Ukrainian].

19. Kriukov O. M. (2012). *Metrolohichne zabezpechennia vyprobuvan i kontroliu parametriv ozbroiennia ta spetsialnoi tekhniky* [Metrological support for testing and controlling parameters of

weapons and special equipment]. Kharkiv : Akad. VV MVS Ukrainy [in Ukrainian].

20. Kriukov O. M., Mihura O. O. (2024). *Matematychne modeliuvannia ta analiz tekhnolohichnoi pokhybky vymiriuvannia heometrychnykh kharakterystyk kanaliv stvoliv vohnepalnoi zbroi* [Mathematical modeling and analysis of technological error of a means of measuring geometric characteristics of firearm barrel channels]. *Chest i zakon*, no. 1 (88), pp. 71–81. DOI: https://doi.org/10.33405/2078-7480/2024/1/88/302247 [in Ukrainian].

21. *Nakaz MVS Ukrainy "Pro zatverdzhennia Instruktsii pro poriadok katehoruvannia raketno-artyleriiskoho ozbroiennia" № 912* [Order of the Ministry of Internal Affairs of Ukraine "On approval of the Instruction on the procedure for categorization of missile and artillery weapons" activity no. 912]. (2017, November 8). Retrieved from: https://zakon.rada.gov.ua/laws/show/z1452-17#Text (accessed 16 January 2025) [in Ukrainian].

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ОЦІНЮВАННЯ ЕФЕКТИВНОСТІ ЗАСОБІВ ТЕХНІЧНОГО ДІАГНОСТУВАННЯ КАНАЛІВ СТВОЛІВ ВОГНЕПАЛЬНОЇ ЗБРОЇ

Запропоновано методичний підхід до кількісного оцінювання ефективності технічної діагностики каналів ствола вогнепальної зброї.

Висвітлено проблему, пов'язану з тим, що бракує такого виду технічного діагностування каналів стволів вогнепальної зброї, який би відповідав умовам сучасної війни. Розглянуто актуальність включення оперативної технічної діагностики у загальну систему заходів технічного діагностування озброєння і військової техніки. Запропоновано підхід до вибору відповідних засобів на основі оцінки їх ефективності.

Проаналізовано публікації, в яких розглядаються підходи до оцінювання ефективності технічних систем різного призначення, зокрема військового. Виявлено обмеження, які не дають змоги безпосередньо застосувати відомі результати досліджень для вирішення виявленої проблеми.

Запропоновано методичний підхід до оцінювання ефективності засобів технічного діагностування каналів стволів вогнепальної зброї, який передбачає введення часткових показників ефективності засобів технічного діагностування каналів ствола, а саме показників інформаційної продуктивності, напрацювання, ефективності (економічної ефективності). Одержано вирази для оцінювання таких показників для різних довільно вибраних комплексів засобів технічного діагностування.

Проведено кількісне оцінювання експлуатаційних показників кількох зразків традиційних і перспективних засобів технічного діагностування каналів стволів вітчизняного та зарубіжного виробництва. Установлено, що діагностичний комплекс на основі лазерного тріангуляційного засобу вимірювання геометричних характеристик каналу ствола характеризується сукупністю показників ефективності, що свідчить про його істотні переваги перед іншими засобами технічної діагностики.

Ключові слова: *канал ствола, ефективність засобів діагностування, технічне діагностування, технічний стан, дефект каналу ствола.*

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