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THE ESTIMATION OF THE EXPERIMENTAL INVESTIGATION RESULTS OF THE POWDER GAS PRESSURE SENSOR IN BARRELS OF SMALL ARMS

The need to develop methods of pressure sensor experimental investigation has been proved. The method of experimental studies gauge pressure of powder gases in the barrel firearms, which allows checking the adequacy of the mathematical model of pressure sensor, has been proposed.

Key words: *techniques for experimental research, pressure sensor, ballistic device.*

The problem setting

Technical characteristics of new small arms, small arms are taken from the manufacturers, the technical condition of small arms that are in operation or taken from long-term storage by groups and units of the Interior Troops of Internal Affairs of MIA of Ukraine are determined by measuring of the parameters internal ballistic processes. These are the initial velocity and the nature of change of the pressure in the barrel. For most initial velocity measurements it is using foreign equipment with known metrological characteristics that meet government standards. But for specialized means of pressure measurement government standards provide only static characteristics definitions.

However, as mentioned in [1, 2], for more detail information about internal ballistic processes it must take into account the dynamic characteristics of the pressure sensor. Internal ballistic processes can be investigated by mathematical modeling of the pressure sensor in the barrel of small arm [3].

The confirmation of the results of the pressure sensor mathematical modeling requires a series of experimental investigations. During the investigation it is important to compare the results of the pressure curve measurement in the small arm barrel with the results of mathematical modeling.

So there is a need to systematize and to combine to the method such processes as an experimental investigation of pressure measuring sensor, for gathering information, sufficient to verify the adequacy of the theoretical calculations of pressure sensor dynamic characteristics and statistical analysis of the results of experimental measurement.

The most well-known analytical methods [1 – 3] can help you find the variation of pressure with time, most fully considered most important parameters in the least number of assumptions in the method of prof. N.F. Drozdov using mathematical tools, which underlies this method can avoid the phase of construction and use of special tables and get a mathematical model of the input signal in an analytical form.

The purpose of the article is the development of the methods for experimental investigation of the powder gases pressure sensor in the barrel of small arms.

The main materials

The method for experimental investigation is divided into the following periods:

1. The theoretical calculations of pressure for small arms and ammunition with previously known sets of parameters. The result of theoretical calculations is a set of theoretical curves of the output pressure sensor signal of the powder gases in the barrel obtained by the mathematical modeling of the input signal and pressure sensor for well-known sets of parameters of the small arms, ammunition, physical and geometrical parameters of the pressure sensor.

2. Preparation for obtaining experimental curves of pressure during firing is including selecting the required number and types of bullets, measuring their parameters, preparation of the pressure sensor and other equipment. Bullets parameters are bullet weight, powder weight and type, shape of grains of gunpowder. Under the preparation of the pressure sensor it is understood fixing it on arm and measuring its geometric dimensions. Preparation of the test equipment includes connection a pressure sensor to computing device or an analog-to-digital converter.

3. Getting an experimental curve of pressure while firing. During the shooting by using small arm with pressure sensor, analog-digital converter or computing device fixes curve of pressure. Then the experiment is repeated a number of times to eliminate the influence of random factors.

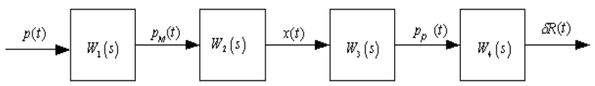
4. Handling of en experimental data and theoretical calculations of pressure curves for a given set of parameters involves using the experimental data analysis methods

to the experimentally obtained output signal, with the results of curve pressure mathematical modeling.

Let's review these periods more details. Each sample of small arms and ammunition is characterized by a combination of physical and geometrical parameters. Mathematical modeling of pressure curves base on the famous mathematical model of pressure sensor input signal [4] and the mathematical model of pressure sensor [3].

As a basis it is taken the known construction of pressure sensor [5], which consists of a body, cavity, filled with heat-insulating liquid, in which it is placed tensoresistive sensing element. In the body 1 it is made a channel, throw which pressure is acting on the membrane. Membrane is fixed to the body of pressure sensor by clamping nut and provides pressure transmission throw the heat-insulating liquid to the tensoresistive sensing elements.

According to the well-known principles of the pressure sensor [4] its construction can be represented as a serial connection of several elementary transducers, whose properties are determined by their transfer function $W_i(s)$ (pic. 1).



Pic. 1. Structural diagram the pressure

On pic. 1 there are input variable of the elementary transducer is pressure of powder gases $p(t)$, output $p_м(t)$ – is the pressure of gas layer that contact with the membrane; $W_2(s)$ – membrane pressure sensor. The output signal is the displacement of the center point of the membrane $x(t)$ is caused by the pressure of the gas layer in contact with the membrane; $W_3(s)$ – heat-insulating liquid that fills the sensor. Output signal is the liquid pressure $p_p(t)$ at the gauges; $W_4(s)$ – tensoresistive sensing elements. Output signal is the relative change of the electrical resistance $\delta R(t)$, caused by the liquid pressure.

The mathematical model of the pressure sensor is a sequence of elementary transducers, which are determined by physical and geometrical parameters of the pressure sensor. Mathematical model of the pressure sensor is the multiplication of the transfer functions of the elementary converters.

$$W(s) = e^{-\tau_з s}\frac{1}{T_н s+1}\frac{k_м}{T_м^2 s^2+2\xi_м T_м s+1}\times$$
$$\times\frac{k_p}{T_p^2 s^2+2\xi_p T_p s+1}K, \qquad (1)$$

where $\tau_з$ – delay time of pressure spreading in the first elementary transducers, which depends on the geometric sizes and the modulus of elasticity of the material of receiving channel and the characteristics of the gas substance that fills it; $k_м$, $T_м$, $\xi_м$ – transfer coefficient, time constant and damping parameter of the membrane, which are determined by its geometrical size, weight, hardness, modulus of elasticity, coefficient of internal friction and Poisson's ratio of the material; k_p, T_p, ξ_p – transfer coefficient, time constant and damping parameter of the liquid, depending on its ability to compress, kinematic viscosity and density, and geometrical dimensions cavity; K – tensoresistive coefficient of the sensing elements material.

Using the transfer function of the pressure sensor with known parameters it is obtained the output signal of pressure sensor based on the existing mathematical model of the input signal – the pressure changes within time in the barrel, taking into account bullets charging and barrels parameters [4].

Model of input sensor is based on solving equations, relating the pressure $p(x)$ in the barrel, the time t since the beginning of the bullet movement until it reached the x coordinate within the barrel and velocity $v(x)$:

$$\begin{cases} p(x) = \dfrac{\eta\cdot f}{s}\dfrac{\psi(x)-(B\cdot\theta/2)\cdot x^2}{l_ф + x}; \\ v(x) = v_{пр}\sqrt{1-\left((x+l_к)/(x+l_п)\right)^{\theta}\cdot\left(1-v_м^2/v_{зв}^2\right)}; \\ t = \dfrac{2x}{v(x)}+\displaystyle\int_o^x \dfrac{dy}{v(y)}. \end{cases} \qquad (2)$$

where η – mass of dust; f – dust force; s – cross sectional area of the barrel; $\psi(x)$ – the relative amount of powder that was burned; B – parameter Drozdova; θ – gas constant; l_φ – reduced free volume of chamber; $\upsilon_{пр}$, υ_k – reduced and maximum speed balls; l_x – the length of the chamber; $l_к$ – the length of the barrel.

The solution of system (2) in the form of dependence of pressure in the barrel and the time since the beginning bullet movement can be obtained as an analytically as numerically. Since the solution of (2) is subject for the further integration, it is appropriate to represent it as a polynomial:

$$p(t) = a_0 + a_1\cdot t + a_1\cdot t^2 + ... + a_{n-1}\cdot t^{n-1}, \qquad (3)$$

where n – the number of system solutions (2); $a_0, a_1, a_2, ..., a_{n-1}$ – coefficients, are depended on the parameters of bullet, powder and geometric parameters of the barrels channel.

Theoretical pressure curve is calculated by mathematical model of input signal and using data about the small arm. Then it is obtained experimental data about pressure curves in the barrel during measurement of pressure sensor output signal. The theoretical pressure curve for calculation with the experimental curves of pressure is obtained using a mathematical model of pressure sensor.

Processing of experimental data is as follows. First it is calculated the relative deviation δ_{exp} of each instantaneous value of the theoretical pressure curve $p(i)$ with the experimentally obtained pressure curve according to the expression (4)

$$\delta_{exp}(i) = \frac{|p_{exp}(i) - p(i)|}{p(i)} \cdot 100\,\%, \qquad (4)$$

where i – the point number.

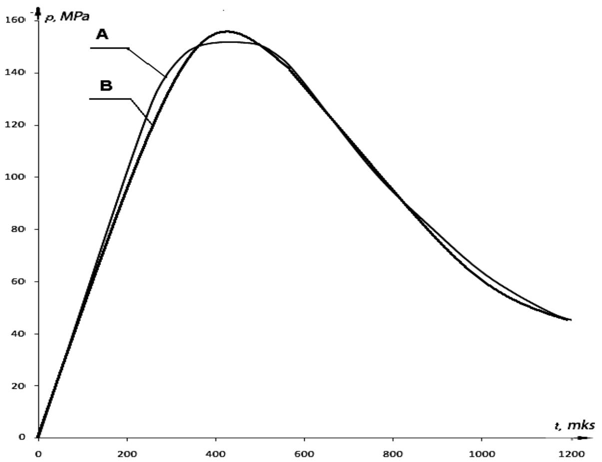
Than it is calculated the average value of the relative deviation $\bar{\delta}_{exp}$ according to the expression

$$\bar{\delta}_{exp} = \frac{1}{N}\sum_{i=1}^{N}\delta_{exp}(i). \qquad (5)$$

It is estimated average quadratic deviation σ_{exp} of the maximum relative deviation $\delta_{exp}(i)$ in accordance with the expression (6) [6].

$$\sigma_{exp} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(\delta_{exp}(i) - \bar{\delta}_{exp}\right)^2}. \qquad (6)$$

On the pic. 2 there is curve that approximates all experimental pressure curves, B – theoretically calculated pressure curve p(t) for a certain set of bullet parameters.



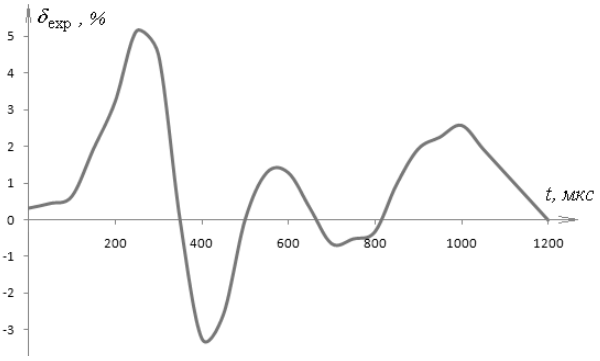
Pic. 2. The result of the theoretical calculation of the pressure curve p(t) for a certain set of parameters in comparison with the experimental results

By changing types of ammunition that differ in powder charge weight, weight of a cartridge and powder type it is obtained an experimental pressure curves. As an example, there are results of the experimental curves comparison with the mathematical modeling of theoretical curves for five different sets of parameters for the hunting ammunition of 12 caliber (pic. 2).

Maximum relative deviations of each instantaneous value in pressure curve for most typical sets of parameters are shown in pic. 3.

The average value of experimental pressure relative deviation is calculated according to the expression (3) $\bar{\delta}_{exp} = 1{,}59\,\%$.

Analysis of the results shows that for all combinations of parameters the duration of transient processes for experimentally obtained curves of pressure and theoretical curves are coincide up to 6%. For each pair of pressure curves average value of maximum relative deviation of $\bar{\delta}_{exp}$ is up to 5.5%.



Pic 3. The relative deviation δ_{exp} of the experimental and theoretical pressure

For the problems of gunpowder dynamics discrepancy of the experimental results to the results of mathematical modeling of 15...10% is acceptable [6].

The conclusion

Presented method allows estimating conformity of the results of pressure sensor experimental investigations to the results of its mathematical modeling. It also allows you to analyze these results for sets of parameters without performing multiple repetitions testing results for each set of parameters.

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ОЦІНЮВАННЯ РЕЗУЛЬТАТІВ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ДАТЧИКА ТИСКУ ПОРОХОВИХ ГАЗІВ У КАНАЛАХ СТВОЛІВ СТРІЛЕЦЬКОЇ ЗБРОЇ

О.А. Александров, С.О. Півоваров, І.В. Костенко

Обґрунтовано потребу розроблення методики експериментального дослідження датчика тиску порохових газів у каналах стволів стрілецької зброї. Запропоновано методику проведення експериментальних досліджень датчика тиску порохових газів у каналах стволів стрілецької зброї, що дозволяє перевірити адекватність математичної моделі датчика тиску.

Ключові слова: *методи для експериментального дослідження, впливовий датчик, балістичний пристрій.*

ОЦЕНКА РЕЗУЛЬТАТОВ ПРОВЕДЕНИЯ ЭКСПЕРИМЕНТАЛЬНЫХ ИССЛЕДОВАНИЙ ДАТЧИКА ДАВЛЕНИЯ ПОРОХОВЫХ ГАЗОВ В КАНАЛАХ СТВОЛОВ СТРЕЛКОВОГО ОРУЖИЯ

А.А. Александров, С.А. Пивоваров, И.В. Костенко

Проведена оценка влияния температуры пороховых газов и электрического тока источника питания на исходящий сигнал тензорезисторного датчика измерения давления в каналах стволов стрелкового оружия. Получена математическая модель температурной погрешности. Предложен способ уменьшения влияния температурной погрешности на результат измерения давления.

Ключевые слова: *методы для экспериментального исследования, влиятельный датчик, баллистическое устройство.*