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Metrological problems in the study of weapon systems

Maciej Dorczuk[1]*, Przemysław Wachowiak[2]

[1] Innovation, Research and Development Department,
Industrial Center of Optoelectronics, Warsaw, Poland,
e-mail: maciej.dorczuk@pcosa.com.pl

[2] Tracked Vehicles Research Laboratory,
The Military Institute of Armoured and Automotive Technology, Warsaw, Poland,
e-mail: przemyslaw.wachowiak@witpis.eu

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* Corresponding author

ABSTRACT

The article presents a summary of knowledge on the research and metrological problems related to the assessment of features and parameters of weapon systems. The basic metrological problem of research laboratories evaluating weapon systems is related to the constant search for new solutions, building unique test stands and seeking metrological equipment with higher accuracy classes than the equipment of military weapon systems which is subject to assessment. This is very difficult for the military technology to perform, even impossible in many cases. Significant research problems raised in the article also concern the study of descriptive and functional features which are not addressed by metrology. The article is an introduction to the commencement of works on the extension of metrology related to measurements and evaluation of the results obtained in research laboratories during the implementation of procedures related to the testing of descriptive and functional indicators. The information included in the article may be a source of knowledge for both the personnel of military laboratories and the personnel of civilian laboratories.

KEYWORDS

metrology, weapon systems, weapon metrology

Introduction

Metrology encompasses all aspects, both theoretical and practical, related to measurements, regardless of their uncertainty and the field of science and technology. It is used on a daily basis in civilian research laboratories, as well as specialized laboratories, conducting research on weapons and military equipment.

Wherever great importance is attached to the development of new technologies and production requires strict adherence to the technological regime, metrology plays a key role (Chyła, 2014). The law regulates the sphere of state responsibility for metrology due to its significant importance in the functioning of the economy (Ustawa z dnia 11 maja 2001 r. Prawo o miarach, 2013). A separate document regulates the tasks of metrology in the area of state defence and security (Rozporządzenie Ministra Gospodarki i Pracy z dnia 15 lutego 2005 r. w sprawie jednolitości miar i dokładności pomiarów związanych z obronnością i bezpieczeństwem państwa, 2005).

It does not matter whether a feature concerns a phenomenon, a body or a substance that can be distinguished qualitatively and quantified. Each measurement has the same purpose. Through each measurement, we obtain some information about the properties of the objects or phenomena subject to measurement (Zawad, 2002).

The information obtained when measuring the parameters of weapon systems has the same purpose of use as the results of the measurements of any objects.

The values obtained are used for (Zawad, 2002):

I. better understanding of objects or phenomena;

II. controlling various processes;

III. testing the compliance of product characteristics with the requirements imposed on these characteristics.

Feature III in relation to the parameters of weapon systems has the greatest importance in the research process described in this article. Ensuring the quality of the product, which, in the case under consideration, is a weapon system, is carried out by determining its parameters and comparing it with the requirements. As a result of this process, an outcome is produced, which is a conformity assessment of the product.

The conformity assessment of defence products, including weapon systems, covers the entirety of activities aimed at determining, directly or indirectly, whether the product under assessment meets the requirements of the contracting authority or not. Typical activities which are related to conformity assessment are tests (Harmoza, 2005), which also involve measurements in order to obtain test results. Checking a weapon system consists in establishing that this system has specific properties or does not have them, so checking the parameters consists in performing activities as part of a simple laboratory exercise. The goal of each task in the research laboratory is to measure certain quantities and then calculate on the basis of these measurement results the value of the tested quantity. The final result of such a test is the numerical result obtained, which defines a system parameter.

There are both measurable and non-measurable parameters when it comes to weapon systems. The result in the assessment of parameters are outcomes measurable as numerical values and non-measurable ones: descriptive results and functional results.

Descriptive results of the research constitute a subjective assessment, referring to an individual, hedonic experience. Only one person observes, reports, or describes them. In order to obtain an objective descriptive assessment, a closed-ended question system can be used, which will allow for obtaining comparable results, reduce the possibility of distorting the results by the group conducting the study and facilitate the interpretation of the final result.

In the descriptive assessment of the system regarding the assessment of the communication interface (user – weapon system) of the system under test, the method adopted by the company Keystone Strategy may be employed. This method assumes the adoption of six groups of factors, which can be assigned to the system under study in an analogous way.

Table. 1. Individual groups of criteria for assessing the communication interface (user – weapon system)

Knowledge	**Efficiency**	**Usability**	**Flexibility**	**Access to particular data sets**
– Ease of learning to operate it; – Intuitive operation; – Comfort of use.	– Efficient use of the interface; – Speed and reliability of the system.	– Simplicity of operation; – Ease of controlling.	– Flexibility in solving problems; – Impression of service.	– Time of access to information; – Easy access to information; – Access to the necessary data.

Source: the authors' own development based on (Rogalski, Niedźwiedziński, 2010).

Another method of subjective assessment that can be adopted is the method of Software Usability Measurement Inventory (SUMI). This method is used to assess the satisfaction and performance of the user using the application and is a tool commonly used in the software developers' community (Januszka, October 1-3, 2013). Thus, it can be used in the assessment of the communication interface implemented in the weapon system. The SUMI method assumes the adoption of assessment categories, which can be as follows for weapon systems:

– system efficiency;
– the quality of the system of explanations;
– ability to control;
– learning ability.

To each of the adopted assessment categories, a scale should be assigned. A commonly used Likert scale, which contains descriptive assessment variants, can be used. For the above-mentioned categories, the following assessment variants can be adopted:

– I definitely disagree;
– I rather disagree;
– I have no opinion;
– I rather agree;
– I definitely agree.

The efficiency category of the system allows for taking measurements of the perceptions of the armament operator in terms of convenience and simplicity in operating the system.

The quality category of the system of explanations allows for measuring the extent to which the system is helpful in solving operation problems.

The control capability category allows for measuring to what extent and with how much ease an armament operator is able to control the execution of tasks using the available functions and handling devices of the system.

The learning capability category allows for measuring the operator's perceptions in terms of intuitive system operation, ease of learning, speed of gaining efficiency and comfort of using the communication interface.

Examples of descriptive results are:

– the results of assessing the user documentation of the weapon system in terms of the sufficiency of the contents for proper operation;
– the results of assessing the application of technology minimizing the need for specialized metrological equipment;
– the results of assessing the application of technology guaranteeing operational safety.

Functional results are a very important group of results from the point of view of the possibility of using the weapon system in accordance with the intended purpose. Functionality is a set of product and/or system functions, defining the capability of providing functions to meet designated and assumed needs, when used in specific conditions (peace and war).

The set of functional assessments may include a subset of descriptive assessments. In order to perform a correct and reliable functional assessment of the weapon system, it is necessary to have documentation specifying the method of its use.

The evaluation of the possibility of performing the required function may produce three results:

– no capability to perform the required function;
– it is possible to perform the required function;
– it is possible to perform the required function with restrictions.

From the ordering party's point of view, the most satisfactory result is the second one. Of course, the third result does not disqualify the weapon system either. The function is feasible, but during its evaluation, problems may have occurred, e.g. with:

– lack of entries in the user manual;
– inaccuracy of the entries in the user manual regarding the functions of the system;
– insufficient detailing of the provisions in the user manual;
– lack of easy access (e.g. to manipulation devices triggering a given function);
– incomplete scope of implementation (e.g. the ability to perform the required function is to be available from the position of the operator and commander, and it is available only from the commander's).

Examples of the results from feasible functions are, for instance:

– the ability of the commander to take control of the weaponry;
– possibility of two-way ammunition supply;
– the ability to control drive units from the operator and commander's position;
– the possibility of firing programmable ammunition (without assessing the parameters of fire effectiveness).

Numerically measurable results are the most important group of results, which – it seems – should be the easiest to interpret in the assessment process. From a metrological point of view, of course, it is the simplest one.

Numerical results are the outcome of measurements taken: direct, indirect or complex, carried out as part of activities aimed at determining the value measured. The measurement consists in comparing (in order to determine the numerical ratio) the value measured *W* with a specific value *Wj* adopted on the basis of an agreement as a unit of measurement (Junghans Defence New Generation Fuzes to improve Munition Efficiency, November 21-23, 2017). Various quantities can be measured, such as length, angular inclination, force, time, speed, number of revolutions. Each of these quantities requires a separate unit appropriate for it. Sometimes, the numerical result achieved makes it impossible to present the assessment in the form of either "Meets" or "Does Not Meet" the requirement.

Figure 1 presents the method for interpreting the numerical result of a measurement and the uncertainty of the result, which is essential in the process of assessing the conformity of a product with the requirements. The first case demonstrates the fulfilment of the requirement, where stating the uncertainty of the result obtained is not compulsory. Cases: the second, third, and fourth cases show results that preclude making an assessment, and stating the uncertainty of measurement in these cases is compulsory. The fifth case is a result that does not meet the requirement, and providing measurement uncertainty is not compulsory.

Direct comparison of the quantities measured with a conventional unit is generally very challenging. For this reason, while conducting the measurement process, a group of technical resources known as measuring instruments is employed (Chwaleba et al., 2007).

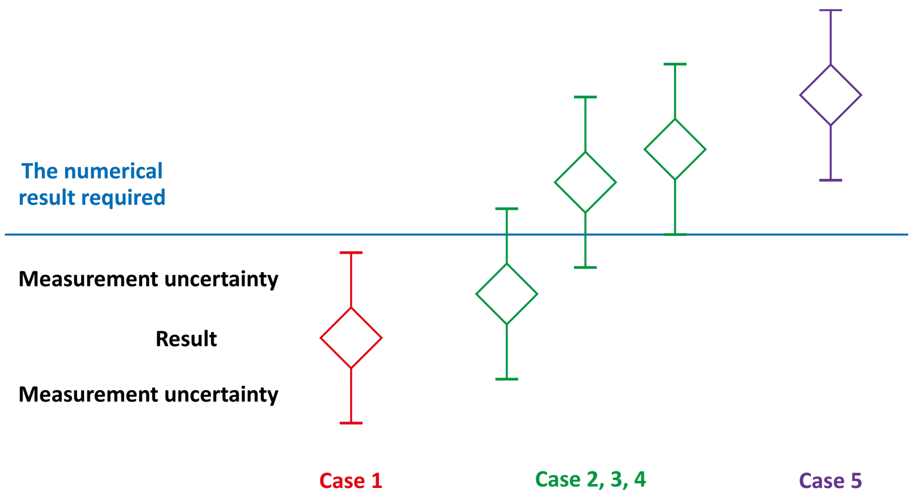

Fig. 1. The significance of uncertainty in the assessment of compliance with the specified limit values

Source: (Accreditation Committee of ILAC, 2009).

1. Metrology, weapon systems – real-life examples

In the process of assessing weapon systems, both standard and non-standard measuring instruments (metrological tools) are used. Due to the nature of the measurements, in many cases, the tools are designed and built from scratch. The metrological process requires: material measures, measuring instruments, measuring arrangements, and, in the case of the measurement of non-standard quantities, measurement systems.

Material measures are measuring instruments that reproduce units of measurement or their multiples.

The requirements for material measures include:

- constancy over time;
- simplicity of comparability;
- simplicity of reproduction;
- simplicity of application;
- high accuracy.

The fundamental parameters of a material measure are (Chwaleba et al., 2007):

- nominal value of the material measure;
- inaccuracy of the material measure's value;
- period of maintaining the inaccuracy of the material measure's value;
- conditions under which the material measurement's value and accuracy are preserved.

In military laboratories engaged in weaponry research, material measures primarily consist of loads equivalent to ammunition weight (Fig. 2) and loads equivalent to crew weight. During test firing with prototype systems, ammunition, which is extensively used for multiple shootings in order to explore the system and establish firing tables, is also considered a material measure.

Measuring instruments (Fig. 3) are basic measuring tools used to perform measurements in ballistic research laboratories. Depending on the method of relaying information to the observer, these measuring instruments are classified as analogue or digital ones. In the case of analogue instruments, the reading is taken from the indicator's position against a numerically marked scale. In digital instruments, the result is displayed in figures belonging to the decimal numeral system. Adopting a practical approach to measurements, it is important to skilfully differentiate between two key concepts: the resolution and the accuracy of a measuring instrument.

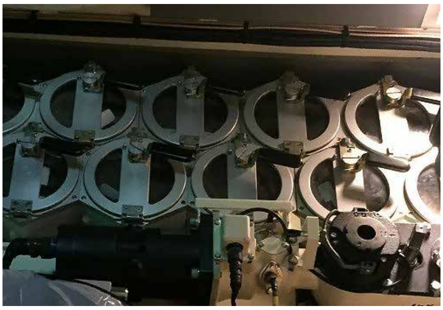

Fig. 2. Equivalent weight material measures for ammunition (mock-ups)

Source: the authors' own development.

Fig. 3. Measuring instrument for boresighting gunsights

Source: the authors' own development.

Given that direct measurement of the quantity *X* with a measuring instrument is not always feasible, it is possible to transform the measured quantity *X* (the input quantity) into a measurable quantity *Y* (the output quantity), preserving the information about the original quantity *X*. This process of converting *X* into *Y* is known as conversion. The instruments utilized for this purpose are measuring transducers.

Based on the type of signals in measurement processes, we can employ measuring transducers such as:

– Analogue transducer (A/A) – converting an analogue input signal into an analogue output signal (for instance, a voltage transducer changing high voltage to low voltage or a pressure transducer that converts pressure into the amperage of electrical current or voltage);
– Analogue-to-digital transducer (A/C) – converting an analogue input signal into a digital output signal (such as a voltage transducer which converts voltage into a digital signal in the binary code);
– Digital-to-analogue transducer (C/A) – a measurement transducer which operates in reverse to the analogue-to-digital (A/C) measurement transducer;
– Digital-to-digital transducer (C/C) – converting a digital input signal into a digital output signal (for instance, a measurement transducer which converts a signal from the binary code to the hexadecimal code).

Measuring systems are complete sets of measuring instruments and other additional devices designed to conduct specific measurements (Fita, n.d.). The measurement sensor is the main component of the measuring system.

Figures 4 and 5 show a basic measuring system constructed for testing the minimum train rate of armament using an indirect method. The quantities directly measured are: the radius of rotation and the linear speed.

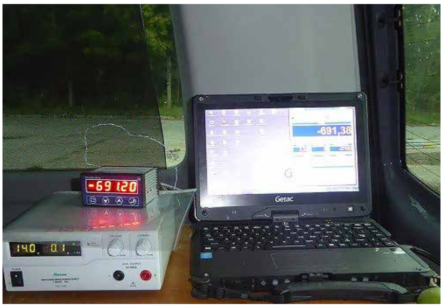

Fig. 4. TTL measurement transducer
Source: the authors' own development.

Fig. 5. A component of the measuring system along with a TTL measurement transducer, computer and power supply
Source: the authors' own development.

Measuring systems (measuring instruments) are cohesive assemblies of transducers and measuring instruments covered by common internal or external control. They form a singular organizational entity intended for collecting measurement data (quantity measured), facilitating its processing, conducting comparisons, performing calculations, and acquiring (recording) the results of these measurements.

Figure 6 shows a constructed measuring system, including a triggering path for working conditions and the path of recording of these conditions. This measurement stand is utilized for evaluating the function and numerical parameters during the operation of weapon systems.

2. Measurement methods of numerical parameters in weapon systems

The term "measurement method of numerical parameters" refers to a series of actions performed during the measurement process in order to determine the value of the quantity measured (the measurement result). Different methods are used depending on the required accuracy, conditions (under which the measurement is performed), the purpose of the measurement results, the nature of the quantity measured, etc. No methods are optimal in all respects; instead, there are methods specifically

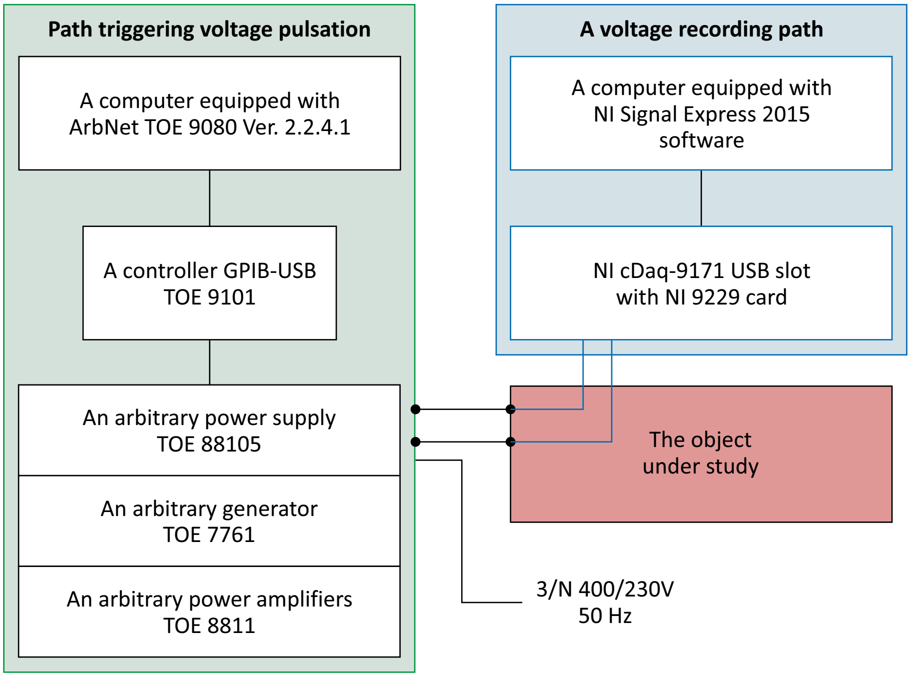

Fig. 6. Constructed measuring system, including a triggering path for working conditions and the path of recording these conditions

Source: the authors' own development.

tailored to measure quantities in a particular group, under certain conditions, etc. Based on the accuracy criterion, the same physical quantity can be measured with various methods. This leads to a large variety of measurement methods in practical applications, which complicates their classification. Meanwhile, the classification is advisable on account of the possibility of facilitating the right choice for them. Therefore, numerous principles are employed for classifying measurement methods, yet none have (so far) taken precedence (Dorczuk, 2018).

Measurement processes in military research laboratories consist of the following activities:

- identification of the weapon system properties which need to be examined;
- construction of a mathematical model of the system, i.e., one expressing its properties using mathematical formulas;
- establishment of a metrological model of the system, involving such a transformation of the mathematical-physical model which is described only by measurable quantities;

– selection of a measurement method;
– selection of metrological equipment for conducting measurements;
– performance of measurements;
– elaboration of measurement results.

Measurement methods are categorized basing on signal conversion into an analogue or digital one and basing on the approach to obtaining the quantity measured into direct, indirect, and complex methods.

In the direct measurement method, the results are obtained directly from the readings of the selected measuring instrument (e.g. measuring the mass and dimensions of a turreted system, the value of the current drawn by the elements of a turreted system equipment or assessing the maximum train rate of the armament).

In the indirect measurement method, the result is obtained by directly measuring other quantities and then calculating the amount desired from a known relationship between it and the quantities measured, established either experimentally or theoretically (e.g., measuring the minimum train rate of armament, measuring the acceleration of turret traverse and cannon elevation).

A complex measurement method is one in which the values of a number of quantities interconnected by a system of algebraic equations are determined directly or indirectly. Determining the values of the quantity measured requires solving the equation (e.g. measuring a magnification of observation and aiming devices).

2.1. Measurement errors and uncertainties

There are various types of errors in the process of assessing each weapon system for compliance with the requirements, ranging from punctuation errors (the weight of which is the lowest, but they can also change the meaning and content of a requirement completely), through interpretation errors, to measurement errors being possible to estimate – such an error is the difference between the measurement value and the true one.

A numeric value obtained as a result of measurement with a unit does not constitute complete information about the value measured. An important element is an assessment of the reliability of the result obtained consisting in an uncertainty estimation. The measurement uncertainty is a parameter associated with a measurement result, characterising the dispersion of values, which can be reasonably attributed to the value measured. Measurement uncertainty cannot be equated with the measurement error.

2.2. Interpretation errors of the entries

In this subchapter, it is appropriate to recall a claim by Josef Mitterer that the interpretation and argumentative techniques used in the field of Western philosophy and in our culture's everyday thinking are inevitably based on the so-called "dualistic way of speaking". The dualistic way of speaking divides discourses into this side and the other one, revealing, next to the area of the discourse, the sphere of essentialised, objects of description defined a priori (Bińczyk, 2004).

If the dualistic way of speaking divides discourses, and speech is transferred onto "paper", we deal with interpretation errors of the regulations contained in the requirements. We cannot avoid it. The best way out of this situation is to create records of requirements by a team composed of people familiar with the subject and ones from outside the sector. People from outside the sector should interpret a record in a manner expected by specialists. Another way out of the situation is the contact between the person analysing and the author, which is often difficult in the evaluation phase, which is conducted after a long period of time after the requirements were created.

In summary, there are no perfect schemes that will completely exclude interpretation errors.

2.3. Errors and uncertainty of direct measurements

Suppose that a measured physical quantity X is determined directly and for this purpose a series of n measurements was performed X_1, X_2, ... X_N. If among the measurements made there is a value or values deviating significantly from the other ones, these are gross errors. They should be omitted and must not be taken into account in further calculations. The causes of gross errors are most frequently ones of a person performing a measurement (e.g. reading a value of 234 A instead of 23.4 A) or temporary disruption of measurement conditions. A decision to consider a measurement to be a gross error depends on the person performing it and is usually made at the stage of interpreting the results. In the absence of interpretation possibilities, the performer of a test should carry out a statistical significance test, which is the one for detecting a gross error. Statistical tests are an important link in the statistical analysis of measurement results. They allow for detecting unfavourable trends in measurements and to correctly interpret the results obtained. The starting point in significance tests is the adoption of the null hypothesis, which assumes that the observed difference is not significant with a given probability – that is, it is caused solely by the occurrence of random errors. The null hypothesis is adopted with an alternative one, which assumes that the observed difference is significant at a given confidence level – i.e. it is caused not only by random errors. The task of the test is to determine which of the hypotheses is true.

Checking the series of measurements for a gross error should be routine. The Dixon's test and Grubbs' tests can be used for this purpose.

The Dixon's test – before performing the test (verification of hypotheses), a set of experimental results should be arranged according to increasing values $X_1 \leq X_2 \leq X_3 \leq ... \leq X_N$ (where: $X_1 = X_{MIN}$ $X_N = X_{MAX}$). A gross error may burden the largest X_{MAX} or the smallest X_{MIN} value of the result in the sample. For the results X_{MAX} and X_{MIN}, the parameters Q_{MAX} and Q_{MIN} are calculated respectively. The Dixon's test is based on the dispersion of measurement results.

$$Q_{MIN} = \frac{X_2 - X_{MIN}}{X_{MAX} - X_{MIN}} \qquad Q_{MAX} = \frac{X_{MAX} - X_{MAX-1}}{X_{MAX} - X_{MIN}} \tag{1}$$

After performing parameter calculations, we check whether the value of the parameter Q_{MIN} (for: $Q_{MIN} > Q_{MAX}$) or Q_{MAX} (for: $Q_{MAX} > Q_{MIN}$) obtained for the test results is lower or higher than the relevant value from the table of critical Q values (given in the table of critical values of the Dixon's test). If the value tested is higher than the value from the table of critical values, then the suspicious result is affected with a gross error, and we can reject it.

The Grubbs' test – before performing the test (verification of hypotheses), the set of experimental results should be arranged in the order of increasing values $X_1 \leq X_2 \leq X_3 \leq ... \leq X_N$ (where: $X_1 = X_{MIN}$ $X_N = X_{MAX}$). A gross error may burden the largest X_{MAX} or the smallest X_{MIN} value of the result in the sample. For the results X_{MAX} and X_{MIN}, the parameters T_{MAX} and T_{MIN} are calculated respectively. The Grubbs' test is based on the deviation of a suspicious result from the arithmetic mean of a series of measurements, measured against a standard deviation of that series.

$$T_{MIN} = \frac{\bar{X} - X_{MIN}}{\sigma} \qquad T_{MAX} = \frac{X_{MAX} - \bar{X}}{\sigma} \tag{2}$$

σ – standard deviation

The parameter with a higher value is then compared with the critical parameter of the Grubbs' test (given in the table of critical values of the Grubbs' test) corresponding to the number of series of measurements (statistical sample) and the selected level of confidence. If an experimental value is greater than a critical value, then a suspicious result is affected with a gross error and can be rejected with a given level of confidence.

Performing a freely chosen test allows you to reject gross errors and perform calculations of type A, B and C standard uncertainty.

Calculations of type A direct measurement uncertainty are performed if we have a series of repeated direct measurements.

$$U(A) = \frac{s(x)}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{3}$$

$s(x)$ – standard deviation

We calculate the type B uncertainty of a direct measurement if we have a standalone direct measurement result and characteristics of an instrument used (scientific study, manufacturer's declaration, certificate of accuracy, calibration certificate, etc.).

$$U(B) = \frac{\Delta x}{\sqrt{3}} = \sqrt{\frac{(\Delta x)^2}{3}} \tag{4}$$

Δx – half of the x variability range (half of the unit, instrument resolution, limit error, indication error, tolerance etc.)

We calculate type C uncertainty of a direct measurement if we have determined type A and B uncertainties.

$$U(C) = \sqrt{U(A)^2 + U(B)^2} = \sqrt{\left[\frac{s(x)}{\sqrt{n}}\right]^2 + \left[\frac{\Delta x}{\sqrt{3}}\right]^2} \tag{5}$$

An example of a direct measurement may be the measurement of the maximum train rate of the armament in a turreted system. A measuring instrument that can be used for this purpose is, for example, an optical fibre gyroscope with the parameters: $ARW \leq 0.7$ °/s/h/Hz^0.5 and $BS \leq$ 0.05 °/s/h. When measuring the maximum train rate of armament, which, for example, lasts approx. 10 s, and the measurement frequency is 100 Hz, after making calculations, the value of Δx will be $4.7 \cdot 10^{-4}$ °/s. Inserting this value to relationship 3, we obtain $U(B) = 2.7 \cdot 10^{-4}$ °/s.

At maximum train rates of armament ranging from 20 °/s for cannons and tank weapon systems up to 240 °/s for 7.62 mm calibre weapon systems, the estimation of uncertainty with the type B method can be omitted.

NOTE!

The most common mistakes made by research staff in direct measurements are errors related to an incorrect selection of the measuring ranges of devices used and improper calibration of the instruments.

In terms of improper selection of the measuring range to a quantity measured, an example may be the measurement of power consumption by the elements of turreted system equipment. The measurement of an amperage value of 10 A with a clamp meter (Dietz clamps), the measuring range of which, declared by the manufacturer, is from 20 A to 2000 A, is unjustified and in this case a measuring device with a scale in the range of the value measured should be selected.

Improper calibration of the instruments concerns measurements of the value measured in the ranges in which no calibration has been performed. An example may also be furnished by the cited clamp meter with a range from 20 A to 2000 A, the calibration of which was made in points, e.g. 1000, 1500 and 2000 A, and the measurement is performed in the range of 100 A.

These two cases make it impossible to make a correct error balance and estimate measurement uncertainty.

2.4. Errors and uncertainty of indirect measurements

We calculate the type A uncertainty of an indirect measurement in the same way as in the case of a direct measurement, when we have a series of repeated direct measurements of the quantities measured, e.g. *x* and *y*. Of course, we can have several quantities measured. Using the relationship 3, the type A uncertainty of *x* and *y* will be determined from the following formulas.

$$U(A_x) = \frac{s(x)}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{6}$$

$$U(A_y) = \frac{s(y)}{\sqrt{n}} = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(y_i - \bar{y})^2} \tag{7}$$

We also calculate the type B uncertainty of indirect measurement in the same way as in the case of direct measurements, using the characteristics of the instruments used (scientific study, manufacturer's declaration, certificate of accuracy, calibration certificate, etc.).

$$U(B_x) = \frac{\Delta x}{\sqrt{3}} = \sqrt{\frac{(\Delta x)^2}{3}} \tag{8}$$

$$U(B_y) = \frac{\Delta y}{\sqrt{3}} = \sqrt{\frac{(\Delta y)^2}{3}} \tag{9}$$

Calculations of the type C uncertainty of direct measurements for the intermediate values *x* and *y* being determined, are performed in accordance with the relationship 5.

$$U(C_x) = \sqrt{U(A_x)^2 + U(B_x)^2} = \sqrt{\left[\frac{s(x)}{\sqrt{n}}\right]^2 + \left[\frac{\Delta x}{\sqrt{3}}\right]^2} \tag{10}$$

$$U(C_y) = \sqrt{U(A_y)^2 + U(B_y)^2} = \sqrt{\left[\frac{s(y)}{\sqrt{n}}\right]^2 + \left[\frac{\Delta y}{\sqrt{3}}\right]^2} \tag{11}$$

In the case of measurements using the direct method, the value of the quantity is determined on the basis of the values of other quantities measured directly (e.g. *x* and *y*). If the determined value *Z* is derived from the relationship (12) and when direct measurement errors are known, then after expanding *Z* (*x*, *y*) into the Taylor series (13) and omitting the components of the higher orders, we will obtain the difference sought after ΔZ (7.14).

$$Z(x, y) = x \cdot y \tag{12}$$

$$Z = Z_0 + \left(\frac{\partial Z}{\partial x}\right) \cdot \Delta x + \left(\frac{\partial Z}{\partial y}\right) \cdot \Delta y \tag{13}$$

$$\Delta Z = Z - Z_0 = \left(\frac{\partial Z}{\partial x}\right) \cdot \Delta x + \left(\frac{\partial Z}{\partial y}\right) \cdot \Delta y \tag{14}$$

An example of indirect measurement may be furnished the measurement of the minimum train rate of the armament in a turreted system. Measuring instruments that can be used for this purpose are, for example, a tape measure and a linear displacement sensor. The value of the minimum armament train rate will be determined by formula 15. Of course, the value of this speed can be read directly from the weapon system encoders, but we consciously eliminate the error entered by the operator. From the point of view of the capabilities of the weapon system, it will always occur in combat conditions and should be included in the research method. The use of external measuring devices makes it possible to determine it.

$$\omega_{min} = \frac{l}{R \cdot t} \tag{15}$$

l – distance of the extended line,
R – rotation radius (of the tower or cannon),
t – rotation time.

To estimate the total composite uncertainty, it is necessary to estimate composite uncertainties $U(C_l)$, $U(C_R)$, $U(C_t)$. Using the relationship 14, $\Delta\omega_{min}$ will be equal to:

$$\Delta\omega_{min} = \sqrt{\left(\frac{1}{t \cdot \bar{R}}\right)^2 \cdot (dl)^2 + \left(\frac{\bar{l}}{t \cdot \bar{R}^2}\right)^2 \cdot (dR)^2 + \left(\frac{\bar{l}}{t^2 \cdot \bar{R}}\right)^2 \cdot (dt)^2} \tag{16}$$

NOTE!

The minimum angular velocity of the weapon is important for the accuracy of the fire and the ability to track the target. In the case of the angular velocity of the target which we intend to fire at, below the angular velocity achievable by the system, we will have a problem with the stable maintenance of the target in the “sights” (Dorczuk et al., 2014). Attention should also be paid to the fact that from a practical point of view the operator is not interested in the minimum speed achievable by the drives used. The operator’s station is equipped with a manipulator to guide the weapons, so we should use at least three independent operators to determine the minimum angular velocity of the weapon, who will make no more than three attempts to train the weapon onto the target at the minimum speed. Experience shows that the greatest values in the uncertainty budget are type A uncertainties related to the measurement of l and R quantities. This does not indicate a poorly selected research method, but it provides a result enabling the assessment of the system as: operator – weapon system.

When discussing the minimum armament train rates, it is possible to mention how important a parameter is also the minimum angle of fire. Especially in the case of the installation of a weapon system on a vehicle, which will ultimately be used to conduct fire in urbanized areas. The minimum distance over which it will be possible to fire from a remotely controlled turreted system having a structural minimum achievable angle is shown in Figure 7.

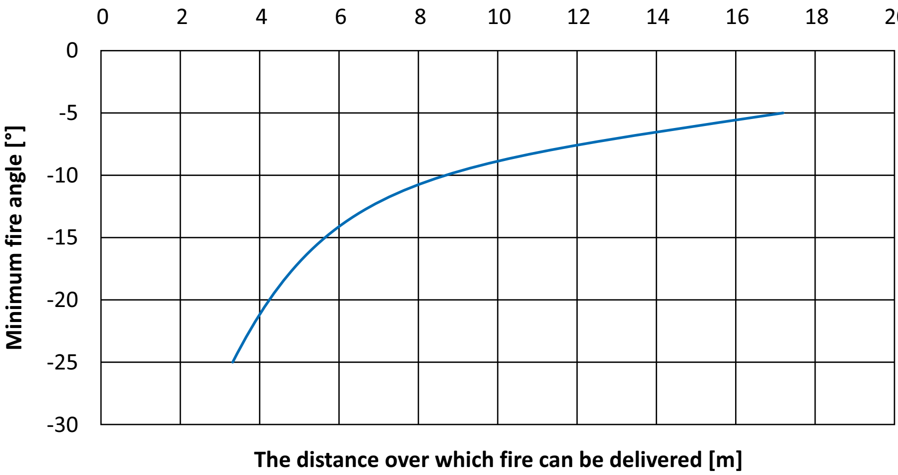

Fig. 7. Comparison of the distance over which it is possible to fire a shot when installing a remote-controlled system on a vehicle (assumed height of the system installation – 3 m)

Source: (Dorczuk et al., 2014).

Analysing the unfavourable conditions of fire delivery, if a vehicle is equipped with an armament system having a minimum angle of -5° and in the case of tilting the vehicle by an angle, e.g. 3°, it can be stated that the minimum distance over which the operator will be able to conduct fire is 42 m. Therefore, the use of the weapon system with such a construction parameter on a vehicle intended for operation in urbanized terrain is unjustified.

Conclusions

Many years of work in a military research laboratory, a wide area of research work carried out, many innovative procedures and research methods allowed for presenting a summary of knowledge in this article.

The assessment of parameters, features or indicators of weapon systems is not always obvious and simple. Problems related to the selection of equipment, error assessment and estimation of uncertainty are encountered practically at every stage of the assessment of weapon systems.

The knowledge presented in this article may be useful not only for the personnel of military research laboratories, but also for the personnel of civilian laboratories.

Continuous development of technology in the military area requires continuous self-education and search for solutions to properly solve research problems, which in many cases turns out to be impossible to implement. The devices used to supervise and monitor the operation of weapon systems are of the highest accuracy classes. The evaluation of the operating parameters of these devices should be carried out using devices having an accuracy class one level higher, which is simply not feasible for experienced research personnel, who know the construction of the weapon system and the metrological capabilities of laboratories.

Searching for alternative methods, building unique research stations, continuous development of research methods and procedures are the daily problems and challenges of the personnel of laboratories assessing the parameters of weapon systems.

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Problemy metrologiczne w badaniach systemów uzbrojenia

STRESZCZENIE W artykule zaprezentowano streszczenie wiedzy dotyczącej problemów badawczych i metrologicznych dotyczących oceny cech i parametrów systemów uzbrojenia. Podstawowy problem metrologiczny laboratoriów badawczych, oceniających systemy uzbrojenia, związany jest z ciągłym poszukiwaniem nowych rozwiązań, budowaniem unikatowych stanowisk badawczych, szukaniem aparatury metrologicznej o wyższych klasach dokładności niż oceniane wyposażanie wojskowych systemów uzbrojenia. Jest to w technologii militarnej bardzo trudne do wykonania, wręcz w wielu przypadkach niemożliwe. Istotne problemy badawcze poruszone w artykule dotyczą także badania cech opisowych i funkcjonalnych, których metrologia nie porusza. Artykuł stanowi pewien wstęp do rozpoczęcia prac nad rozszerzeniem metrologii związanej z pomiarami i oceną wyników uzyskanych w laboratoriach badawczych podczas realizacji procedur związanych z badaniami wskaźników opisowych i funkcjonalnych. Informacje zawarta w artykule mogą być źródłem wiedzy zarówno dla personelu laboratoriów wojskowych, jak również personelu laboratoriów cywilnych.

SŁOWA KLUCZOWE metrologia, systemy uzbrojenia, metrologia uzbrojenia

Biographical note

Lt. Col. Res. Ph.D. Eng. Maciej Dorczuk – doctor of technical sciences, graduate of the Military University of Technology, faculties: Armament and Aviation and Electronics, chief specialist for product validation at Przemysłowe Centrum Optoelektroniki S.A. The main area of his interest is the assessment of the operating parameters of unmanned and manned on-board weapons modules. Author of innovative research methods implemented by SPW and a researcher performing studies of weapons and military equipment. Number of publications: 22, monographs 1. Co-organizer of the conference "Eksplobalis 2020", "Rozwój, eksploatacja i modernizacja sprzętu wojskowego – problemy i rozwiązania (Development, exploitation and modernization of military equipment – problems and solutions)". Distinctions: diploma of the Director of WITU at the 18th International Scientific and Technical Conference "Uzbrojenie (Armaments)" 2011, Pułtusk.

Lt. M.Sc. Eng. Przemysław Wachowiak – a graduate of the Military University of Technology, Faculty of Mechanical Engineering and the Academy of National Defence, Faculty of Management and Command. Head of the Caterpillar Research Laboratory at the Military Institute of Armoured and Automotive Technology in Sulejówek. The main area of his interest is the operation of military motor vehicles. Researcher performing numerous tests of military equipment. Number of publications: 8.

ORCID

Maciej Dorczuk https://orcid.org/0000-0003-2749-8411

Przemysław Wachowiak https://orcid.org/0000-0003-2336-7844

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Author contributions

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Ethical statement

The research complies with all national and international ethical requirements.