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EXPERIMENTAL DETERMINATION OF THE ARTILLERY GUN BREAKING PARTS OF THE BRAKE BASIC PARAMETERS AFFECTING ITS CHARACTERISTICS

Approach proposing in the article allow the authors to carry out an experimental complex advancement of the hydrodynamic working process of the brake of separate parts with one-hour warning of changes in dynamic and cinematic characteristics to the center of the mass of visible parts. There are two ways of controlling the characteristics of the brake – the change of the total effective passive overflow of the calibrating jets, the slot in the moderator's valve, or the power of the pulse. On the basis of the method of small ones, the authors proposed the experimental idea of the boundary permissible views of the characteristics of the brake formation, as well as the refinement of the approach to updating the characteristics of the brake of the visible parts.

Keywords: internal chamber processes of artillery systems, hydraulic brake, breaking part.

STATEMENT OF THE PROBLEM

The need for experimental research in the study of the main parameters of the brake of the recoil parts of an artillery gun was dictated, first of all, by the need to confirm the reliability of the new results obtained in theoretical studies. Note that all mathematical models of workflows given by the authors use experimental coefficients [1, 2] of multiparameter relationships, which cannot be distinguished separately. For example $\Sigma\mu_i f_i$, where μ is the efflux coefficient, which depends on the pressure, shape and dimensions of the section f_i. In the course of theoretical studies, the values were selected according to well-known literary sources [1 – 3]. The results of theoretical studies of the working process of the brake of the recoiling parts of the tool give grounds to formulate the requirements for the developed general experimental technique.

Requirements for the general methodology for experimental research on the brakes of the recoiling parts of the tool (spindle type).

Experimental studies of the brakes of the recoiling parts of the tool should provide for the solution of the following tasks: the development of a general methodology, the development of a circuit of measuring circuits with sensitive elements, the choice of instrumentation and recording equipment, a methodology for processing experimental data and evaluating errors. When constructing a general methodology, all measured parameters should be classified into groups [4, 5], namely:

- mechanical parameters: movement, speed and acceleration of the brake piston, moderator valve, compensator piston (9 parameters);
- hydrodynamic parameters: pressure and rate of pressure change in the brake volumes of the retractable parts (5 volumes – 10 parameters);
- heat engineering parameters: temperature of the inner and outer surfaces of the cylinder, ambient temperature (3 parameters);
- consumption characteristics: the flow rate of liquid through the calibration sections and the integral flow rate of the liquid through the calibration sections in one cycle – along the spindle section and along the cylinder slots (4 parameters).

The general methodology should provide for taking into account changes in the thermophysical parameters of the liquid depending on the rate of fire. Separate registration of changes μ, v, ρ, Z is not provided, since they are included in the equations of mathematical models in small deviations.

The characteristic features of the general test procedure should be the following: reproduction of single firing cycles by means of a squib; reproduction of continuous firing cycles – through the operation of a diesel-compressor, the piston stroke of which is equal to the stroke of the brake piston and the gun knob; in terms of power, a diesel compressor (by regulating the consumption of diesel fuel) should provide an imitation of the action of gun charges; the force transmitted to the carriage must be recorded with a dynamometer and recorded with an oscilloscope; the variable mass of the recoil parts should allow expanding the range of tested designs of weapons samples. On the basis of the requirements put forward, the authors have developed a diagram of an experimental setup for measuring the parameters and functions of the brake of the sliding parts (Fig. 1).

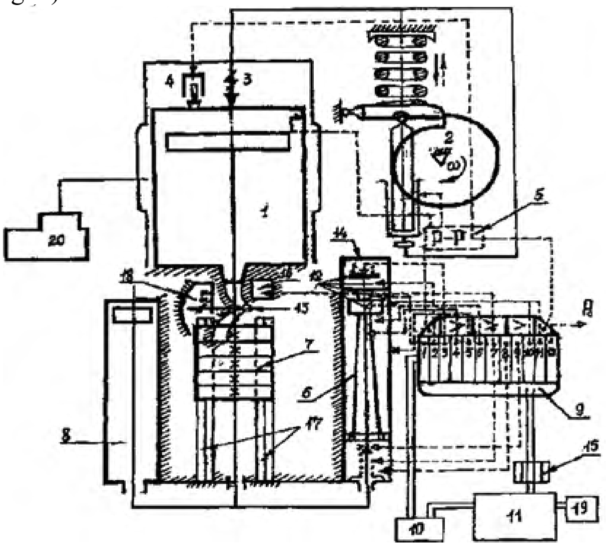

Fig. 1. Diagram of the experimental setup with control and recording equipment of the parameters of the brake of the recoiling parts of the tool: 1 – diesel compressor; 2 – fuel equipment; 3 – nozzle; 4 – squib; 5 – control relay-regulator: 6 – brake of sliding parts; 7 – the mass of the retractable parts; 8 – knurler; 9 – amplifier unit УТС 1-ВТ-12; 10 – power supply unit; 11 – magneto-electric multichannel oscilloscope Н-700; 12 – sensors of registered parameters; 13 – rotary device in horizontal and vertical planes; 14 – compensator; 15 – differentiating and integrating circuits; 16 – dynamometer; 17 – guide skids of the center of mass of the retractable parts; 18 – coordinate scales; 19 – timer (sound generator); 20 – air compressor.

A brief description of the experimental setup and the features of recording the brake parameters of the recoiling parts of the gun

A specially designed diesel compressor (1) with fuel equipment (2), a nozzle (3) for continuous reproduction of firing cycles and a squib (4) for a single firing cycle is used in the setup diagram for experimental research (Fig. 1). The compressor power, simulating a charge, is controlled by a relay-regulator (5), i.e. the amount of fuel injected into the cylinder of the diesel-compressor. The brake of the recoil parts (6), the mass of the recoil parts (7), the reel (8) perform the same functions as when firing. The rotary device (13), skids (17) act as standard units of the tool. Compressor (20) is used to purge and clean the diesel compressor cylinder at the end of the test. Coordinate scales (18) are associated with a stationary coordinate system for assessing the motionlessness of the tool [6, 7].

The peculiarities of the registration of parameters should include the fact that the experiment is aimed not at obtaining the values of the main functions, but their derivatives and integrals of the flow rate of the working fluid through the calibration sections. The first and second derivatives in the experiment were obtained by introducing differentiating and integrating circuits into the measuring circuit, designed specifically for low-frequency processes (1 ... 10 Hertz). The integration operation is carried out by a current amplifier, the input voltage is supplied from the sensitive element (sensors) (Fig. 1). At the input of the circuit, an active resistance R_{ent} is set, and in the feedback C – a capacitance, then the output will be the integral of the output voltage:

$$V_{ex.} = -\frac{1}{R_{ent.} \cdot C} \cdot \int V_{ent.} d\tau, \tag{1}$$

where $V_{ex.}$ – output voltage, $V_{ent.}$ – input voltage, τ – hour.

The calibration characteristic of this measuring circuit was obtained both on a constant pressure test bench and on an impulse test bench (diesel-compressor fuel equipment). The maximum jump was created of the same order as the pressure jump in the volume of the recoil brake (it was set by the preliminary tightening of the fuel pump spring). The measuring circuit (Fig. 2) worked according to the registration principle $\mu f_{ent.} = f(x)$. P_1 and P_2– pressure values before entering the section and after the section, the input voltage is proportional to the pressure, the flow rate of the working fluid is:

$$Q = V_{ent.} = \int_{0,01}^{1,1} \left(\mu f - (x) \sqrt{\frac{2}{\rho}} \cdot \sqrt{P_1 - P_2} \right) d\tau. \tag{2}$$

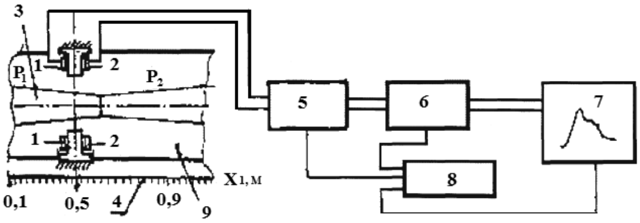

Fig. 2. Measuring circuit of the liquid flow rate through the calibration sections: 1, 2 – liquid pressure sensors; 3 – spindle; 4 – cone of movement along the spindle; 5 – amplifier; 6 – integrating circuit; 7 – oscilloscope; 8 – power supply unit; 9 – volumetric capacity (0.01) for small movements

The hydrodynamic and mechanical parameters are measured in a similar way, with the only difference that instead of an integrating circuit, differentiating cells are included in the measuring and calibration circuit. An active resistance R_{os} was set at the amplifier in the feedback, and a capacitance C was set at the input. To register the mechanical parameters of the moderator valve displacement, at which the lower limit $(\mu f)_k = 0$ at $x_k = 0$ and the upper free coordinate at $x_k \leq x_{\max} \cdot (\mu f)_k = \max$, an induction sensor (Fig. 3) designed by V. Anisimov, described in [8] for small displacements, was used.

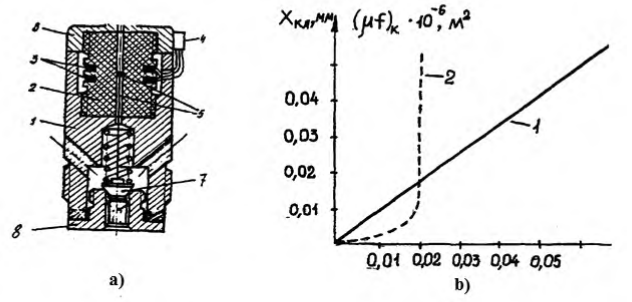

Fig. 3. Diagram of a small displacement induction sensor: a – sensor; b – calibration characteristic (curve 1) and change $(\mu f)_k = f(x)$ (curve 2); 1 – case; 2 – dielectric; 3 – coils; 4 – plug connector; 5 – a needle with a pathogen; 6 – sealed cover; 7 – moderator valve; 8 – saddle

In the case of large displacements (brake rod travel), such a sensor has a non-linear calibration characteristic. In fig. 4 a diagram for measuring the movement of the piston of the brake rod of the sliding parts is shown.

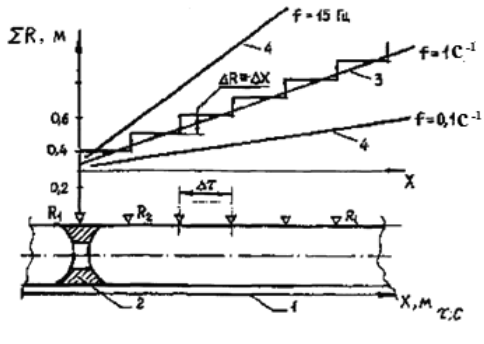

Fig. 4. Scheme for measuring large displacements by a chain of active resistances:
1 – scale; 2 – rod piston; 3 – calibration curve by *x(τ)*;
4 – speed (frequency) calibration curve $\left(\frac{dX}{d\tau}\right)$.

The principle of operation of the measuring cell is as follows. Active resistances are included in the accumulator by the movement of the piston (2), and the marks on the scale (1) duplicate the position. Then, the relative displacements, proportional to the additional average resistances $\Delta X \equiv \Delta R$ by average ΔX, give the curve (3).

As you can see, it is linear in X and, therefore, easily differentiable.

In order to coordinate the kinematic characteristics in time on the scale τ, according to the known frequency parameters, an artificial label was imposed with specified frequencies f_i (curves 4) for such a range of speeds that occur in real processes, which corresponds to the first derivative of the displacement speed $\left(\frac{dX}{d\tau}\right)_{f=const}$.

To eliminate errors in calibration and processing of oscillograms, special attention was paid to the frequency characteristics of the control and measurement and recording equipment.

Control, measuring and recording equipment

When developing measuring and recording circuits, special attention was paid to the analysis of losses in electrical circuits and their amplitude-frequency characteristics. Let's consider the most general registration scheme, for example, acceleration of the compensator piston movement. It is required to know the parameters: m_k, F_k, f_5 [11], on which, in accordance with the displacements and time, the values $\delta_k, P_5, \frac{dX}{d\tau}, x(\tau)$ depend. Then the measuring and calibration circuits can be represented by the diagram shown in Fig. 5.

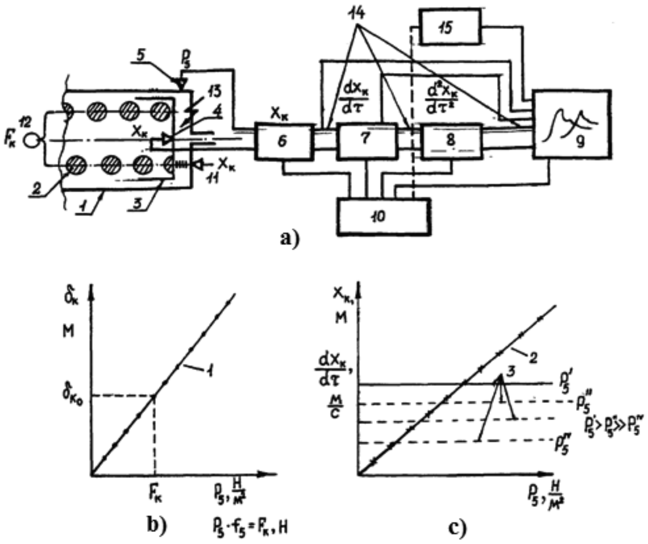

Fig. 5. Measuring and calibration circuits for recording the parameters of the compensator a):
1 – compensator cylinder; 2 – spring; 3 – piston;
4 – inductive sensor for piston displacement;
5 – strain gauge fluid pressure sensor; 6 – amplifier TCB – 12; 7, 8 – differentiating circuits;
9 – magneto-electric oscilloscope; 10 – power supply unit; 11 – micrometric movement screw;
12 – dynamometer; 13 – exemplary pressure gauge;
14 – cables; 15 – sound generator,
b) – characteristic of the spring (1); c) 2 – displacement of the piston from pressure;
3 – change in piston speed from pressure

When calibrating the piston movement (carried out by a micrometric screw (11)), the pressure is recorded with a model manometer (13), while the oscilloscope (9) registers the deviation according to the function (6) or according to its derivatives (7, 8). The constant components of the connecting cables (capacitance and resistance) are not taken into account, since they do not change when measured δ_k, P_5, X_k, and their derivatives. The same technique excludes errors in measuring the geometric dimensions of parts f_5.

The frequency characteristics of the oscilloscope loops, as a rule, are selected two or more orders of magnitude higher than the frequency of the recorded parameters (even the lowest frequency ones), therefore, no oscilloscope loop distortion is observed.

Similarly, circuits for measuring other groups of parameters are formed, with the exception of measuring and calibration circuits for measuring the temperatures of the liquid and the outer surface of the brake cylinder of the sliding parts.

Fig. 6 shows the calibration and measuring circuits, which include thermocouples as a temperature sensor, the thermal conductivity of which is close to the material of the brake cylinder of the sliding parts.

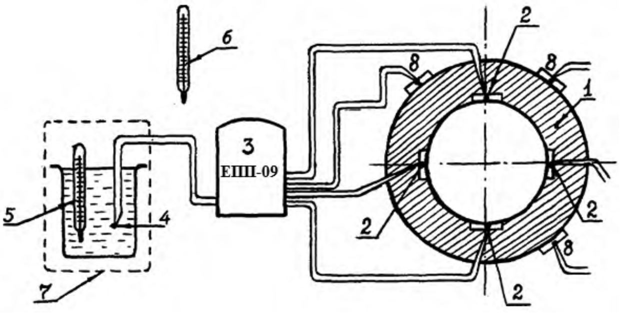

Fig. 6. Calibration measuring circuit for recording the temperatures of the working fluid and the surfaces of the brake cylinder of the sliding parts: 1 – cylinder; 2 – thermocouples in slots; 3 – EPP-09 multipoint potentiometer; 4 – cold junction of thermocouple; 5 – exemplary thermometer; 6 – environmental thermometer; 7 – thermostat; 8 – thermocouples on the surface of the cylinder

Thermocouples inside the cylinder are installed in throttling sections so that the junction does not affect the size of the calibration hole, and on the surface of the cylinder they are fixed by springs so that the clamp does not affect the heat exchange screen with the environment. The total heat transfer coefficient was determined by calculation using the Pomerantsev criterion [9] only for the cylindrical part of the brake.

For a comprehensive analysis of changes in the parameters and functions of the brake of the recoil parts of the tool, the general method provides for the simultaneous registration of 12 processes (12 differential equations in mathematical models [11]), of which: 3 movements of the brake piston (center of mass of the recoil parts, compensator piston, moderator valve); pressure in five volumes [11] ($P_1 - P_5$), there are also four parameters: 2 speed characteristics of the liquid along the spindle and grooves of the cylinder, 2 integral values of these flows. Thermal parameters are recorded by measuring chains from five external and five internal thermocouples. The derivatives of the registered functions and the second derivatives of the three kinematic characteristics are removed by differentiating contours, as shown in Fig. 5.

The procedure for processing the results of experimental measurements of any of the parameters for comparison with their calculated values must meet the following requirements: rounding of the initial data, reference scales, zero lines, calibration value scales must have the same number of significant digits after the decimal point as the tabular data of international units of measurement, used in calculations; the scaling factor in amplitude and in time for all processes should be the same for the main derivatives of the second derivatives of functions, integrals and calibration pulses.

Errors in the experimental determination of the parameters of the brake of the recoiling parts of the gun

Taking into account the requirements of the general methodology for organizing the experiment, the peculiarities of recording functions and parameters, the class of control and measuring and recording equipment, the authors analyzed the errors of the measuring circuits for individual groups of parameters.

The relative measurement error of any group, taking into account the instrument error and oscillogram scaling, is determined by the equation [11]:

$$\delta_A = \pm\frac{2}{3}\sqrt{\frac{\delta_A}{\bar{a}} + \delta_p + \delta_y}, \quad (3)$$

Where $\delta_A = \left(\dfrac{(\bar{a}-a_1)^2 + (\bar{a}-a_2)^2 + \ldots + (\bar{a}-a_n)^2}{n(n-1)}\right)^{\frac{1}{2}}$

is the mean square error of the results for n – cycles; δ_p – relative registration error; $a = \dfrac{a_1 + a_2 + \ldots + a_n}{n}$ – arithmetic mean for n cycles; δ_y – error of distortion along the axes X and Y with increasing oscillograms.

The errors of indirect measurements of parameters were determined by the formula [11]:

$$\delta_y = (\delta_A^2 - \delta_B)^{\frac{1}{2}}, \quad (4)$$

where δ_A are the errors in measuring geometric dimensions; δ_B – measurement errors during calibration. The values of the errors of direct measurements by groups of parameters are summarized in tabl. 1, and indirect measurements, respectively, in tabl. 2.

The total relative registration error [11] was determined by the equation:

$$\delta_p = \delta_g + \delta_0 + \delta_0' + \delta_{amp} + \delta_{dc}, \qquad (5)$$

where δ_g is the error of the galvanometer; δ_0 – calibration error; δ_0' – error in processing oscillograms; δ_{amp} – amplifier error; δ_{dc} – the error of the differentiating cell.

The values δ_0 and δ_0' were determined by the equations:

$$\delta_0 = \delta_a + \delta_{pg} + \delta_{pg}', \qquad (6)$$

$$\delta_0' = \delta_a + \delta_{00}' + \delta_{on} + \delta_y, \qquad (7)$$

where δ_a is the error in the middle of the calibration schedule; δ_{pg} – class of an exemplary pressure gauge; δ_{pg}' – scaling error; δ_{oo}' – error in measuring the ordinate of the oscillogram; δ_{on} – error of verticals of oscillograms on paper; δ_y – the error of increasing the oscillograms.

The obtained error values meet the requirements for the accuracy of measurements of mechanical displacements, hydrodynamic measurements, and thermal engineering experiment.

The main results of experimental research on the brakes of the retractable parts of the 2A65 artillery gun

In order to compare the results of theoretical and experimental studies Fig. 7 shows the corresponding characteristics of the brake of the sliding parts and shows their parameters. Note that it is impossible to consider as real in the ideal (curve 2), as it was constructed on the basis of experimental data for calculation by the equations [11]:

$$P_1 = \frac{f_1(x)}{\beta V_1(x)} \cdot \frac{1}{1 - \dfrac{(\mu f)\tau}{Z \cdot \beta \cdot V_1(x)}},$$

$$P_2 = \frac{f_2(x)}{\beta V_2(x)} \cdot \frac{1}{1 - \dfrac{(\mu f)\tau}{Z \cdot \beta \cdot V_2(x)}},$$

and this is the result of indirect measurements. In addition, the pulse density and the pressure value are taken constant, i.e. equal to the average values in the range of change for rollback and roll forward.

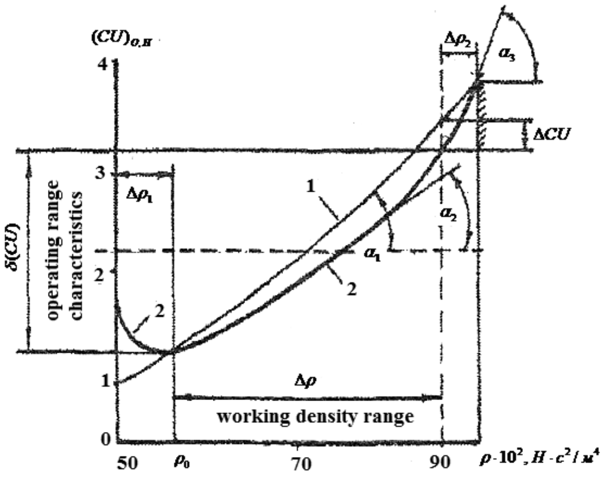

Fig. 7. Parameters of the characteristics of the brake of the sliding parts in terms of density change «Steol-M»: 1 – calculated; 2 – experimental; characteristic parameters at Z = 0,3·10^7 [N·s/m^3], P_l=83·10^5[N/m^2], $\Delta\rho_1$ is the ensity of the liquid at the beginning of boiling; $\Delta\rho_2$ – the density

Table 1. Error of direct measurements

No	Parameter name	Relative instrumental error, taking into account the increase, %	Relative measurement error, %
Mechanical parameters	$X_{01}(\tau)$	±0,5	±0,8
	$X_0(\tau)$	±0,7	±0,75
	$X_k(\tau)$	±0,7	±0,75
	$\dfrac{dX_0}{d\tau}(\tau)$	±1,4	±0,96
Hydrodynamic parameters	$P_i(\tau)$	±2,2	±2,5
	$\dfrac{dP_i}{d\tau}(\tau)$	±4,0	±4,0
Consumable characteristics	$\dfrac{dV_i}{d\tau}(\tau)$	±2,4	±2,4
Heat engineering parameters	$t_{80}(\tau)$	±2,5	±2,5
	$t_{20}(\tau)$	±2,4	±2,4

Table 2. Errors of indirect measurements

No	Parameter name	Parameter determination equation	Relative error, %
1	V_1	geometric formulas for determining the volume of complex shapes	±1,5
2	$\mu f_i(x)$	annular effective section, groove section	±2,0
3	X_{ol}	linear length	±1,0
4	d_i	$\frac{D_i}{4}$	±1,0
5	Y_i − function coordinate with respect to the independent variable	$Y_i \cdot \mu_i$, where μ_i − calibration scale	±1,5

of the liquid at the beginning of crystallization; ρ_0 − the measurement error is 0; ΔCU− maximum divergence of characteristics; $\Delta a_1, a_2, a_3$− rate of change of brake characteristics depending on fluid density

A positive fact should be recognized as close coincidence α_1 and α_2 at $\Delta\rho = (54...90)\cdot 10^2$ [$N\cdot s^2/m^4$] and a change *CU* in the range from 1.32 to 3.5 units. The brake characteristic in this range (curve 1) is practically linear and similar to the characteristic of the spring.

The range of variation of critical values $\Delta\rho_1$ and $\Delta\rho_2$ does not contradict the physics of phenomena in the «Steol-M» liquid. It is impractical to include them in the working range of changes due to a sharp change in the pulse density, at $\mu f = const$. Considering that the $\Sigma \cdot \mu f$ tends to $(\Sigma \cdot \mu f)_{\min}$ parameter "time − section", it can sharply increase and turn the characteristic $(CU)_0$ values to infinity. Such a missing reserve of braking energy is not advisable, since it will lead to an increase in the rollback time, and if Z decreases, to the occurrence of a shock at the final stages of rollback and rollback.

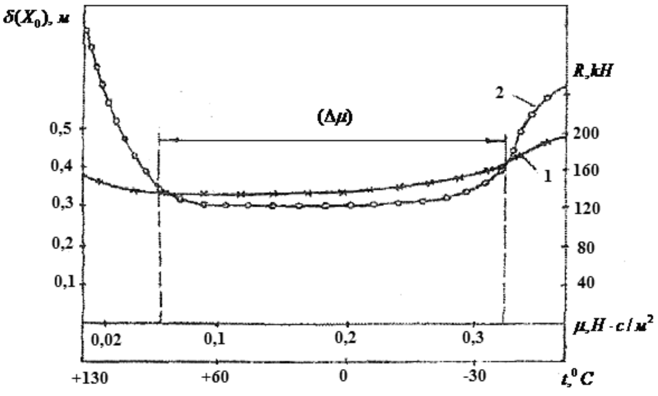

Fig. 8. Moving the center of gravity of the 2A65 tool depending on the change in the density of the brake working fluid:

1- —×— $\delta(x_0)$; 2 - —○— R; 3- —— theoretical

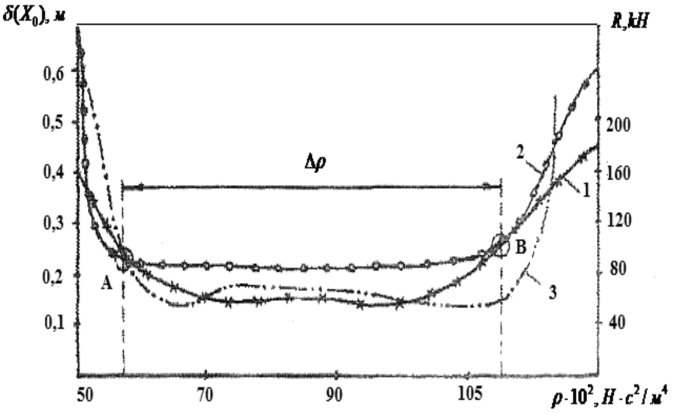

Fig. 9. Displacement of the center of gravity of the 2A65 tool depending on the change in the dynamic viscosity of the working fluid of the brake

The above analysis of the parameters of the characteristics of the brake of the rolling parts gives the right to assert that theoretical studies reliably reproduce the working process. The theory of small deviations, taking into account the design features and the parameters of the working fluid, the operating conditions of the tool, makes it possible to find the maximum permissible deviations of the parameters with a reliability that meets the requirements of the assigned research tasks.

One of the main tasks of experimental research was the task of establishing the nature of the relationship between the parameters of the brake of the gun and its immobility. Fig. 8 − 13 shows the results of such an experimental evaluation.

Analysis of the experimental results shows that the displacement of the center of gravity of the tool depending on the change in the density of the working fluid (Fig. 8, curve 1) can be divided into three phases, similar to the behavior of the brake characteristics of the recoil parts (Fig. 7, curve 2). This is confirmed by the experimentally removed reaction of the support *R* (Fig. 8, curve 2); points *A* and *B*, where the value *R* rises sharply. Therefore, the change $\Delta\rho$ cannot go beyond the specified ranges for the brake characteristic $C = f(\rho)$ (Fig. 7).

Since $\rho = f_1(T)$, then or $\delta(x_0) = f_3(T)$, then the authors carried out an experiment to establish the working range in magnitude $\Delta\mu$ (Fig. 9, curve 1). It should be noted that the rigidity of the stand support made it possible to remove the maximum permissible values of the parameters only at positive temperatures, at negative temperatures the experiment was provided only by the ambient temperature.

One of the tasks of the experiment was to establish the degree of dependence of the displacements of the center of gravity of the tool on the compressibility of the working fluid. Fig. 10 clearly demonstrates the nature of the change $\delta(x_0) = f(\beta(\rho))$, which basically coincides with $\delta(x_0) = f(\mu t)$ (Fig. 9). The compressibility practically does not affect the value of the reaction of the supports during rollback and rolling in the range (0,26...0,84)·10^{-7}[m^2/N].

Changing the parameters of the brake characteristic of the sliding parts has a greater effect than changing the density and compressibility of the working fluid, since the displacement of the center of gravity decreases with increasing (Fig. 11, curve 1).

Of particular interest are also experimental data on the displacements of the center of gravity depending on the pulse density, which determines the characteristics of the brake for which the parameter «time − section» and the values *Z* have a mutually opposite effect on the change *CU*. For this purpose, the dependence $\tau = f(Z)$ was superimposed on the graph of functions $\delta(x_0) = f(Z)$, where τ is the time (final) rollback period and the first rollback period with a continuous rate of cycles (Fig. 12.) Analysis of these data shows that for any *Z* with an increase in the number of cycles, the center of gravity of the tool decreases.

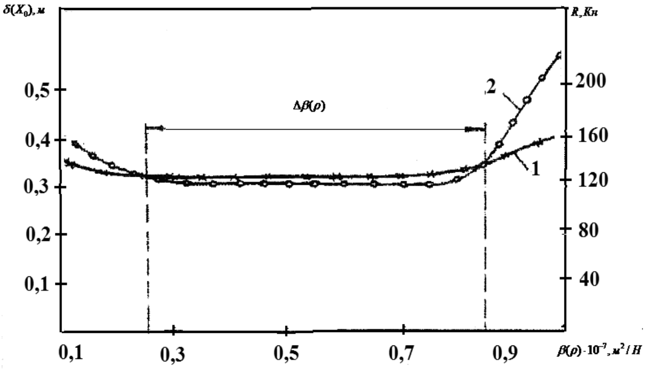

Fig. 10. Moving the center of gravity of the tool 2A65 depending on the compressibility of the working fluid

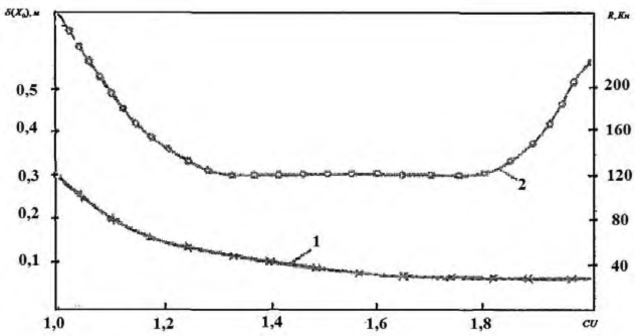

Fig. 11. Moving the center of gravity of the 2A65 gun depending on the change in the brake characteristics of the retractable parts

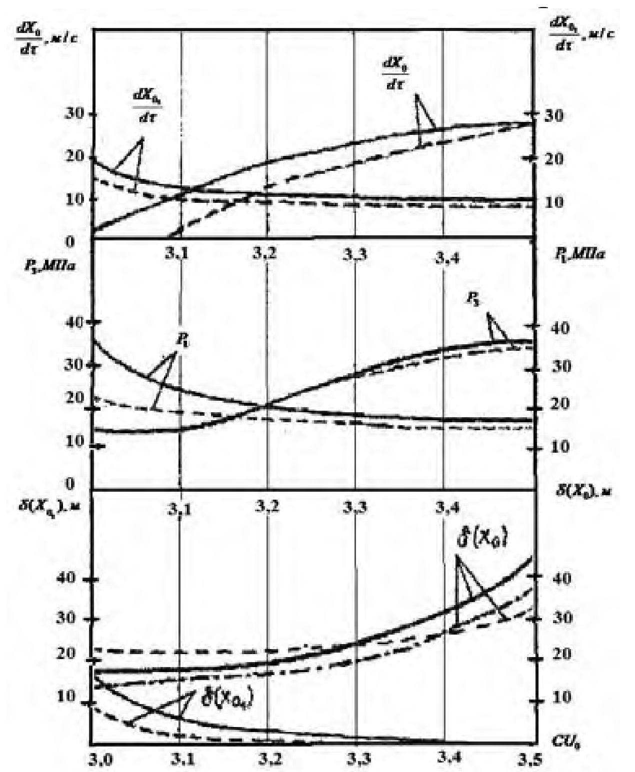

Fig. 12. Changes in the kinematic and dynamic functions of the brake of the sliding parts of the 2A65 implement depending on the change in the brake characteristics $(CU)_0$: - theoretical data; ------ calculated data; •-•-•- experimental data

This is due to the fact that the density of the working fluid decreases with increasing temperature. Parameters α_1 and α_2 (Fig. 7) also decrease, an equivalent effect of quantities *Z* and $\tau\ \Sigma\cdot\mu f$ on the process of absorption of kinetic energy occurs, while the final periods decrease with an increase in the number of cycles (Fig. 5, curves 6 – 10).

Due to the fact that the ambient temperature varies within the range from -35 °C to + 40 °C, it is possible to keep discrete values of the parameters of the brake characteristic only by artificially changing the conditions of heat exchange between the cylinder and the environment, or by changing the geometric parameters

$(\Sigma\mu f_i)_{O,H}\cdot\tau=\left(\frac{dX}{d\tau}\right)$. Then the immobility of the artillery piece can be kept within the permissible deviations. At the same time, the problem of restoring the brake characteristic, formulated in this way, is not adequately solved for rollback and ordering processes. During rollback, part of the kinetic energy is taken in parallel with the brake and compressed gas in the reel, the energy reserve must be spent on the roll-off, according to the specified parameters, and a part is absorbed by the roll-off brake. It is possible to establish these relations of kinetic energy only by a numerical solution to analyze the working process of the brake, by analyzing the results of a numerical solution of the mathematical model of the working process of an artillery gun as an irreversible thermohydraulic machine. For example, by choosing discrete parameters of the brake characteristics (Fig. 7): $\rho=90\cdot10^2\ N\cdot s^2/m^4$;

$$\alpha_{mid}=\frac{\alpha_1+\alpha_2}{2}=\frac{25+41}{2}=33\frac{volt}{meter\cdot degree};$$

$\Delta CU=3{,}2...3{,}5;\quad (CU)_{mid}=3{,}35$ and having solved the system of equations of the mathematical model of the working processes of the hydraulic brake of the sliding parts [11] for the cases of the brake with the standard moderator valve and the proposed design, it is possible to establish the dependence $\frac{dx_{0_1}}{d\tau}$ and $\frac{dx_0}{d\tau}=f(\Delta CU)_H$ (Fig. 12). Analysis of the calculated and experimental data (Fig. 1) shows a significant decrease in the dynamic and kinematic functions of the rollback brake, provided that the value $(\Sigma\mu f)_0$ changes smoothly. The stability of the tool along the axis is increased. Therefore, the equation with the value $(\Sigma\mu f)_0$ or $(\Sigma\mu f)_H$ can be one of the ways to restore the brake performance of the sliding parts. A characteristic feature here should be noted that a decrease in the value C*U* from 3.0 to 1.8 ... 1.2 with a decrease in the density of the working fluid leads to the fact that the deviation of the center of mass of the moving parts and the center of gravity of the tool decrease by 10 %. This process is confirmed by experiment.

Using the results of experimental studies of the working processes of hydraulic brakes of sliding parts, let us consider the degree of influence of the parameters on the characteristics of the brake.

Let us use the equations for CU_O, CU_H, presenting them as small deviations of the parameters on which they depend and the influence of which is experimentally (Fig. 7-11) and theoretically determined (Fig. 13):

$$CU_O=\frac{1}{1-\frac{(\Sigma\mu f)_0\tau}{Z\cdot\beta\cdot\Delta V_1}};\ CU_H=\frac{1}{1-\frac{(\Sigma\mu f)_H\tau}{Z\cdot\beta\cdot\Delta V_2}},$$

where $\delta(Z,\beta,(\Sigma\mu f)_{O,H})$ – accepted as small deviations.

The denominators in the presented equations differ only in indices (O, H, 1, 2) which, in small deviations, can be represented as:

$$\frac{(\Sigma\mu f)\cdot\tau}{Z\cdot\beta\cdot\Delta V}=\frac{[\delta(\Sigma\mu f)]\cdot\tau}{Z\cdot\beta\cdot\Delta V}-\frac{(\Sigma\mu f)\cdot\tau\cdot\delta Z}{Z^2\cdot\beta\cdot\Delta V}-\frac{(\Sigma\mu f)\cdot\tau\cdot\delta\beta}{Z\cdot\beta^2\cdot\Delta V}.\quad(8)$$

Then the rollback brake characteristic is represented as follows:

$$\delta(CU)_O=\left\{1-\frac{[\delta(\Sigma\mu f)]\cdot\tau}{Z\cdot\beta\cdot\Delta V_1}-\frac{(\Sigma\mu f)\cdot\tau\cdot\delta Z}{Z^2\cdot\beta\cdot\Delta V_1}-\frac{(\Sigma\mu f)\cdot\tau\cdot\delta\beta}{Z\cdot\beta^2\cdot\Delta V_1}\right\}^{-1},\quad(9)$$

and the characteristics of the roll-over brake will be written in the same way:

$$\delta(CU)_H=\left\{1-\frac{[\delta(\Sigma\mu f)]\cdot\tau}{Z\cdot\beta\cdot\Delta V_2}-\frac{(\Sigma\mu f)\cdot\tau\cdot\delta Z}{Z^2\cdot\beta\cdot\Delta V_2}-\frac{(\Sigma\mu f)\cdot\tau\cdot\delta\beta}{Z\cdot\beta^2\cdot\Delta V_2}\right\}^{-1}.\quad(10)$$

Finally

$$\left.\begin{aligned}\delta(CU)_O&=1-\frac{1}{k_1}\cdot[\delta(\Sigma\mu f)]+\frac{1}{k_2}\delta Z+\frac{1}{k_3}\delta\beta\\ \delta(CU)_H&=1-\frac{1}{k_4}\cdot[\delta(\Sigma\mu f)]+\frac{1}{k_5}\delta Z+\frac{1}{k_6}\delta\beta\end{aligned}\right\},\quad(11)$$

Where:

$$\left.\begin{aligned}k_1&=\frac{Z\cdot\beta\cdot\Delta V_1}{\tau};\ k_2=\frac{Z^2\cdot\beta\cdot\Delta V_1}{(\Sigma\mu f)\cdot\tau};\ k_3=\frac{Z\cdot\beta^2\cdot\Delta V_1}{(\Sigma\mu f)\cdot\tau}\\ k_4&=\frac{Z\cdot\beta\cdot\Delta V_2}{\tau};\ k_5=\frac{Z^2\cdot\beta\cdot\Delta V_2}{(\Sigma\mu f)\cdot\tau};\ k_6=\frac{Z\cdot\beta^2\cdot\Delta V_2}{(\Sigma\mu f)\cdot\tau}\end{aligned}\right\}.\quad(12)$$

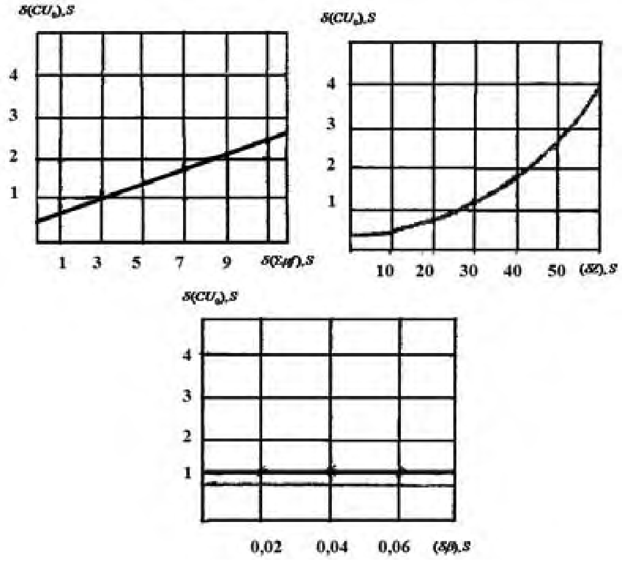

Fig. 13. Relative changes in the characteristics of the brake of the sliding parts depending on the change in the defining parameters

Having constructed the deviations $\delta(CU)$ for unknown small deviations $\delta(Z,\beta,(\Sigma\mu f))$ from the system of equations (11), we find that the most influencing argument is the pulse density δZ. Compressibility β does not affect the brake performance, the average degree of influence is characterized by the total effective flow area of the calibration jets, slots and the moderator valve $\sum \mu f$.

Thus, two ways of controlling the brake characteristic are obvious − by changing the total effective flow area of the calibration nozzles, slots and the moderator valve $\sum \mu f$ or δZ pulse density. Technically this can be achieved by: using a stepless moderator valve; using a variable spindle profile and passage sections of the grooves; using a variable controlled section of a compensator V_5 with a volume V_2.

Comprehensive studies of the indicated ways to preserve the characteristics of the brake of the retractable parts are a separate scientific task that is not considered in the article.

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ЕКСПЕРИМЕНТАЛЬНЕ ВИЗНАЧЕННЯ ОСНОВНИХ ПАРАМЕТРІВ ТОРМОЗУ ВІДКАТНИХ ЧАСТИН АРТИЛЛЕРІЙСЬКОЇ ГАРМАТИ, ЩО ВПЛИВАЮТЬ НА ЙОГО ХАРАКТЕРИСТИКИ

Запропонований в статті підхід дозволив авторам провести експериментальне комплексне дослідження гідродинамічного робочого процесу гальма відкотних частин з одночасним спостереженням змін динамічних і кінематичних характеристик центру мас відкотних частин. Підтверджені два шляхи управління характеристикою гальма зміною сумарного ефективного прохідного перетину калібрувальних жиклерів, пазів й клапану модератора або щільності імпульсу. На основі методу малих відхилень авторами запропонований експериментальний підхід з обґрунтування гранично допустимих відхилень характеристик гальма, а також уточнені підходи до відновлення характеристик гальма відкотних частин. Необхідність експериментальних досліджень при дослідженні основних параметрів гальма відкотних частин артилерійської гармати диктувалася, перш за все, необхідністю підтвердження достовірності нових результатів, що отримані під час теоретичних досліджень. Зауважимо, що всі математичні моделі робочих процесів, наведені авторами, використовують експериментальні коефіцієнти багатопараметричних взаємозв'язків, виділити які окремо не представляється можливим. З метою перевірки адекватності результатів теоретичних досліджень із стійкості та нерухомості артилерійської гармати авторами розроблені загальна й приватна методики експериментальних досліджень робочого процесу гальма відкотних частин, експериментальна установка для дослідження параметрів гальма відкотних частин. Результати експериментальних досліджень підтверджують встановлений теоретичний зв'язок нерухомості та стійкості гармати від величини зміни параметрів робочої рідини гальма відкотних частин (характеристики гальма) і конструкції вдосконаленого модератора. Проведені дослідження показали адекватність теоретичних й експериментальних результатів, отриманих авторами. Експериментально встановлено збільшення параметрів стійкості та нерухомості артилерійської гармати на 13 − 15% при реалізації запропонованого авторами способу ступеневої зміни перетікання робочої рідини і застосування удосконаленого модератора.

Ключові слова: внутрішньокамерні процеси артилерійських систем, гідравлічні гальма, відкотна частина.

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