The forcing pressure stabilization during shot

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Abstract. The paper presents results of the energy expenditures evaluation for cutting the leading belt in barrel channel grooves during shot. The effect of the airspace diameter tolerance on a change of a forcing value and on an energy consumption when cutting artillery shell into the BB rifling has been investigated. It is shown that the artillery shell with a new type of leading belt provides a reduction of the indicated energy expenditures by almost half, which leads to stabilization of the boost pressure and, as a result, to an ammunition dispersion reduction. The obtained results were implemented at different utility models for artillery shells.

1. Introduction
The search for ways to improve the technical characteristics (accuracy, range, etc.) of an artillery projectile (AP) while reducing its cost is one of the urgent design problems. A possible solution is to change the design of the leading belt (LB).

The influence of the projectile design on the processes occurring during the shot depends on the gunpowder gases energy, which was spent on cutting the ammunition into the barrel bore (BB) rifling. It changes depending on the material, shape, dimensions of the projectile and tolerances (diameter of the airspace, width of the airfoil etc.) [1,2]. On the one hand, this part of the energy is spent on the necessary profile formation of the leading belt, that is, plastic deformation of the LB material in order to ensure guidance along the rifling of the bore. And on the other hand, part of the energy is spent to create the necessary forcing pressure with gunpowder gases at the moment of completion of the airfoil profile, that is, the greatest impulse which ensures the maximum acceleration of the projectile [3-7].

LB designs with the dispersion of the geometric parameters within the tolerance affect the change in the amount of gunpowder gases energy, which affects the dispersion of the projectile velocity from shot to shot. Thus, by controlling the design of the LB, it is possible to minimize the dispersion of the forcing pressure value during shots, thereby increasing the overall accuracy of shooting.

The aim of the work is to assess the projectile design influence on the expenditure of a gunpowder gases energy during the formation of the projectile leading belt profile in the barrel bore. This is achieved by establishing the range of energy consumption change during the process of pressing the LB to the bore for two designs: a typical leading belt and a new LB, which has the form of several annular protrusions.

The present paper will mainly describe and discuss the influence of leading bend design on the properties of artillery shell. The paper is structured as follows: the evaluation of energy change for different types of LB is stated in section 2; the result applications including various utility models is
presented in section 3; section 4 contained the estimation of mass change caused by transition to a new time of LB. Section 5 presented the conclusions derived from the results of the study.

2. The evaluation of energy change

The assessment of the stresses arising in the LB when passing through the cutting cone of the BB determines that for a typical LB material M1, the maximum stress $\sigma_z$ in the radial direction under biaxial compression is seven times higher than the value of the yield stress ($\sigma_S^*$) of the LB material in the middle along the width of the contact area with the surface groove fields (figure 1 a), and along the edges corresponds to the yield point $\sigma_S^*$. The transition to a new design of the LB in the form of annular protrusions, that is, the combination of the LB and the projectile body into one piece, the transition from the M1 material to the projectile body material with higher physical and mechanical properties provides an increase in the efficiency and strength of the LB.

Figure 1 shows the stress diagrams for a typical LB (figure 1, a) and a new type of LB, both made from copper M1 (figure 1, b) and from the projectile body material (figure 1, c). By changing the height ratio of the LB $h$ and the width of the protrusion $a$, it is possible to set the required stresses during the interaction of the AP with the BB.

![Figure 1. Diagrams of stresses for a typical leading belt and a new type.](image)

Figure 2 shows the metallography of a single rifle of the new type LB. The deformation corresponds to the deformation along the diagram in the theoretical calculation.

![Figure 2. Metallography of a single rifle of the new type LB.](image)

1 – LB single rifle cross-section, 2 – artillery shell cross-section, 3 – joint area for two deformed LB riffles, 4 – space between LB riffles
There is a large number of ways to estimate contact stresses of LB during shot [8-16]. In accordance with the method described in [14], the dependence of the typical shape LB contact stresses on the coordinate of the section \( x \) for a large hardening of the material was calculated. Calculations have shown that the amount of energy spent on deformation of the LB corresponds to the integral along the curve of the dependence of contact stresses on the coordinate of the section \( x \). It was found that if for a typical LB the energy is \( X \) J, then for a leading belt of a new type made of the same material it is about 0.46\( X \) J.

In accordance with the calculations of the energy spent on the LB deformation, taking into account the tolerance, the following conclusions can be drawn.

For a standard LB in the bore with 2\% rifling, the energy varies from \( X \) to 1.02\( X \) (2\%). At the same time for a new type LB the energy varies in the region 0.46\( X \) to 0.47\( X \) (1\%) of the total energy of the gunpowder gases. For a standard LB, in the bore with 1\% rifling of the calibre of the ammunition, the values will change in the region \( X \) to 1.01\( X \) (1\%), and for a new type LB in the range from 0.463\( X \) to 0.468\( X \) (0.5\%).

The pressure changes in the barrel bore during firing, taking into account the influence of tolerances on the diametrical dimensions of the projectile, depending on time, is presented in figure 3. For each of the types of the leading belt (type "a" and new type "b"), the range of pressure changes is presented, limited by two pressure change curves corresponding to the pressures arising at the maximum (maximum manufacturing tolerance) diametric dimensions of the LB and at the minimum (minimum manufacturing tolerance). Each of the curves has several reference points: the beginning of the movement of the projectile (1), reaching the maximum pressure (2), the end of combustion of the powder (3) and the moment of departure (4). Forcing pressure is the pressure at the point where the projectile begins to move.

![Figure 3](image-url)

**Figure 3.** The change in pressure in the barrel bore when fired, depending on the time \( t \).

When the diametric dimensions of the projectile are varied, the pressures arising in the bore channel will change accordingly. Thus, the estimate [13,17] showed that for a typical LB, the values...
vary from $X$ (the minimum diametrical dimensions of the LB) to $1.13X$ (the maximum diametrical dimensions of the LB) - 13% scatter, and for a new type of LB - from $0.98X$ to $1.04X$ - 6.5 % spread.

Thus, the transition to a new type of design provides less energy dissipation during firing and thereby increases the accuracy.

3. The result application

A utility model of a new type of airspace has been developed [18], as it shown in fig. 4. The proposed LB is an element of the artillery shell. When the AP enters the BB, the leading belt protrusions of a larger diameter 1, 3, 5 are deformed to a greater extent than the protrusions of a smaller diameter 2, 4, 6.

![Figure 4. Useful model of an artillery projectile for a rifled weapon.](image)

For a new type of airspace with annular protrusions of the same height, estimation of the energy spread for the projectile shows the following results. If for a typical LB the energy changes from $X$ to $1.02X$ (2%), then for a utility model LB - from $0.45X$ to $0.465X$ (0.5%). This means that with usage of this LB design the range projectile scatter will be practically independent of the design of the leading belt.

There are other design options for a new type LB, which are also made from the shell material and provide a decrease and stabilization of the forcing pressure value. Thus, a utility model of an artillery projectile for a rifled weapon is proposed, containing a steel case and a LB made in one piece with it in accordance with figure 5. The leading belt has longitudinal and annular slots, the shape and location of which repeat the location of the rifling in the barrel bore. The diameter of the slots corresponds to the diameter of the centering thickening of the projectile body [19].

The principle of operation of the utility model is as follows. When preparing for a shot, it is necessary to combine the artillery shell and the barrel bore so that the rifling 5 of the leading belt 1 and the bottom of the rifling of the gun barrel coincide. Since the shape of the rifling of the leading belt corresponds to the rifling of the barrel, neither the projectile nor the barrel will experience an increased load when fired, and the speed and flight range will increase due to a decrease in the consumption of kinetic energy for pushing. Since with the proposed form of the leading belt, its crushing practically does not occur, there is no need for large recesses between the formed protrusions to accommodate the crumpled material, therefore the diameter of the body in the grooves 4 and 5 does not exceed the diameter of the centering thickening of the body of the artillery shell. The flow of powder gases 2, penetrating along the longitudinal grooves 5 into the gaps between the barrel bore and the leading belt, fills the resulting "pockets" 4 between the annular protrusions 3, which increases the area of interaction of gases with the projectile body and leads to the transfer of more energy to the projectile. This, in turn, increases the range of the projectile.
A design variant is also proposed, which consists in the fact that the LB differs in that each of its protrusions has an even number of alternating segments with a normal width and segments with thinning, while on adjacent protrusions the thinning belts are staggered [20], as shown in the figure 6.

The proposed utility model works as follows. At the moment the projectile enters the threaded part of the barrel, the projections of the leading belt are deformed in accordance with the shape of the rifling of the barrel bore, and for deformation of the thinned parts 4, less load is required compared to the deformation of the elements of the projections of normal width 3. As a result, less pressure energy is spent on deformation of the belt powder gases than on deformation of a belt with protrusions without thinning. Not spent energy increases the kinetic energy of the projectile, thereby increasing its initial velocity when exiting the barrel and, accordingly, the firing range. The material of the projections displaced by the groove field is freely placed in the annular grooves between the projections and practically does not remain in the bore.
4. The evaluation of mass change

The transition from the material used in standard designs of LB (copper M1) to the material of the shell (steel 60) provides other advantages in addition to the above. The range and accuracy of the flight of the projectiles depends on the value of the muzzle velocity, which, in turn, is determined by the mass of the propellant charge \( M_{\text{met}} \) and the mass of the projectile \( M \). Assuming \( M_{\text{met}} \) and the mass of the equipment constant, change in the mass of the airspace affects the change in the mass of the projectile. For this, the maximum and minimum masses of the leading belts can be calculated. Figure 7 shows leading belts with designated tolerance fields, and for the two options the tolerance field is the same.

![Figure 7. Tolerance fields of a typical leading belt and a leading belt of a new type](image)

For a typical LB, \( S_{LB} \) is the cross-sectional area of the LB, \( L_{\text{max}} \) and \( L_{\text{min}} \) are the maximum and minimum widths of the outer part of the leading belt, \( l_b_{\text{max}} \) and \( l_b_{\text{min}} \) are the maximum and minimum widths of the inner part of the leading belt, \( D_{\text{max}} \) and \( D_{\text{min}} \) are the maximum and minimum diameters of the outer part of the LB, \( d_{\text{max}} \) and \( d_{\text{min}} \) are the maximum and minimum diameters of the inner LB.

For new type LB, \( L \) is the width of the leading belt, \( S_{LB} \) - cross-sectional area of the air intake, \( l_1 \), \( d_1_{\text{max}} \) and \( d_1_{\text{min}} \) - width, maximum and minimum diameters of the larger annular ledge. \( l_2 \), \( d_2_{\text{max}} \) and \( d_2_{\text{min}} \) are the width, maximum and minimum diameters of the smaller annular ledge, \( d_3_{\text{max}} \) and \( d_3_{\text{min}} \) are the maximum and minimum diameters between the annular ledges, \( d \) is the diameter corresponding to the diameter of the groove under a typical LB.

Calculations for a medium diameter projectile had shown the following results. The mass of a typical leading belt of the specified projectile, depending on the tolerance field, varies from 370 to 403 g, that is, it changes by 5%. Comparing with the mass of the entire projectile, we find that the indicated change is 0.14% of the total mass \( M \). It follows from this that during shot, the amount of
consumed energy will fluctuate by the indicated amount, proportionally affecting the muzzle velocity, projectile flight range and accuracy.

At the same time, for a new type of airborne projectile with annular protrusions of alternating diameters (figure 4), the mass of a similar area of the projectile body varies from 352 to 356 g (dispersion of 1%), and compared to the mass of the entire projectile - 0.018%, that is, the change in weight is 8 times less than when using a typical leading belt.

Consequently, the transition from a typical LB to a new type LB while maintaining the tolerance field reduces the dispersion of the mass of projectiles, thereby increasing the accuracy and accuracy of shots.

5. Conclusion
In the course of the work carried out, the influence of the LB design on the processes occurring during the shot was determined, a comparison was made in terms of the force of the formation of the combat protrusions. The effect of the airspace diameter tolerance on the change in the forcing value and on the energy consumption when cutting ammunition into the BB rifling has been investigated. For a standard type air defense (rifling height or air defense height is about 2% of the ammunition caliber), for a typical leading belt, the energy changes by 2% of the energy spent on pushing through the air defense with minimum dimensions within the tolerance, while for a new type of air defense - by 1%. For a LB, the height of which is about 1% of the caliber of the ammunition, the values will be as follows: for a typical LB - 1%, for a new type of LB - 0.463%.

The article analyzes and proposes such a design of the LB of a new type, which reduces the amount of energy spent on punching the LB by half in comparison with a typical leading belt, and the spread becomes minimal.

In addition, it was shown that a change in the airfoil profile ensures a twofold decrease in the pressure spread during a shot: for a typical airspace, the values change by 13%, and for a new type of airspace - 6.5%.

Appendices

AP – artillery projectile
LB – leading belt
BB – barrel bore

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