COMETa 2022
6th INTERNATIONAL SCIENTIFIC CONFERENCE
17th - 19th November 2022
Jahorina, B&H, Republic of Srpska
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

OPTIMIZATION AND EFFICIENCY ANALYSIS OF MUZZLE BRAKE FOR SNIPER RIFLE

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Abstract: Muzzle brakes have a significant effect on reducing the recoil force of weapons during firing. In this paper, muzzle brake as recoil compensator and recoil force for sniper rifle with and without muzzle brake are considered. The objective is to obtain the optimum inclination angle for the blades (side openings) of the muzzle brake in order to reduce recoil force. The calculation of the muzzle brake was performed according to the methods of Ratto and Orlov-Tolockov. Based on the obtained input data for the calculation of muzzle brakes according to the Orlov-Tolockov method, a software solution was made in the Matlab software package. Based on the performed simulations, the optimal value of the side openings angle of the muzzle brake was determined in order to improve efficiency. The advanced muzzle brake model was created in the CATIA V5 software package. The prototype solution was produced using a 3D printer. After that, the muzzle brake prototype was made by processing the semi-finished product. Experimental testing of prototype and a comparison with the existing muzzle brake solution was performed. Based on the presented results, it can be concluded that the new muzzle brake design is more efficient than the existing one.

Key words: Muzzle brake, Recoil force, Sniper rifle, Experiment

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1 INTRODUCTION

During the previous few decades many improvements in small weapons technology were performed. Recoil management has always been the main concern with all small weapons varieties currently in use. Muzzle brakes are most often used devices for this purpose. A muzzle brake is a device that is attached to the muzzle of the barrel designed to reduce the barrel recoil energy or the entire weapon. They divert hot gases with high pressure and high velocity through ports at the sides, creating a force that is directed forward and reduces recoil.

In this paper, the existing and improved muzzle brake efficiency, as well as the sniper rifle recoil force, were investigated. The experimental tests were conducted by measuring the recoil force when firing a sniper rifle without a muzzle brake, with an existing muzzle brake and with a improved muzzle brake. The muzzle brake model was created in the CATIA V5 software package. According to the Orlov - Tolochkov method, the program solution was implemented in the Matlab software. Calculation and experimental results are presented for the existing and improved muzzle brake.

2 THEORETICAL BASIS

Fig. 1 defines the impulse and moment of momentum of the mass system (projectile, powder gases, and recoil mass for barrels with and without muzzle brakes) [1].

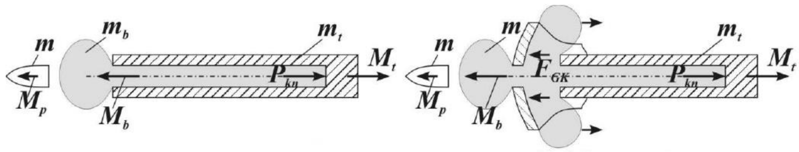

Figure 1. *Barrel without muzzle brake – left, and barrel with muzzle brake – right [1]*

In accordance with the moment of momentum law, barrel recoil moment without a muzzle brake is defined as

$$\int_0^{t_k} P_{kn} dt = M_t \ .$$

The force impulse on the bolt can be calculated from the force/time diagram in Fig. 2 based on the behavior of the powder gas forces on the barrel with and without a muzzle brake

$\int_0^{t_k} P_{kn} dt = I_g$ and on the muzzle brake $\int_0^{t_n} F_{gk} dt = I_{gk}$ [1].

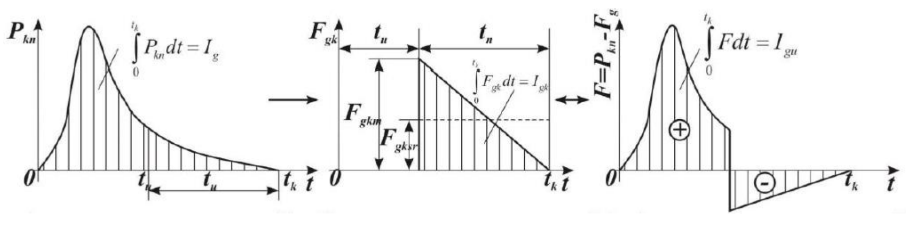

Figure 2. *Impulse forces of gunpowder gases on the barrel [1]*

2.1 Muzzle brake efficiency calculation by Ratto

The effectiveness of the muzzle brake during firing can be defined using the Ratto method [2]. In order to calculate the efficiency of the muzzle brakes, it is necessary to know its efficiency coefficient λ which is:

$$\lambda = \frac{W_{\max}^{'} - W_{GK}}{W_{\max}^{'}} = 1 - \frac{W_{GK}}{W_{\max}^{'}} \tag{1}$$

where: $W_{\max}^{'}$ represents free recoil velocity of the barrel without muzzle brake, W_{GK} is free recoil velocity of the barrel with the muzzle brake.

Efficiency of the muzzle brakes λ_E is given by the equations (2) and (3):

$$\lambda_E = \frac{W_{\max}^{'2} - W_{GK}^2}{W_{\max}^{'2}} = 1 - \frac{W_{GK}^2}{W_{\max}^{'2}} = 1 - \left(\frac{W_{GK}}{W_{\max}^{'}}\right)^2 \tag{2}$$

$$\lambda_E = \lambda \cdot (2 - \lambda) \tag{3}$$

It is clear that the different labels ΔE , λ_E , and η_{gk} represent the same quantities. From here it can be concluded that, in order to calculate the efficiency of the muzzle brake λ_E it is necessary to calculate λ beforehand, because $\lambda_E = f(\lambda)$. Calculating the value of λ as a function of the weapon ballistic characteristics and the geometric shape of the muzzle brakes is reduced to the calculation of the $W_{\max}^{'}$ and W_{GK} [2].

The recoil mass velocity without muzzle brake is given by the equation:

$$Q_{tr} \cdot W_{\max}^{'} = q \cdot V_0 + \omega \cdot W_{sr} \tag{4}$$

where: Q_{tr} represents the recoil mass, V_0 is the initial velocity of the projectile, $r \cdot \omega$ is the the mass of gases passing through the blades (side openings), $(1-r) \cdot \omega$ is the the mass of gases passing through the muzzle brake, q is the projectile mass, and W_{sr} is the mean velocity of the gass flowout.

The equation for the side openings inclination angle of the muzzle brake by Ratto is [2]:

$$\rho = 0.65 + 0.35 \cdot \sin\left(45^\circ - \frac{\alpha + 3^\circ}{2}\right) \tag{5}$$

In the equation (5) ρ represents the friction coefficient of the gases on the muzzle brake blades. This coefficient is used to correct the obtained results in order to achieve better match with the experimental results.

2.2 Calculation of efficiency of the muzzle brake by Orlov-Tolockov

Unlike the Ratto method, this method considers the amount of gas taken through the side openings, the separation of the gas stream from the side channel axis, the shape of the muzzle brake cavity entrance and the angle of the entrance cone. In this way, a more precise match with the experimental results can be achieved [2,3].

Muzzle brake efficiency is expressed by the coefficient ΔE. This coefficient is critical for the free recoil velocity at the end of the gas flowout:

$$W_{GK} = W_{\max} \cdot \sqrt{1-\Delta E} \tag{6}$$

Replacing expressions for W_{GK} and $W_{\max}$ efficiency coefficient ΔE is defined as:

$$\Delta E = 100 \cdot \left[1 - \left(\frac{1+\alpha \cdot \frac{\beta \cdot \omega}{q}}{1+\frac{\beta \cdot \omega}{q}} \right)^2 \right] \tag{7}$$

Coefficient α represents:

$$\alpha = \frac{R_H}{R} \tag{8}$$

where: R represents the reaction of currents at the muzzle brake entrance, and R_H is the horizontal component of the current reaction at the the muzzle brake exit.

The functional dependence of the parameter α on the dimensions and shape of the muzzle brake can be determined assuming that the flow of powder gases is critical and isotropic.

For a muzzle brake with n rows, coefficient α is given as:

$$\alpha = K\sigma_1\sigma_2...\sigma_n + \sum_{i=1}^{n} \sigma_1\sigma_2...\sigma_{i-1}\left(1-\sigma_i\right)K_i\xi_i\cos\psi_i \tag{9}$$

where: K is the coefficient that characterizes the relative increase in the momentum of the powder gases in the muzzle brake cavity, σ_i is the relative amount of unused powder gases of the muzzle brake chamber, K_i is the coefficient of reactivity of the muzzle brake side channels; ξ_i is the coefficient that defines gas stream separation from the direction of the side channel axis due to the influence of the oblique section and is:

$$\xi_i = \frac{\cos\left(\psi_i \pm \Delta\psi_i\right)}{\cos\Delta\psi_i \cdot \cos\psi_i} = 1 \pm tg\psi_i \cdot tg\Delta\psi_i \tag{10}$$

where: $\Delta\psi_i$ is the jet deflection angle due to the influence of the oblique section.

3 RECOIL FORCE – SIMULATION

Muzzle brake model is created in CATIA V5 software package based on the measured dimensions of the existing muzzle brake (Fig.3). Based on the created model, input parameters required for the efficiency, as well as the recoil force calculation in Matlab software are obtained.

Figure 3. *Muzzle brake 3D model*

3.1 Software solution

Based on the Orlov - Tolochkov method for calculating muzzle brake efficiency, the software solution "AnalizaGK.m" was developed in the Matlab software package. The algorithm for the software solution "AnalizaGK.m" is shown in Fig. 4.

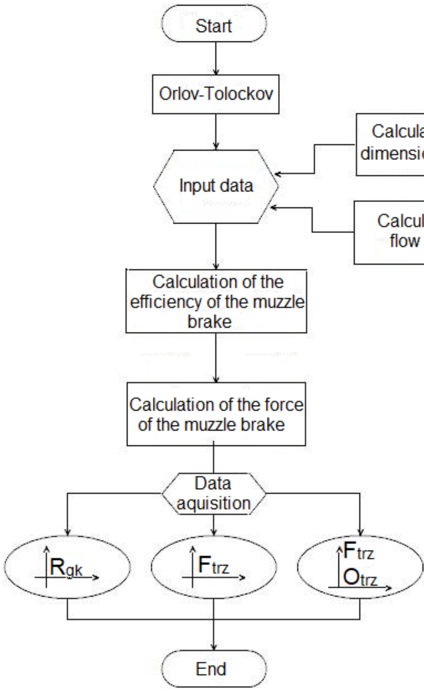

Figure 4. *Algorithm for the software solution "AnalizaGK.m"*

The software solution calculates ideal dimensionless velocity and the deflection of the gas stream. The software solution, apart from the efficiency of the muzzle brake, also provides the value of the calculated structural characteristic as an output data. The structural characteristic (*α*) calculated in this way is used as one of the input data in the program that solves the recoil force. By applying this software solution, the impact of the muzzle brake on the reduction of the recoil force, as well as the recoil process, can be analyzed.

4 MUZZLE BRAKE EFFICIENCY ANALYSIS

The dependence of the muzzle brake force on the inclination angle of the side openings is shown in Fig. 5 – left. An interval from 100° to 150° was used to analyse the influence of the inclination angle of the side openings. It can be concluded that with an increase in the inclination angle, higher force values are obtained.

Fig. 5 - right shows the dependence of the muzzle brake efficiency on the angle ψ. From the Fig. 5 – right can be concluded that with an increase in the inclination angle, higher efficiency values are obtained. For an angle value of 120° (production measure), the efficiency of the muzzle brake is 47.8%, and the force of the muzzle brake is 10.22 kN.

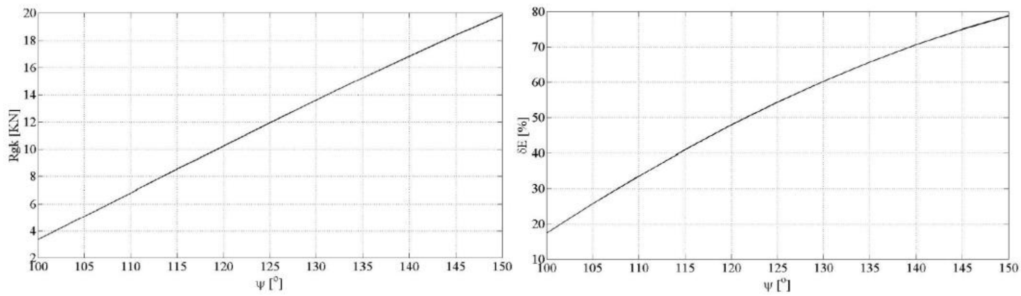

Figure 5. *Dependence of the muzzle brake force on the angle of the side openings – left and efficiency of the muzzle brake on the angle of the side opening – right*

Fig. 6 shows dependance of the muzzle brake force on time.

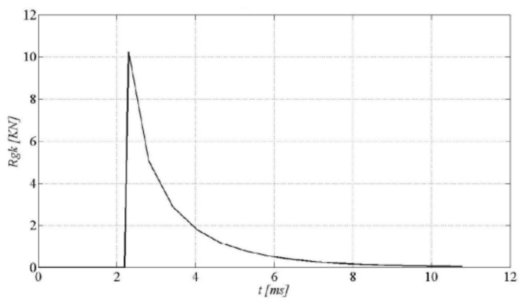

Figure 6. *Muzzle brake force-time dependance*

At the time interval from 0 to 2.2 ms, no pressure is applied to the muzzle brake, because the projectile is still moving in the barrel. After 2.2 milliseconds the muzzle brake starts to take effect. The muzzle brake has a maximum force value of 10.22 kN, after which it slowly decreases.

4.1 Analysis of the recoil process

The following forces act within the recoil process of a sniper rifle: the pressure force of powder gases – P, and the force of the muzzle brake – F_{gk}. On Fig. 7 – left is shown a comparison of the recoil force and the recoil resistance force on time.

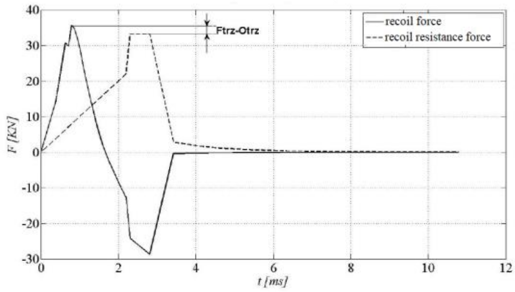

Figure 7. *Recoil force and recoil resistance force – left; Recoil force in dependance of time - right*

The difference between the maximum recoil force and the recoil resistance force represents the force exerted by the sniper rifle on the shooter. The maximum recoil force is 35.64 kN, and the recoil resistance force is 33.2 kN. The force exerted by the sniper rifle on the shooter is 2.48 kN.

5 EXPERIMENTAL TESTING

Based on the results obtained using a mathematical method improved muzzle brake was constructed. A comparative experimental analysis of the existing muzzle brake and improved muzzle brake effectiveness for the sniper rifle was done. During the experiment, the following forces were measured: recoil force without a muzzle brake, recoil force with the existing muzzle brake and recoil force with with the improved muzzle brake.

In order to obtain the experimental analysis results of the muzzle brake effectiveness, improved muzzle brake is constructed. Improved muzzle brake has retained the assembly and dimensional characteristics of the existing muzzle brake, while inclination angle of blades was changed. Improved muzzle brake should enhance efficiency, reduce the recoil force on the shooter and increase precision.

During the experiment, it is necessary to ensure operators safety. It was necessary to provide a secure grip for the sniper rifle in order to achieve a rigid connection. Rigid connection was established between the sniper rifle and the support on which the linear strain gauges were placed. In order to ensure a safe grip, it was necessary to produce an adapter that was tied to the rifle, instead of the sniper rifle stock. The other end of the rifle was tied to a fixed stand [4,5]. The prototype muzzle brake was obtained by 3D printing. The prototype muzzle brake and experimental setup are shown on Fig. 8.

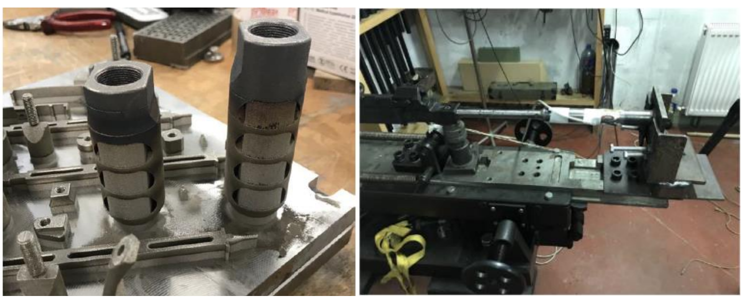

Figure 8. *Muzzle brake prototype – left and experimental measuring of recoil force – right*

The difference between the recoil force without the muzzle brake and the recoil force with the muzzle brake is the muzzle brake force. The obtained results of experimental testing are shown in Table 1.

Table 1. *Results of the experimental testing*

Recoil force without muzzle brake	Recoil force with the existing muzzle brake	Recoil force with the improved muzzle brake	Force of the existing muzzle brake solution	Force of the improved muzzle brake
23509 N	17033 N	15435 N	6476 N	8074 N

Deviation of the results obtained by calculation using Orlov-Tolochkov method from the experimental results is a consequence of the calculation method imperfection. For the calculation it was assumed that the side openings are circular in shape and have equal cross-sectional areas. In addition to the imperfection of the calculation, the influence of the recoil pad and the influence of the rifle stand were not taken into consideration. Based on the above, it can be concluded that the mentioned method of the muzzle brake efficiency calculation gives satisfactory results.

6 CONCLUSIONS

This paper presents a theoretical and experimental analysis of improved muzzle brake of the sniper rifle. Theoretical basis of Ratto and Orlov-Tolochkov methods are given. Calculation of improved muzzle brake was performed according to Orlov-Tolochkov method, because it gives more accurate results. Improved muzzle brake model is created in CATIA V5 software package based on existing muzzle brake dimensions and characteristics. Based on the created model, input parameters required for the efficiency and the recoil force calculation are obtained. The improved muzzle brake efficiency calculation was performed in the Matlab software. Using the "AnalizaGK.m" software solution, the muzzle brake efficiency and the sniper rifle recoil force are analyzed. Initial data within software solution were changed and varied in the desired interval. This provided different values at the output of the program. By varying the initial data, optimal values were determined and used for the construction of improved muzzle brake. The efficiency and recoil force is most affected by the angle of inclination of the side openings. On the basis of ballistic parameters, constructional dimensions and characteristics using aforementioned software solution, the obtained value of the new muzzle brake efficiency was 47.8% and the muzzle brake force was 10.22 kN. Based on the calculation results, improved muzzle brake was produced. Experimental tests of new muzzle brake were performed. Value of the muzzle brake force obtained by experimental testing of the new muzzle brake was 8.074 kN. It can be concluded that the presented calculation gives satisfactory results. These results can be used as a starting point for designing, construction and analyzing the parameters that affect the efficiency of muzzle brakes.

ACKNOWLEDGEMENT

This research is partly supported by the Ministry of Education and Science, Republic of Serbia, Grant 451-03-68/2022-14/ 200378, and Grant TR32036.

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