# Comprehensive study of the effect of a structural parameter of hydraulic buffer on the firing stability of grenade launchers

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*Abstract:*

*Introduction/purpose: The article's main goal is to present a novel method for evaluating the stability of automatic weapons mounted on tripods when firing in series.*

*Methods: The mathematical model is established based on the theory of many-body mechanics. The Lagrange II equation is used to establish the system of differential equations of motion of mechanical system. The mathematical model considers the influence of the ground elasticity and the impact of the gunner through elastic-damping connections. Dynamic simulations were performed on the AGS-17 grenade launcher. The calculated results were then compared with the experimental results to verify the proposed model.*

*Results: The comparison results show an unexpected confidence level between the theoretical model and experimental results. The errors in muzzle velocity and firing rate are 2.52% and 6.18%, respectively. Based* *on the theoretical basis of the mathematical model, the influence of some structural parameters of the hydraulic buffer on the firing stability of the automatic grenade launcher was investigated. The research results provide a reliable theoretical basis to improve, design, and manufacture hydraulic buffers for grenade launchers in particular and automatic guns in general.*

*Conclusion: The research results presented in this paper ensure high accuracy and reliability. This paper provides a reliable scientific document for the optimal design of the overall structure of the weapon system.*

*Keywords: grenade launcher, firing stability, automatic weapon, automatic firing systems, hydraulic buffer.*

## Introduction

In the current development trend of military science, the development of weapons is a matter of concern for many countries. In addition to procuring modern weapons, numerous governments are always interested in designing, manufacturing, and improving existing weaponry. This is to improve the combat strength of the Army and ensure its autonomy in defending the country. To master this problem, an in-depth study of the nature of shooting phenomena is necessary. Furthermore, examining the firing stability of the gun under different combat conditions provides a more accurate understanding of the cause of firing errors. From there, specific design, manufacturing, and production solutions are recommended to improve the weapon's shooting efficiency.

To evaluate the firing efficiency of a weapon, one of the important parameters is firing accuracy. Many factors affect the accuracy of shooting, among which the stability of the shot plays the most important role. The more stable the gun, the higher the firing efficiency of the weapon. As a result, numerous studies have been published on the shooting stability of weapons. Notable studies that have presented the stability of the weapon's shot can be found in the literature (Balla et al, 2015;  Doan et al, 2023). A common limitation in previous studies is the lack of attention to the simultaneous operation of the automatic firing system and the movement of the entire weapon system. As a result, the interaction between the automatic firing system and the overall weapon system has not been thoroughly investigated (Ich, 2017; Macko et al, 2021). An automatic fire system is a system whose kinetic characteristics directly affect the stability of the entire weapon system. Furthermore, this system is also a constituent element of automatic weapons. Some studies on the firing stability of automatic guns on tripods have not yet addressed the effect of the gunner's impact (Sy et al, 2019), or have only mentioned the gunner's effect on the weapon system as a passive elastomer or a constant load (Lu et al, 2019). Several studies have addressed the influence of the elastic background on the weapon system as an elastic element with viscous drag (Bien et al, 2021; Doan et al, 2023). These studies have focused on studying the firing stability of automatic weapons in different directions and have achieved certain results.

Modern grenade launchers often operate using the free bolt principle. A key drawback of automatic weapons utilizing this mechanism is the significant mass of the bolt, which generates a substantial impact force when it strikes the rear and front of the gun housing. This leads to several adverse effects during rapid firing, such as reduced firing stability, potential damage to components, and a shorter weapon lifespan. To mitigate these issues, a hydraulic buffer is employed to slow the bolt's movement in both directions. This mechanism helps reduce the impact force between the bolt and the gun housing, thereby enhancing the gun's overall firing stability.

However, after a period of using this weapon, some failures mainly appear in the hydraulic buffer mechanism. Some adverse effects occur during firing, such as decreased shooting accuracy, and increased dispersion of bullets when firing in series. Some serious effects also damage the gun, such as: leaking hydraulic oil, flattening the push-in spring, not ejecting the bullet, the bolt not closing completely, and the shell being deformed, etc. Therefore, it is necessary to study the effects of some structural parameters of the hydraulic buffer mechanism on the firing stability of automatic guns when firing in series. This research not only helps to overcome the above failure phenomena but also gives recommendations for the exploitation and use process as well as the manufacture of suitable replacement hydraulic buffer mechanisms. The previous publications of the research groups have solved the dynamics problem of the automatic firing system of automatic guns operating according to the principle of free reverse bolts (Bien et al, 2021) and the dynamics of grenade launchers mounted on the tripod when firing (Bien et al, 2021).

In this study, the authors build a mathematical model to determine the firing stability parameters of automatic weapons mounted on tripods. This mathematical model is established using the theory of many-body mechanics based on Lagrange II equations. The research content focuses on establishing mathematical models, using numerical methods to solve problems, and evaluating the mathematical models using experimental measurement results. The AGS-17 grenade launcher (Figure 1) was used to calculate the theory and experimentally verify the mathematical model. In addition, the study also evaluates the influence of some structural parameters of the hydraulic buffer mechanism on the stability of the weapon system. The results obtained from this study can be used to optimize the structure of the weapon system.

*Figure 1 – Overview of the AGS-17 grenade launcher*

## Problem formulation

### *Overview of the hydraulic buffer mechanism in automatic grenade launchers*

Due to the large mass of the automatic grenade launcher, the contact between the bolt and the gun box in the rear and front positions is particularly large. When the rate of fire is not too high, using a hydraulic buffer mechanism is a reasonable solution. Figure 2 shows the structure of the hydraulic buffer mechanism of the AGS-17 grenade launcher.

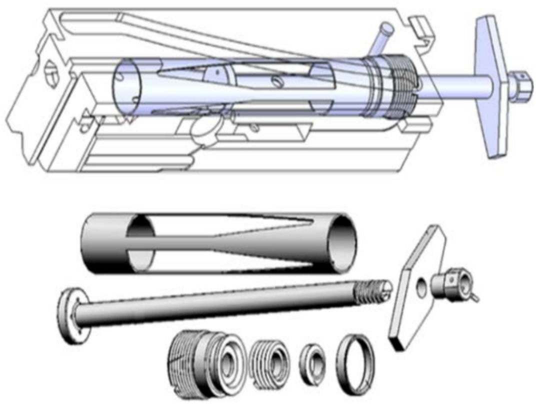


*Figure 2 – Hydraulic buffer mechanism*

The hydraulic buffer mechanism must meet the following requirements:

- Working reliably, braking smoothly, reducing collisions in both directions;
- Simple structure, ensuring convenience for fabrication and exploitation;
- Ensuring that key operational parameters, such as braking force, recoil length, recoil speed, and return speed, remain within allowable limits while still providing sufficient energy for the automatic firing system to function stably.

### **. Seting up the computational model*

Based on the structural characteristics of the hydraulic buffer mechanism used on the AGS-17 grenade launcher, the principle model for determining the hydraulic braking force is presented in Figure 3.

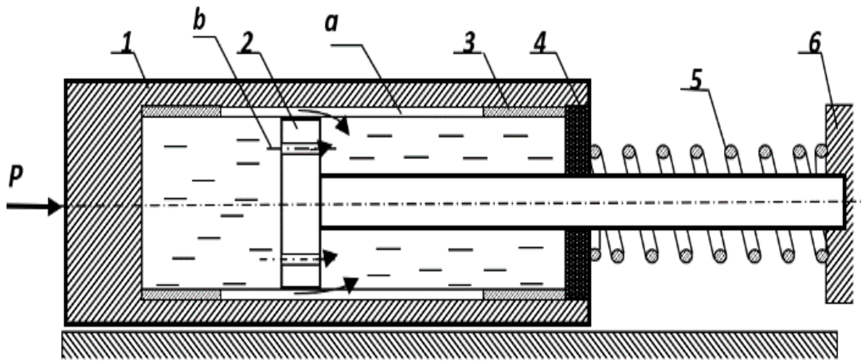



*Figure 3 – Working principle model of hydraulic buffer mechanism*
*1. Bolt; 2. Piston; 3. Regulating tube; Sealing Parts; 5. Return spring;*
*6. Gun body; a - Oil drain; b - Oil drain hole*

In order to determine the hydraulic braking force, the following assumptions are made:

- The oil used in the hydraulic buffer is an ideal incompressible fluid, and the oil flow is steady and continuous.
- The energy loss of the flowing oil due to friction is considered proportional to the kinetic energy of the flowing oil.
- A correction factor is used for flow constriction when oil flows through the cross-section $a_x$.

The hydraulic braking force is generated by fluid flow between chambers through different gaps. The hydraulic braking force is a function of the variables $a_x$ (oil flow gap area) and $V_{kn}^2$ (bolt displacement velocity):

$$F_{tl} = f_{(a_x)} V_{kn}^2 \quad (1)$$

### *. Determining the hydraulic braking force

Because the slope of the oil flow gap of the hydraulic damper on the AGS-17 grenade launcher varies with the travel length (see Figure 3 and Figure 4), the hydraulic braking force also varies accordingly.

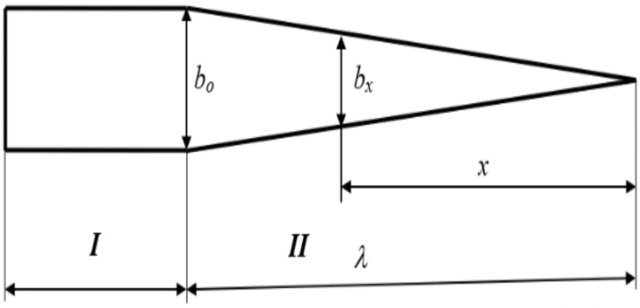



*Figure 4 – Oil flow groove diagram*

According to the documents (Bien et al, 2021), the hydraulic braking force is determined as follows:

- On section I: The section where the oil flow cross-section is constant.

$$F_{tl} = \frac{k\gamma}{2g} \cdot \frac{A_t^3}{\left(a_0 + a_1\right)^2} V_{kn}^2 \quad (2)$$

- On section II: Section with variable oil flow cross-section.

$$F_{tl} = \frac{k\gamma}{2g} \cdot \frac{A_t^3}{\left(a_x + a_1\right)^2} V_{kn}^2 \quad (3)$$

where $k$ – main flow drag coefficient, $\gamma$ – specific gravity of the liquid, $a_0$ – the area of the oil groove on section I, $a_1$ – cross-sectional area of oil flow hole, $V_{kn}$ – reverse part velocity, $A_t$ – cross-sectional area of the piston; $a_x = a_0 \frac{x}{\lambda}$ – oil flow area at position $x$ on segment II.

The calculated results of the hydraulic braking force of the AGS-17 grenade launcher are shown in Figure 5.

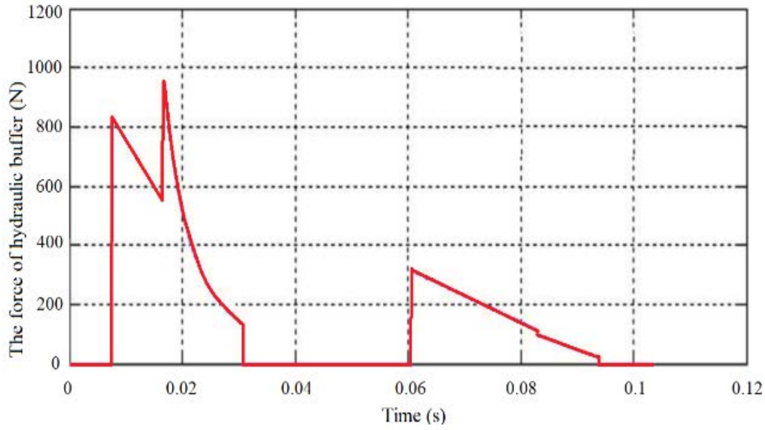



*Figure 5 – The braking force of the hydraulic buffer*

### *Model of AGS-17 grenade launcher on a tripod*

The problem of oscillation of the AGS-17 grenade launcher on a tripod firing on an elastic foundation has been detailed by Bien et al. (2021). Accordingly, the dynamic model consisting of 3 solids with 9 degrees of freedom (DOFs) is presented in Figure 6, and the mechanical structure of the weapon system is shown in Figure 7.

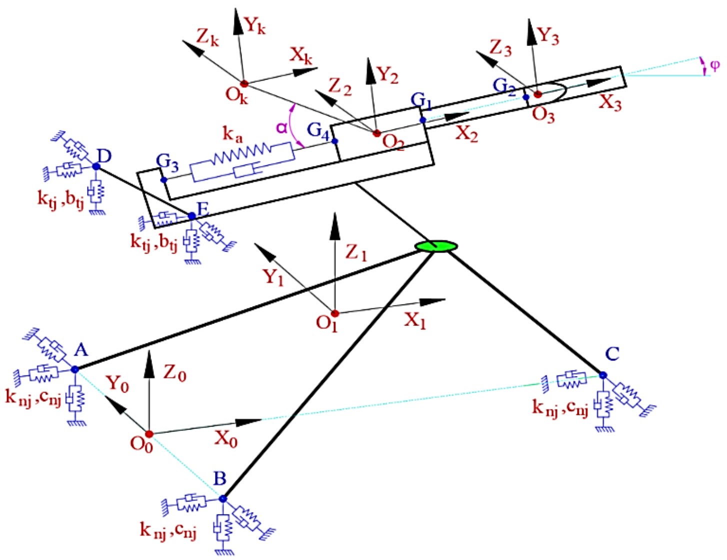


*Figure 6 – Automatic gun model mounted on the tripod (Bien et al, 2021)*

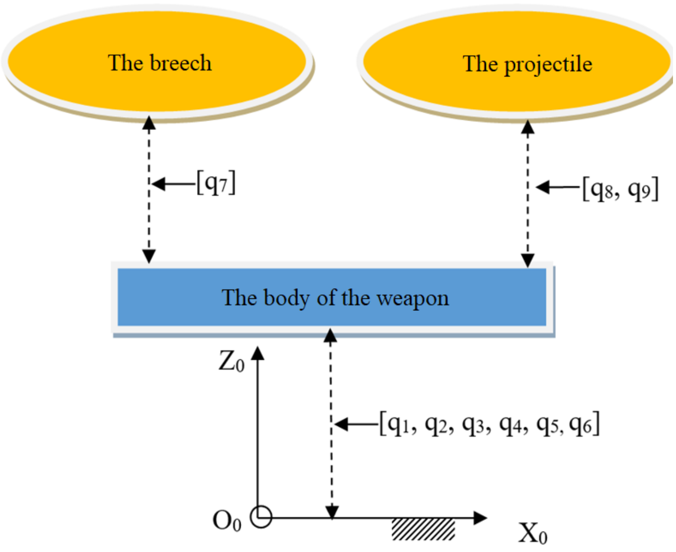



*Figure 7 – Diagram of weapon structure*

To investigate the dynamics of the system, we assign the system and each object in the system a Cartesian coordinate system so that the description of the configuration of the mechanical system is most effective (see Figure 6):

- Fixed coordinate system (earth coordinate system) $O_0$: The origin is located at the point between the hind legs in the initial position. The $X_0$ and $Z_0$ axes belong to the firing plane (the vertical plane containing the barrel axis) and the $x_0$ axis is parallel to the horizontal plane, the $Z_0$ axis is perpendicular to the horizontal plane, and the $Y_0$ axis is perpendicular to the $X_0O_0Z_0$ plane.

- Moving coordinate system $O_1$: attached to object 1, the origin $O_1$ coincides with the center of mass of object 1, and the $X_1$ axis is parallel to the barrel axis, the $Z_1$ axis is perpendicular to the horizontal plane, $Y_1$ axis is perpendicular to the $X_1O_1Z_1$ plane.

- Moving coordinate system $O_2$: attached to object 2, the origin $O_2$ coincides with the center of gravity of object 2. The $X_2$ axis is parallel to the $X_1$ axis, the $Z_2$ axis is parallel to the $Z_1$ axis, and the $Y_2$ axis is parallel to the $Y_1$ axis.

- Moving coordinate system O3: attached to object 3, the origin O3 coincides with the center of gravity of object 3. The X3 axis is parallel to the X1 axis, the Z3 axis is parallel to the Z1 axis, and the Y3 axis is parallel to the Y1 axis.

- Moving coordinate system Ok: the origin coincides with the center of gravity of the body k. The Xk axis is parallel to the relative motion of the body k in the O1 coordinate system, and the Yk and Zk axes are parallel to the corresponding axes of the O1 coordinate system.

As shown in Figure 6 and Figure 7, the mechanical system is considered to be a chain configuration, containing 3 solids with 9 DOFs. Object 1 is the gun body (including the gun box, gun rack, range mechanism, direction mechanism, ammunition box, and the compacted mass of the gunner) with mass $m_1$. Body 1 has 6 DOFs: 3 rotations around the 3 axes $X_0$, $Y_0$, and $Z_0$ and 3 translational displacements along the $X_0$, $Y_0$, and $Z_0$ axes. Object 2 is a bolt of mass $m_2$. Body 2 has a translational displacement relative to body 1 along the $X_1$ axis. Object 3 is a bullet of mass $m_3$. Body 3 has 2 DOFs: translational displacement and rotational motion relative to body 1 along the $X_1$ axis. In addition, in this study, the working mechanisms of the automatic firing system (object *k*) are also taken into account (see Figure 6). These links move in directional grooves on body 1 and have a motion connection with body 2. The motion characteristics of the working links are taken into account when using the transmission linkage equations between the working link and the base link (object 2) of the automatic firing system.

Based on the analysis above, the mechanical system is set up with 10 generalized coordinates as follows $[q_j]=[q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8, q_9, q_k]$, where: $q_1$ - translational motion of body 1 along the $X_0$-axis; $q_2$ - translational motion of body 1 along the $Y_0$-axis; $q_3$ - translational motion of body 1 along the $Z_0$-axis; $q_4$ - rotation about the $X_0$-axis of object 1; $q_5$ - rotation about the $Y_0$-axis of object 1; $q_6$ - rotation about the $Z_0$-axis of object 1; $q_7$ - translational motion of body 1 along the $X_1$-axis; $q_8$ - translational motion of body 1 along the $Y_1$-axis; $q_9$ - rotation about the $X_1$-axis of object 3; $q_k$ - translation or rotation about the $X_k$-axis of object *k*. The investigated mechanical system has 9 DOFs and 10 generalized coordinates, in which the independent generalized coordinates are from $q_1$ to $q_9$. The remaining coordinates, $q_k$, depend on the generalized coordinates.

According to the document (Bien et al, 2021), the system of differential equations describing the motion of the mechanical system in space is established based on the Lagrange II equation, equation (4), (Ahmed, 2013).

$$\frac{d}{dt}\left(\frac{\partial T}{d\left(\frac{dq_j}{dt}\right)}\right)-\frac{\partial T}{dq_j}=Q_j \quad \left(j=1\div10\right) \tag{4}$$

where, $T$ – total kinetic energy of the whole system; $q_j$ – generalized coordinate $j$-th; $Q_j$ – generalized force corresponding to the generalized coordinate $q_j$.

The establishment of a system of equations determining the kinetic and potential energy of the mechanical system as well as the generalized forces is detailed in (Bien et al, 2021). The system of differential equations describing the vibrations of the mechanical system is expressed by formula (5).

$$EQS=\left\{eq_1,eq_2,eq_3,...,eq_8,eq_9\right\} \tag{5}$$

The determination of the forces acting on the mechanical system has been detailed in (Bien et al, 2021). Input parameters are determined based on design documents, and some parameters such as the center of gravity and moment of inertia of the objects are determined using Inventor software (see Figure 8). Some other parameters are measured directly on the gun. The system of equations (5) is solved numerically by the Matlab programming software presented in the document (Bien et al, 2021).

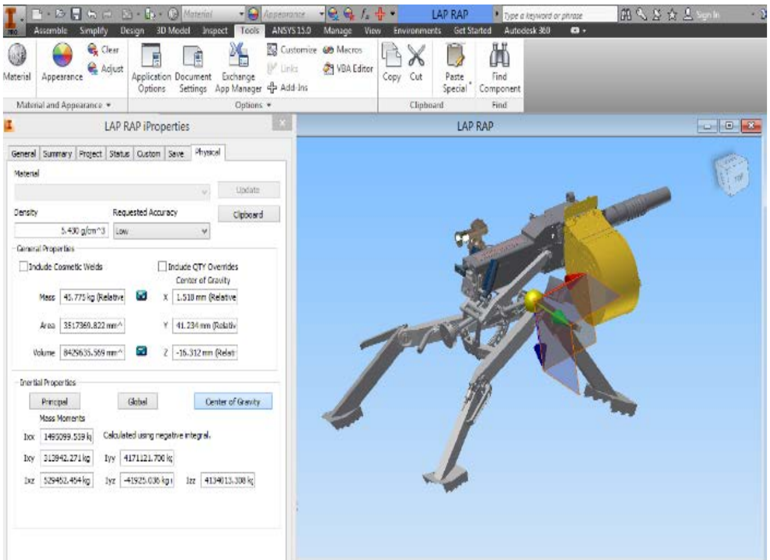



*Figure 8 – Determining input parameters using Inventor software*

### *Verification test*

To verify the vibration model of the AGS-17 grenade launcher on a tripod when firing, the authors developed a plan and conducted a test with the selected parameters as follows: the bouncing angle of the gun’s barrel in the vertical plane; the bouncing angle of the gun's barrel in the horizontal plane and the gun's backward movement. The structural diagram of the measuring system, as well as the equipment used in the experiment, have been detailed in Bien et al. (2021). The structural diagram of the experimental measurement system and the experimental deployment is shown in Figure 9. Some experimental images are shown in Figure 10 and Figure 11.

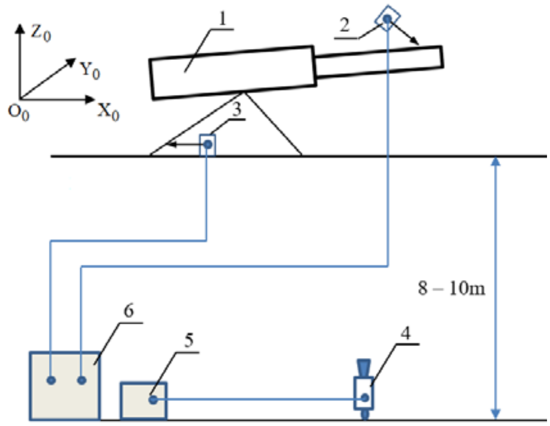



*Figure 9 – Experimental diagram: 1. Gun; 2,3. Displacement measuring device; 4. High-speed camera; 5. Computer; 6. DEWETRON 3000 device.*

*Figure 10 – Experimental layout*


*Figure 11 – Ammunition used in the test*

The results of the test are the displacement of the barrel in the vertical plane, displacement of the barrel in the horizontal plane, and the gun's backward movement. The experimental bounce angle of the gun is calculated using the following formula:

$$\alpha_y = arctg\frac{z_n}{l}; \quad \alpha_z = arctg\frac{y_n}{l} \qquad (6)$$

where: $z_n$, $y_n$ - displacement of the barrel tip relative to the initial position; $l$ - length from barrel tip to armrest.

The steps for conducting the experiment and processing the results have been detailed in previous publications of the research team (Bien et al, 2021).

## Results and discussion

### *Verifying the mathematical model*

To obtain results with high accuracy, the system of equations (5) is solved simultaneously with the system of differential equations for the interior ballistics of the AGS-17 grenade launcher (system of equations (7)). Numerical methods were used to solve the problem. Matlab software was used as a tool to help the author solve this problem. The algorithm diagram for solving the system of oscillation equations of the AGS-17 grenade launcher is shown in Figure 12.

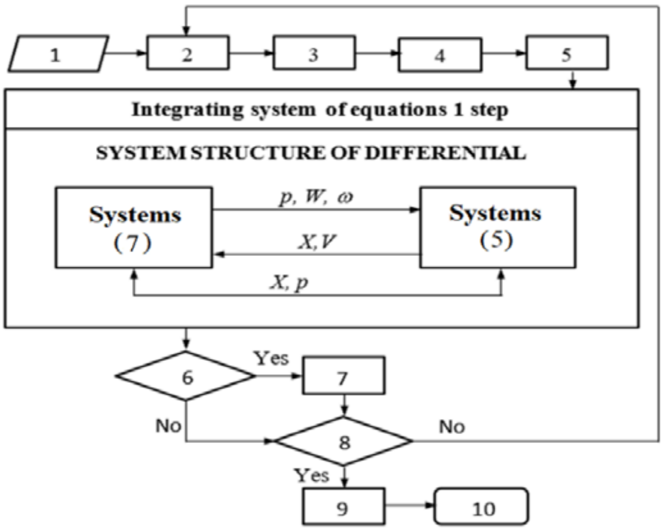



Figure 12 – Problem solving diagram

Symbols in Figure 12: 1 – enter initial parameters; 2 – determine the forces acting on the base link (bolt); 3 – determine the value of the resistance force; 4 - determine the gear ratios ki and transmission efficiency ηi; 5 – determine the coefficients ξi; 6 – check whether there is a collision; 7 – calculate the base link velocity after the collision; 8 – condition analysis to finish the calculation; 9 – record results; 10 – end.

$$\begin{cases} \dfrac{dv}{dt} = \xi_1\xi_3 \dfrac{p.S}{\varphi.m}, \\ \dfrac{\mathrm{dl}}{\mathrm{dt}} = \xi_1\xi_3.v\ , \\ \dfrac{\mathrm{dz}}{\mathrm{dt}} = \xi_2 \dfrac{p}{I_k}\ , \\ \dfrac{\mathrm{d}\omega_c}{dt} = \xi_2\chi.\omega_t\left(1+2\lambda z\right)\dfrac{p}{I_k} - \left(1-\xi_3\right)G\ , \\ \dfrac{dw}{dt} = \xi_2 \dfrac{1-\alpha\delta}{\delta}\chi.\omega_t\left(1+2\lambda z\right)\dfrac{p}{I_k} + \xi_3 Sv + S\dfrac{dx}{dt}\xi_x\ , \\ \dfrac{dp}{dt} = \dfrac{1}{w}\left\{\xi_2 \dfrac{p\chi.\omega_t}{I_k} f\left(1+2\lambda z\right) - kp\dfrac{dw}{dt} - K_{\mathrm{p}}\left(1-\xi_3\right)G\ - K_{\mathrm{t}}\,p\right\}. \end{cases} \tag{7}$$

where $v$ – bullet's velocity; $p$ – combustion gas pressure in the barrel; $S$ – cross-sectional area of the barrel; $\varphi$ – coefficient of secondary works account; $\alpha$ – covolume; $\delta$ – specific gravity of the propellant; $f$ – powder force; $k$ – adiabatic exponent; $w$ – volume of space after the bottom of the bullet; $w_0$ – initial volume of the combustion chamber; $m$ – mass of the bullet; $\omega_t$ – weight of the propellant; $\omega_c$ – weight of combustible gas; $I_k$ – pressure impulse of the combustible gas; $\chi$, $\lambda$ – geometrical properties of the propellant; $z$ – relative burning thickness of the propellant; $x$ – displacement of the bolt; $K_t$ – heat loss function; $l$ – bullet displacement in the barrel; $K_p$ – combustible gas flow function; $G$ – air flow through the barrel mouth; $\xi_1$, $\xi_2$, $\xi_3$, $\xi_x$ - the correction coefficients are determined according to Table 1.

*Table 1 - Values of correction coefficients in the system of equations (7)*

| ξ | ξ1 | | ξ2 | | ξ3 | | ξx | |
|---|---|---|---|---|---|---|---|---|
| Value | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 |
| Condition | p>po | p<po | z<1 | z≥1 | l<ld | l≥ld | x≠0 | x=0 |

where $p_o$ – shot start pressure; $l_d$ - length of the barrel with a spiral groove.

Solving the system of differential equations according to the block diagram in Figure 12 using Matlab programming software, some typical results are presented in Figures 13-18: The pressure of the combustion gas in the barrel and the velocity of the bullet are shown in Figure 13; the velocity and displacement of the bolt with respect to time are shown in Figure 14; The barrel's bounce angle in the vertical plane when firing bursts of three rounds is shown in Figure 15; The barrel's bounce angle in the horizontal plane when firing bursts of three rounds is shown in Figure 16; The barrel's bounce angle in the vertical plane when firing bursts of five rounds is shown in Figure 17; The barrel's bounce angle in the horizontal plane when firing bursts of five rounds is shown in Figure 18.

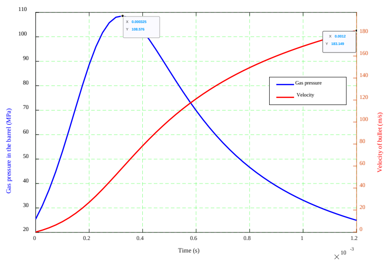


*Figure 13 – Combustion gas pressure and bullet velocity in the barrel*

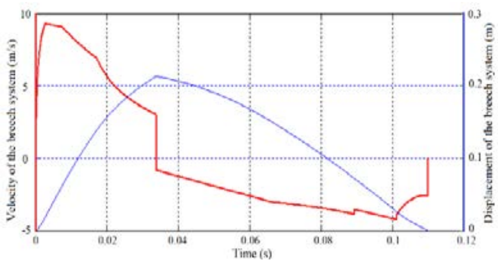
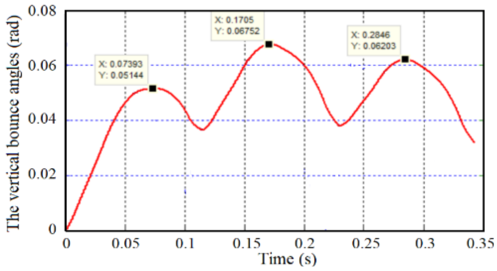
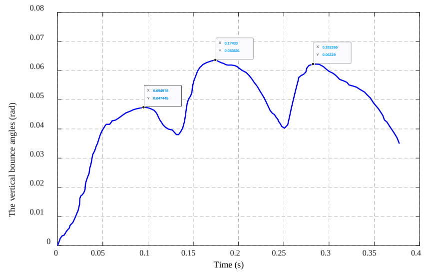



*Figure 14 – Velocity and displacement of the bolt with time*

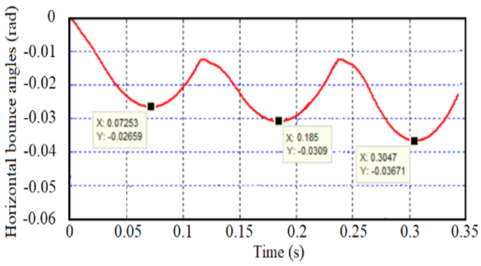



*a. Theoretical results*

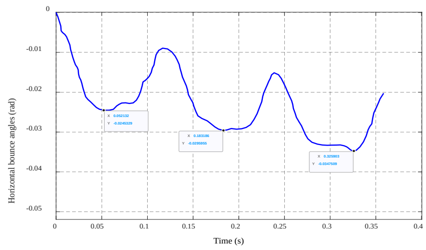



*b. Experimental results*

*Figure 15 – The barrel's bounce angle in the vertical plane when firing bursts of three rounds*

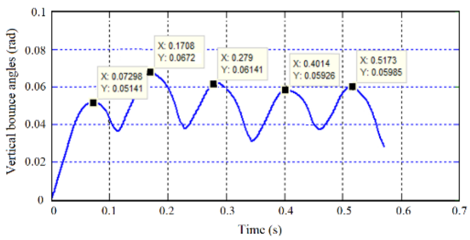



*a. Theoretical results*

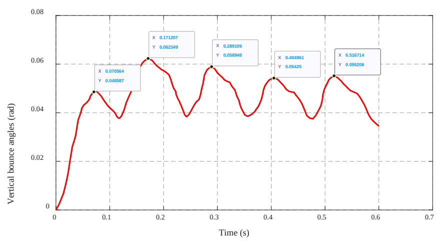



*b. Experimental results*

*Figure 16 – The barrel's bounce angle in the horizontal plane when firing bursts of three rounds*

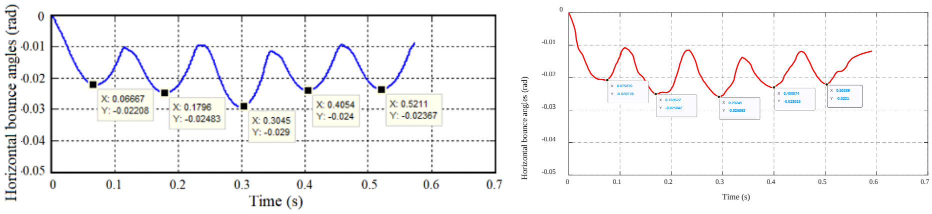



*a. Theoretical results*




*b. Experimental results*

*Figure 17 – The barrel's bounce angle in the vertical plane when firing bursts of five rounds*




*a. Theoretical results* *b. Experimental results*

*Figure 18 – The barrel's bounce angle in the horizontal plane when firing bursts of five rounds*

The obtained results can be interpreted as follows:

- Solving the interior ballistic problem gives quite reliable results, with the maximum combustion gas pressure in the barrel being 108.576 MPa (Figure 13), while the published measurement results are 112.58 MPa (Bien et al, 2021), and the error is 3.566%. The maximum velocity of the bullet is 183.149 m/s (Figure 13), whereas the published measurement results are 187.88 m/s (Bien et al, 2021), and the error is 2.52%.

- The cycle of a firing is 0.1092 s (Figure 14), the corresponding theoretical rate of fire is 549 rds/min, the published rate of fire is 517 rds/min (Bien et al, 2021), and the error is 6.18%.

- The comparison between the theoretical calculation results and the experimental measurement results shows that (Figures: 15-18): the mathematical model and solution method are consistent and reliable. The error is within the allowable limit (less than 10%). This dynamic model can be used in the further study of the AGS-17 grenade launcher.

## *Investigating the effect of the oil type used in the hydraulic buffer*

The buffer force has a great influence on the operation of the automatic firing system as well as the vibration of the gun when firing in series. According to formulas (2) and (3), this force depends on many factors such as the type of oil used in the hydraulic buffer mechanism, the velocity of movement of the barrel, the cross-section of the oil flow, etc. Within the framework of the article, the authors focus on investigating the effects of changing the oil types used in the hydraulic buffer and changing the oil flow cross-section on the stability of the grenade launcher when firing in series.

During the use of the AGS-17 grenade launcher, the amount of oil in the buffer mechanism will be consumed and degraded. Oil changes and additions should be carried out regularly. However, if only a specific type of oil can be used, it will cause significant difficulties during operation and use, especially in combat conditions. For this reason, the article investigates the influence of some oils used for the buffer mechanism on the stability of the gun when firing. These oils are commonly used in weapons. The basic characteristics of the oils used in this study are presented in Table 2.

*Table 2 – Properties of some hydraulic oils*

| Characteristic | Oil Steol-M | Oil AY | Petroleum |
|---|---|---|---|
| Specific weight (γ) | 1.09 ÷ 1.1 (kG/dm3) | 0.89 ÷ 0.9 (kG/dm3) | 0.78 ÷ 0.83 (kG/dm3) |
| Evaporation temperature (td) | > 57oC | > 45oC | - |
| The boiling temperature at atmospheric pressure (tk) | 89 ÷ 92oC | 350oC | 300oC |
| Viscosity: | | | |
| 0oC | 0.279 | 1.65 | - |
| 20oC | 0.109 | 0.4 | - |
| 40oC | - | - | 0.1 ÷ 0.9 |
| 50oC | 0.37 | 0.106 | - |

Solve the system of differential equations for the oscillations of the AGS-17 grenade launcher according to the algorithm diagram shown in Figure 12, while changing the type of oil used in the hydraulics buffer; other parameters remain unchanged. Some typical results are given as follows, Figures 19 - 22.

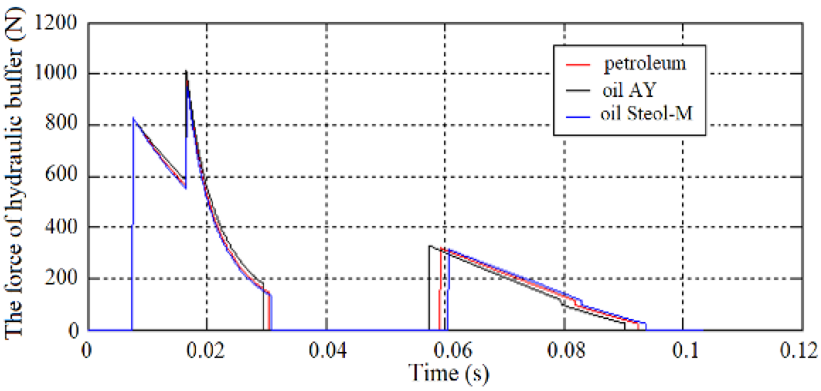



*Figure 19 – Force of hydraulic buffer*

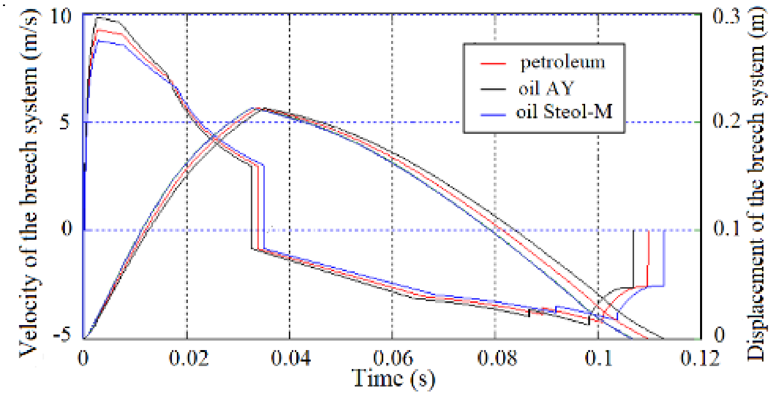



*Figure 20 – Velocity and displacement of the bolt*

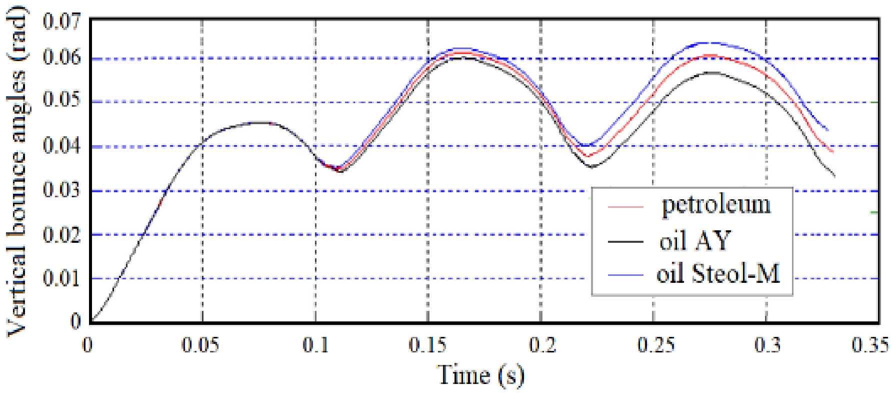



*Figure 21 – The barrel's bounce angle in the vertical plane when firing bursts of three rounds*

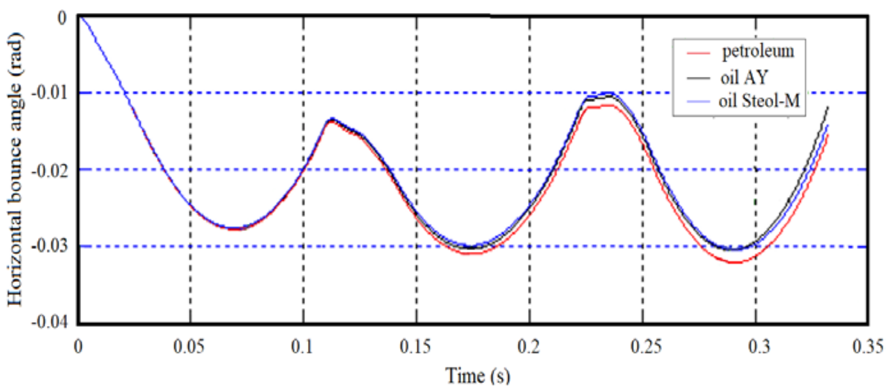



*Figure 22 – The barrel's bounce angle in the horizontal plane when firing bursts of three rounds*

The obtained results can be commented on as follows:

The hydraulic braking force, displacement, and velocity of the bolt chang when the oil type used in the hydraulic buffer is changed (Figures 19-20). However, the survey results show that the variation of the bounce angle in the vertical plane (Figure 21) and the bounce angle in the horizontal plane (Figure 22) of the barrel is relatively small. This is explained by the fact that these oils have similar properties and can be substituted for each other during operation and use. This facilitates the repair and use of the gun.

### *Influence of the oil flow cross-section in the hydraulic buffer mechanism*

According to the design characteristics of the AGS-17 automatic grenade launcher, the oil flow area in the hydraulic buffer includes the oil hole area on the piston, the oil flow area on the piston pipe, and the gap between the piston and the piston pipe (Figure 3).

Changes in the oil flow area of the hydraulic buffer may be due to manufacturing tolerances and wear over time. This can change the hydraulic braking force compared to the original design, causing instability in the gun. Investigating the influence of this factor on the stability of the gun helps designers determine the allowable tolerance range during manufacturing as well as repair. The system of differential equations describing the gun's oscillation is solved according to the diagram in Figure 12, while keeping other parameters unchanged and varying the cross-sectional area of oil flow. The results are obtained as shown in Figures 23-25.

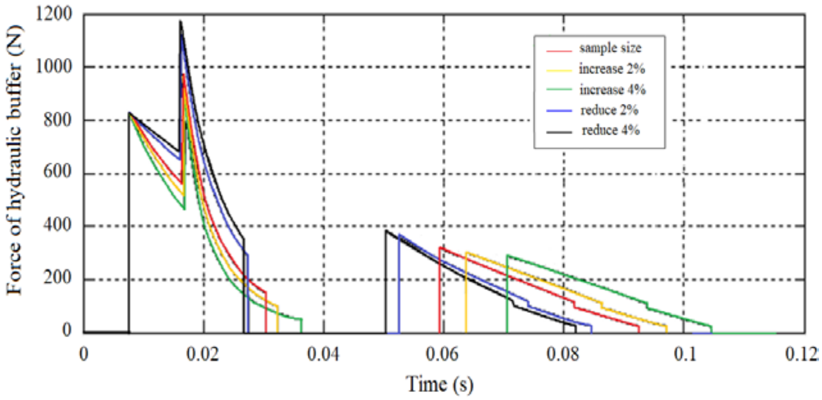



*Figure 23 – Hydraulic braking force with different oil flow area*

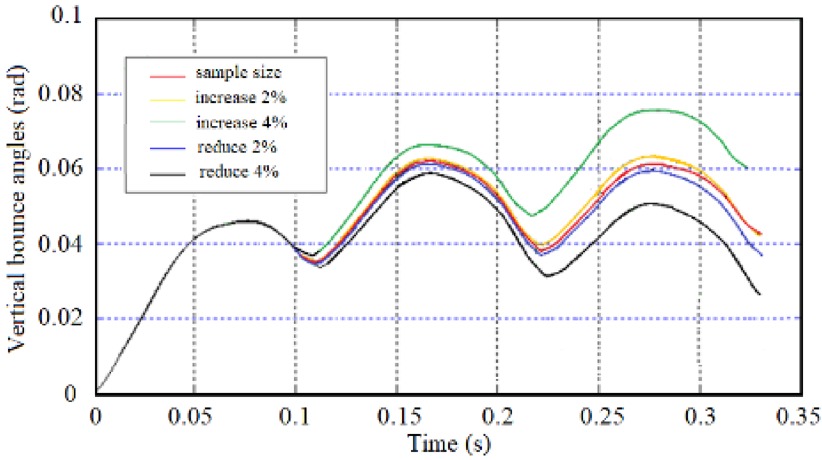



*Figure 24 – The barrel’s bounce angle in the vertical plane*

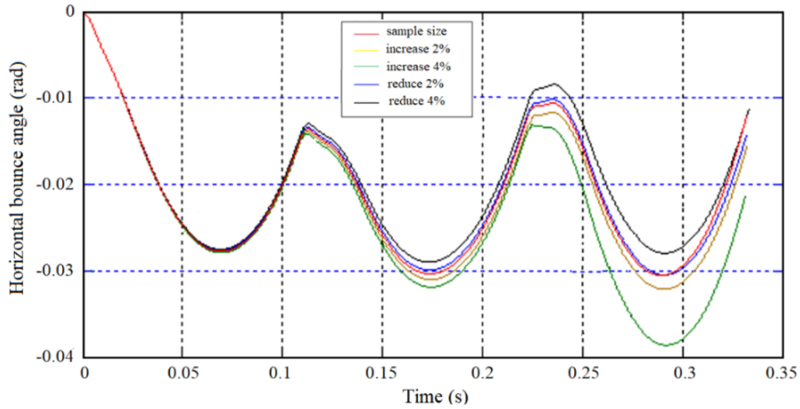



*Figure 25 – The barrel’s bounce angle in the horizontal plane*

The obtained results can be commented on as follows:

The hydraulic braking force changes significantly when changing the oil flow area in the hydraulic buffer mechanism (Figure 23). This change causes instability in the gun. The vibration of the system is inversely proportional to this change in cross-section (Figures 24-25). According to the survey results, to ensure that the vertical bounce angle and the horizontal bounce angle do not exceed the allowable limit, the increase or decrease in the oil flow cross-section must not exceed 2% (0.07 rad for vertical bounce angle and 0.05 rad for horizontal bounce angle) from the 2$^{nd}$ shot onwards when the system oscillates. This limit is determined by testing the standard Russian gun model and the results of solving the stability problem of the system according to the model presented in documents (Bien et al, 2021). This will be a reliable theoretical basis for the designer to refer to during the design of hydraulic buffer mechanisms, giving the allowable tolerance range when manufacturing products.

## Conclusion

The content of this study presents a method for setting up a dynamic model of small automatic weapons mounted on tripods when firing in series. The mathematical model is established based on the theory of many-body mechanics and the Lagrange II equations. In this dynamic model, the influence of the elastic ground and the impact of the gunner are taken into account through elastic-damping connections. The AGS-17 grenade launcher was selected for dynamic simulation and validation of the mathematical model. Based on the obtained results, some main conclusions can be summarized as follows:

- The content of the research has perfected the dynamics model of an automatic weapon mounted on a tripod when firing in space. The results of weapon system dynamics analysis can be performed at locations with different background characteristics.

- A detailed diagram for solving the system of oscillation differential equations of the weapon system on a tripod is established. This diagram can be used as a reference source for researchers when assessing the firing stability of automatic weapons on racks.

- The research content has also provided a measurement method with modern high-precision equipment to evaluate the firing stability of the weapon system.

- The analytical results ensure high accuracy and reliability. This is a reliable scientific document for the optimal design of the overall structure of the weapon system.

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## Sveobuhvatna studija uticaja strukturnog parametra hidrauličnog amortizera na stabilnost gađanja bacača granata

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OBLAST: matematika, mašinstvo
KATEGORIJA (TIP) ČLANKA: originalni naučni rad

*Sažetak:*

*Uvod/cilj: Glavni cilj rada je predstavljanje nove metode za procenu stabilnosti automatskog naoružanja montiranog na tronožac tokom rafalne paljbe.*

*Metode: Matematički model je uspostavljen na osnovu teorije mehanike sistema sa više tela. Lagranževa jednačina druge vrste korišćena je za formiranje sistema diferencijalnih jednačina kretanja mehaničkog sistema. Matematički model uzima u obzir uticaj elastičnosti podloge i uticaj* *nišandžije putem elastično-prigušnih veza. Dinamičke simulacije sprovedene su na bacaču granata AGS-17. Dobijeni rezultati proračuna su upoređeni sa eksperimentalnim rezultatima radi verifikacije predloženog modela.*

*Rezultati: Rezultati poređenja pokazuju neočekivano visok nivo podudaranja između teorijskog modela i eksperimentalnih rezultata. Greške u početnoj brzini projektila i brzini paljbe iznose 2,52%, odnosno 6,18%. Na osnovu teorijske osnove matematičkog modela, ispitan je uticaj pojedinih strukturnih parametara hidrauličnog amortizera na stabilnost gađanja automatskog bacača granata. Rezultati istraživanja predstavljaju pouzdanu teorijsku osnovu za unapređenje, projektovanje i proizvodnju hidrauličnih amortizera za bacače granata, kao i za automatsko naoružanje uopšte.*

*Zaključak: Rezultati istraživanja prikazani u ovom radu pružaju visoku tačnost i pouzdanost. Rad predstavlja pouzdan naučni dokument za optimalno projektovanje strukture sistema naoružanja.*

*Ključne reči: bacač granata, stabilnost gađanja, automatsko naoružanje, sistemi automatske paljbe, hidraulični amortizer.*

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