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THE METHOD OF STRENGTHENING OF DURABILITY OF A MORTAR BARREL

The subject of the article is an assessment of the possibility of improving the security of the personnel of units during the operation of mortars. **The purpose of the article** is to study the possibility of increasing the strength of mortar barrels. **The task** is to analyze the causes of the increased deaths of mortar fire teams during the operation of mortar barrels. Identify the main areas of work to prevent mine explosions in the mortar channel and identify ways to eliminate them by improving the methods of combat use; keep security measures during the shooting; increase the technical training of the personnel of the units; development and use of new technical solutions for the development of mortars. The work considers and suggests an analytical method for increasing the strength of mortars, based on the application of the principle of combined structures. As a result of the researches the model of definition of the resulted pressure and limiting pressure in the combined cylinders is offered. The results of calculating the limiting pressure in cylinders are given in the paper. **Conclusions:** the article investigates the possibility of increasing the strength of mortars. The theory of combined cylinders was proposed to increase the strength of mortars. The calculation of the internal pressure for the construction of the mortar in the form of combined cylinders is carried out. Further studies are related to the fact that the theory of combined cylinders creates prospects both in the development of high-pressure technology and in the creation of lighter and more stable structures.

Keywords: a mortar barrel; a powder gases; a rate of fire; a cylinder; a caliber; a cylinder radius; a security measures during the shooting; a pressure in the barrel construction; a combined structures; an internal stress and ultimate pressure; a fracture.

Introduction

Despite the intensive development of weapons on new physical principles, advanced modern weapons are in the arsenal of modern armies. By boosting the strength of the army, the commandment of the armed forces of different countries pays much attention to the improvement of weapons, including mortars. When conducting combat operations, mortars should be actively used in the interests of small units of the tactical level (platoon-company-battalion) together with other means of armed struggle to defeat the enemy's manpower and equipment. It is believed that they will be the main means of fire support for company tactical groups on the battlefield [1].

In recent decades, various countries are working to improve mortar weapons: their weight and weight of ammunition is reduced; improved tactical and technical characteristics; homing mines are created; universal fuses used in various systems are being developed; Improved fire control system and tactics of action.

Analysis of the problem and formulation of the problem. Experience in the combat use of mortar weapons in local wars and international conflicts of the late XX - early XXI century. showed that mortars, as a class of weapons, were widely used. It was this armament that became one of the main artillery means of fire support for the infantry units of the tactical level (platoon-company-battalion) [2]. This is due to the following advantages of mortars [3]:

- the mortar has a sufficiently high accuracy and range of fire, ensuring a reliable defeat of the enemy's manpower, weapons and unarmored equipment in battle;
- the mortar gives the possibility of a relatively hidden fire (a closed fire position and a small force of sound during a shot make it difficult for the enemy to detect the calculation);
- a high rate of fire - from ten to twenty rounds per minute provides a high density of fire in the critical moments of combat;
- the relatively low weight of weapons and ammunition increases the maneuverability of infantry units and reduces their dependence on the fire of supporting artillery, which is not always effective due to the time spent on passing teams and the possibility of hitting their troops with a reduced radius of safe disposal.

However, the increasing number of deaths of mortar combat crews (during exercises) with the rupture of barrels pose new challenges for the developers of this type of weapon to improve the safe operation of mortars (Fig. 1).

Based on the results of the work of the commissions investigating the deaths of mortar fire teams, the main direction to prevent the explosion of mines in the mortar barrel during double loading is:

- improvement of methods of combat employment and exploitation of mortars;
- observance of security measures during the shooting;
- increase of technical training of personnel;
- use of new technical solutions in the development of mortars.

It should be noted that methods of increasing the strength of the barrels are not exhausted [4].

Fig. 1. A mortar barrel rupture

The classic mortar consists of a barrel, bipods are devices for giving the barrel the desired elevation angle (for example, a biped) and a base plate transmitting the impulse to recoil to the ground (Fig. 2).

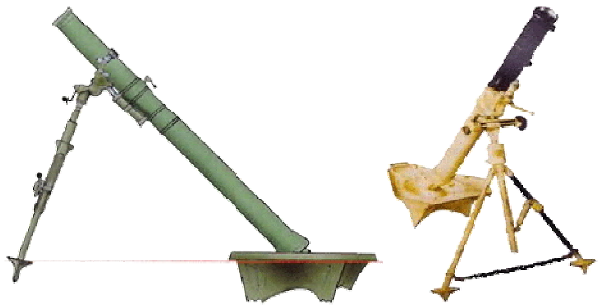

Fig. 2. Appearance of a classic mortar

The barrel is the main part of a firearm intended for pushing a mine with a certain initial velocity and providing it with a stable flight in a given direction. The barrel is a pipe on a support, closed on one side, the bottom of which is the drummer. When a mortar mine is placed in the barrel, the drummer ignites the propellant charge. His burning pushes the projectile out of the barrel (Fig. 3). The thermal energy from the combustion of the powder charge determines the parameters of the internal ballistics: the speed of the mine when it moves in the barrel channel, the direction and initial velocity of the mine at the time of its departure from the barrel [5].

Fig. 3. A moment of a fire of mines from the barrel of a mortar

The main functions that the barrel must perform [6]:

- creation of conditions for complete combustion of the powder charge;
- mine-making necessary flight direction;
- setting the required initial speed of flight.

Mortar barrels are made of carbon steel with improved thermal conductivity.

When the charge is combusted, the powder gases in the barrel of the weapon develop a very high pressure. The lowest pressure in the muzzle of the barrel at the time of the launch of the mine is equal to several hundred atmospheres.

In order for the barrel to withstand such a preasure, during its manufacture, much attention is paid to the strength of the barrel.

The strength of the barrel depends on the thickness of its walls and the quality of the metal.

Given the practical operation of the mortar, the thickness of the walls of the barrel is calculated with such a margin of strength that it can withstand the pressure of the gases is much greater than normal. Therefore, the strength of the barrel always exceeds the normal pressure of the powder gases by several hundred and even thousands of atmospheres.

When firing the barrel walls, resisting the pressure of gases, expand. The strength of the barrel is calculated so that the metal is subjected only to elastic expansion deformations: at the gas pressure it expands, and after the pressure ceases to take its original dimensions. If, however, the pressure in the barrel exceeds the value to which the barrel strength is calculated, then a residual deformation will occur and the barrel will be blown or broken.

In the scientific literature, much attention is paid to the determination of stresses arising in the walls of the barrel during a shot [7, 8, 9].

Depending on the level of prepressure, which appears in the walls of the barrel before the shot, the barrel are distinguished and they are not milled. Before the shot in the walls of the non-fretting barrel, there is no specially called prestress. Only small stresses arising during production processes, for example heat treatment, can appear in it. Non-fretting barrels are widely used in small arms and artillery weapons, with the exception of barrels under the influence of very high pressure (above 300 MPa) [8].

The non-fretting barrel consists of winding several layers of steel wire on the pipe of the barrel, or in putting on rings, liners or pipes heated to a temperature of 700-7500 K. After cooling, the reinforcing elements compress the barrel tube, causing in it a preliminary radiation pressure directed to the opposite side of the stresses arising from the pressure of the powder gases during the shot. Fretted barrels (multilayered) were used in guns in which the maximum pressure of powder gases exceeded 400 MPa. They could withstand the load (pressure) by 50% greater than the unreturned barrels.

Currently, mainly used autofretched barrels, in which the increase in strength of the barrel is achieved by strengthening the material and prestressing in the walls of the barrel. Auto-fretting occurs as a result of an increase in the plasticity boundary of the inner layers of the barrel bore, which occurs as a result of a load caused by an internal pressure (for example, created hydraulically) of 1000-1400 MPa (about twice the maximum pressure of the powder gases). Then deformation of the inner layers of the barrel occurs constantly (reinforcement of the material), and external – elastic. Deformable elastic layers cause in the layers, deformed constantly, preliminary stresses directed in the opposite direction from the stresses arising during the shot.

Calculations of stresses in thick-walled cylinders were carried out by the scientists G. Lam and A.V. Gadolin, formulas for determining the dimensions of multilayer cylinders, calculated by the theory of strength of A. Guber, R. Mises, and G. Henki under the influence of internal pressure, were proposed by I.M. Naidich and A.M. Rozen [8, 9].

Different researchers have proposed various methods of increasing the strength of the barrel [6-9], confirmed by experimental data.

However, the proposed methods do not allow to ensure the safety of calculations during the mine explosion in the barrel channel.

Thus, the data presented indicate that the theory of the mechanical strength of mortar barrels has not received its full completion, the processes occurring in this case have not been fully studied. Further improvement of mortar barrels can be achieved by applying the optimal combination of new materials and modern structural and circuit solutions.

A complex experimental and calculation study of the features of the process of mine explosion in the barrel channel is the most important condition for reliable forecasting of calculation results and can significantly increase the efficiency of design solutions. Such a scheme of research (study of the behavior of structural elements under real dynamic loading conditions, numerical and experimental modeling) allows us to create the basis for the development and justification of recommendations for rational design, and the choice of materials, their structural state, which increase the efficiency of their use in structures.

The scientific basis for studies of the loading process of a mortar barrel during a shot is: the theory of elasticity, plasticity and strength of materials, the theoretical basis for ensuring the survivability of weapons in combat operations, the theory of the reliability of weapon models, mathematical modeling, mathematical planning of experiments, methods of bonded structures, coupled cylinders.

The purpose of the article is to study the possibility of increasing the strength of mortar barrels.

Main part

The following forces act on the barrel of a mortar during a shot [6]:

– force of pressure of powder gases, causing stresses and deformations in the walls of the barrel;

– axial and transverse components of the friction force of the outer shell of the mine on the inner surface of the bore of the barrel;

– the forces of inertia arising in the walls of the barrel due to the rapid increase in the pressure of gases;

– Axial forces due to the method of securing the barrel.

A precise account of all these forces makes the solution of the problem of calculating the barrel for strength difficult. Therefore, when calculating the barrels for strength, a number of assumptions make it possible to reduce the difficult problem of calculating the barrel to the calculation of a thick-walled cylindrical tube. These assumptions include the following:

– the friction forces of the outer shell of the mine on the surface of the barrel channel cause negligibly small axial stresses in the walls of the barrel;

– loads experienced by the barrel, are static in nature with the shot;

– the barrel material is homogeneous and isotropic, the pressure at each point is normal to the surface, the shape of the section remains constant during deformation, and any cross-section remains flat.

The determination of stresses arising in the construction of a mortar barrel during a shot is based on the theory of calculation of the strength of thick-walled cylinders [8, 9, 10].

Consider the process of firing from mortar when an internal pressure arises in the barrel $p_в$ (external pressure $p_н$=0). We use the known materials of the formula [9,10] to calculate the normal stresses in the tangential σ_θ and radial directions σ_r:

$$\sigma_r = \frac{R_B^2}{R_H^2 - R_B^2}\left(1 - \frac{R_H^2}{r^2}\right) \cdot p_B;$$

$$\sigma_\theta = \frac{R_B^2}{R_H^2 - R_B^2}\left(1 + \frac{R_H^2}{r^2}\right) \cdot p_B,$$

where R_B – internal barrel radius;

R_H – outer barrel radius.

Note that radial stresses σr in this case are everywhere compressive, and circumferential σθ are everywhere tensile (that is, σ1 = σθ, σ3 = σr) and reach the highest values on the inner surface of the cylinder ($r = R_B$):

$$\sigma_r = -p_B;$$

$$\sigma_\theta = \left(1 + \frac{R_B^2}{R_H^2}\right) \Bigg/ \left(1 - \frac{R_B^2}{R_H^2}\right) \cdot p_B. \qquad (1)$$

Let us write the strength condition for the third theory of strength:

$$\sigma_{экв.3} = \sigma_1 - \sigma_3 \le [\sigma].$$

Taking (1) into account, we find that

$$\sigma_{экв.3} = 2 \Bigg/ \left(1 - \frac{R_B^2}{R_H^2}\right) \cdot p_B \le [\sigma].$$

We determine the allowable internal pressure in the cylinder with an unlimited increase in the wall thickness, that is, for $R_n \to \infty$. In this case

$$\sigma_{экв.3} = 2 \cdot p_B \le [\sigma];$$

$$p_B = \frac{[\sigma]}{2}.$$

As can be seen from the last expression, starting with a certain internal pressure [$p_в$], increasing the wall thickness of the cylinder ceases to be an effective way to increase strength, the allowable pressure tends to half the permissible voltage. Thus, the maximum permissible pressure for a single cylinder (barrel) can not be more than half the allowable voltage. Given that the ultimate strength of the best weapon steels is 1000 MPa [6], the maximum permissible pressure for a single barrel is 500 MPa (5000 атм). When a mine explodes, the pressure in the barrel reaches a value (5-30) GPa (50-300 thousand atm), a single barrel will be broken [11].

Further increase in strength is possible either through the use of stronger materials (increase [σ]) or through measures aimed at creating external pressure on the outer surface of the barrel. For this, for example, it is possible to make the cylinder compound, and its inner layer must be pressed with interference into the outer layer, thereby creating an external pressure on the surface of the inner layer [8, 9].

However, the initial tightness is one of the widely known ways to improve the performance of structures, in general, and the strength of the barrels, in particular. A. Guber has found a way to obtain the same result as in compound cylinders without a gap, not a heated nozzle with interference, but by forming between the cylinder components a gap into which a gaseous or liquid filler is injected under pressure. The theory of combined cylinders was developed by V.I. Zayarnyi [8].

Consider the construction of a mortar, in which instead of one thick-walled cylinder (barrel) several combined ones are used, the pressure between the walls of which can vary. The permissible pressure in the inner cylinder (barrel) in this case is determined by the formula [8]:

$$p_B = \sigma \cdot \frac{C^2 - 1}{2 \cdot C^2 \cdot (1 - K_P)},$$

где $$C = \frac{R_H}{R_B}, \quad K_P = \frac{p_H}{p_B}.$$

For the outer cylinder:

$$K_{P0} = \frac{p_{H0}}{p_{B0}} = 0.$$

and the allowable pressure will have the form [8]:

$$p_0 = \sigma \cdot \frac{C_0^2 - 1}{2 \cdot C_0^2}.$$

For any intermediate cylinder, the allowable internal pressure is written as:

$$p_{Bi} = \sigma \cdot \frac{C_i^2 - 1}{2 \cdot C_i^2 \cdot (1 - K_{Pi})}.$$

Allowable internal pressure in the inner cylinder (barrel) with n cylinders is obtained by the formula:

$$p_B = \sigma \cdot \frac{C^2 - 1}{2 \cdot C^2} + \sum_2^{n-1} \sigma_i \frac{C_i^2 - 1}{2 \cdot C_i^2 (1 - K_{Pi})} + \sigma_0 \cdot \frac{C_0^2 - 1}{2 \cdot C_0^2}.$$

From this formula it follows that the value of the internal pressure pB depends on: the value of the ratio C of the outer radius to the internal, the value of the ratio of the external pressure to the internal pressure, the magnitude of the permissible voltage and the number of cylinders. The amount of permissible voltage depends on the properties of the material, the operating conditions of the cylinders and the loading method.

For aligned cylinders with

$$R_H \to R_B, \; C \to 1,$$

permissible pressure regardless of the magnitude K_p tends to zero. If

$$R_H \to \infty, \; C \to \infty,$$

то the permissible pressure is taking a number of values

$$p_{Bi} = \frac{\sigma}{2 \cdot (1 - K_P)}.$$

depending on the size K_p.

When Kp = 0, we get the result for a single cylinder. If Kp tends to 0.5, then the allowable internal pressure for the superimposed cylinder is equal to the allowable voltage.

Determine the value of the internal pressure in the barrel for the design of the mortar in the form of aligned cylinders with the following initial data: the internal radius of the barrel of the mortar

RBC = 0.06 m = 60 mm;

outer radius of the mortar barrel

RHC = 0,07m = 70mm;

internal radius of the first combined cylinder

RB1 = 0,105m = 105mm;

outer radius of the first co-located cylinder

RH1 = 0,115 m = 115 mm;

(the hydraulic gaps between the cylinders and their thickness are the same),

C = 1.5; when KP = 0.9; [σ] = 1000 MPa.

The formula for determining the maximum pressure for KP = 0.9 has the form [8]:

$$p_{мах} = 5 \cdot \sigma \cdot \left(1 - 1/C^2\right) = 3 \cdot \sigma = 3000 МПа.$$

Assuming that the internal pressure during the explosion of a mine in the barrel of 15,000 MPa, the design of the mortar will consist of 5 aligned cylinders.

Conclusions

1. The article investigates the possibility of increasing the strength of a mortar barrels.

2. It was proposed to use the theory of combined cylinders to increase the strength of a mortar barrels.

3. The calculation of the internal pressure for the construction of the mortar in the form of combined cylinders is carried out.

4. Further studies are related to the fact that the theory of combined cylinders creates prospects both in the development of high-pressure technology and in the creation of lighter and more stable structures.

References

1. Dymchinsky, N.V. (1984), "Combat application of mortars", *Foreign Military Review*, No. 8, pp. 34-35.
2. Musienko, A.V. (2010), "Artillery of infantry and not only: the experience of combat use of mortar weapons in local conflicts of the XX - early XXI century", *Weapons*, No. 12, pp. 38-46.
3. O'Malley, T.J. (2000), *Modern artillery: guns, MLRS, mortars* (Original name: ARTILLERY: GUNS AND ROCKET SYSTEMS), Publishing house "EKSMO-Press", Moscow, 159 p.
4. Zgurets, S. (2018), *The explosion of the mortar "Hammer"*, available at: https://censor.net.ua/b3075511 (last accessed on May 30, 2018).
5. Shirokorad, A.B. (2000), *Domestic mortars and rocket artillery*, Harvest Publishing House / AST, Minsk, 206 p.
6. Shvinning, V.I. (1937), *The design and material of firearm barrels*, Artillery Academy, Leningrad, 201 p.
7. Rozov, Yu.G., Steblyuk, V.I., Sidorenko, Yu.M. and Shkarluta D.B. (2012), "Estimation of the effect of the barrel channel profile on the strength of small arms", *Artillery and small arms*: Int. Scientific and Technical Journal, No. 1, pp. 35-39.
8. Zayarny, V.I. (1972), *Fundamentals of the theory of combined vessels*, The Publishing House of Lviv University, Lviv, 122 p.
9. Terebushko, O.I. (1984), *Fundamentals of the theory of elasticity and plasticity*, Science, Moscow, 320 pp.
10. Deebir, A.G., Makarov, O.V., Pekelny, N.I., Yudin, G.I. and Grebennikov M.N. (2007), *Practical calculations on the strength of structural elements*, National Aerospace University "Kharkiv Aviation Institute", Kharkiv, 102 p.
11. Ershov, A.P. (2000), "Explosion", *Physics. Soros Educational Journal*, Vol. 6, No. 1, pp. 85-90.

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Метод підвищення міцності стволів мінометів

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Предмет статті - оцінка можливості підвищення безпеки особового складу підрозділів при експлуатації мінометів. **Науковою основою** досліджень процесу навантаження ствола міномету при пострілі є: теорія пружності, пластичності і міцності матеріалів, теоретичні основи забезпечення живучості зброї при веденні бойових дій, теорія надійності зразків озброєння, математичне моделювання, математичне планування експериментів, методи скріплених конструкцій, суміщених циліндрів. **Мета статті** - дослідження можливості підвищення міцності стволів мінометів. **Завдання -** проаналізувати причини випадків загибелі бойових розрахунків мінометів, що почастішали, при розриві стволів під час експлуатації мінометів. Виявити основні напрями роботи по відвертанню вибухів мін в каналі ствола мінометa і визначити шляхи їх усунення за рахунок удосконалення способів бойового застосування; дотримання заходів безпеки при проведенні стрільб; підвищення технічної підготовки особового складу підрозділів; розробки і використання нових технічних рішень при розробці мінометів. **Результати досліджень.** У роботі розглянутий і запропонований аналітичний метод підвищення міцності стволів мінометів, на основі застосування принципу поєднаних конструкцій. В результаті проведених досліджень запропонована модель визначення приведеної напруги і граничного тиску в поєднаних циліндрах. У роботі приведені результати розрахунку граничного тиску в циліндрах. **Висновки:** в статті досліджена можливість підвищення міцності стволів мінометів. Запропоновано для підвищення міцності стволів мінометів використати теорію поєднаних циліндрів. Проведено розрахунок величини внутрішнього тиску для конструкції міномета у вигляді поєднаних циліндрів. Подальші дослідження пов'язані з тим, що теорія поєднаних циліндрів створює перспективи як в розвитку техніки високих тисків, так і в створенні легших і міцніших конструкцій.

Ключові слова: міномет; ствол; порохові гази; скорострільність; циліндр; калібр; радіус циліндра; заходи безпеки при проведенні стрільб; напруга в конструкції ствола; поєднані конструкції; внутрішня напруга і граничний тиск; розрив.

Метод повышения прочности стволов минометов

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Предмет статьи – оценка возможности повышения безопасности личного состава подразделений при эксплуатации минометов. **Научной основой** исследований процесса нагрузки ствола миномета при выстреле являются: теория упругости, пластичности и прочности материалов, теоретические основы обеспечения живучести оружия при ведении боевых действий, теория надежности образцов вооружения, математическое моделирование, математическое планирование экспериментов, методы скрепленных конструкций, совмещенных цилиндров. **Цель статьи** – исследование возможности повышения прочности стволов минометов. **Задача** – проанализировать причины участившихся случаев гибели боевых расчетов минометов при разрыве стволов во время эксплуатации минометов. Выявить основные направления работы по предотвращению взрывов мин в канале ствола миномета и определить пути их устранения за счёт усовершенствования способов боевого применения; соблюдения мер безопасности при проведении стрельб; повышения технической подготовки личного состава подразделений; разработки и использования новых технических решений при разработке минометов. **Результаты исследований**. В работе рассмотрен и предложен аналитический метод повышения прочности стволов минометов, на основе применения принципа совмещенных конструкций. В результате проведенных исследований предложена модель определения приведенных напряжений и предельного давления в совмещенных цилиндрах. В работе приведены результаты расчета предельного давления в цилиндрах. **Выводы:** в статье исследована возможность повышения прочности стволов минометов. Предложено для повышения прочности стволов минометов использовать теорию совмещенных цилиндров. Проведен расчет величины внутреннего давления для конструкции миномета в виде совмещенных цилиндров. Дальнейшие исследования связаны с тем, что теория совмещенных цилиндров создает перспективы как в развитии техники высоких давлений, так и в создании более легких и прочных конструкций.

Ключевые слова: миномет; ствол; пороховые газы; скорострельность; цилиндр; калибр; радиус цилиндра; меры безопасности при проведении стрельб; напряжения в конструкции ствола; совмещенные конструкции; внутреннее напряжение и предельное давление; разрыв.