Research on high efficiency muzzle brake technology of small caliber automatic gun

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Abstract. Muzzle brake provides a recoil force by controlling the powder gas flow distribution and velocity to reduce the recoil energy, so the study on the muzzle brake efficiency in reducing the recoil energy plays a great role. A new muzzle brake is developed, and the muzzle flow field is simulated and analyzed by Fluent. According to the simulation results, the muzzle brake structure is optimized. Precision casting technology was used to solve the manufacturing problem of complex special-shaped holes. The prototype was processed and verified by experiments. The experimental results show that the braking efficiency of the new muzzle brake is nearly twice that of the traditional structure, and the recoil force of the automatic gun can be reduced by more than 40%.

1. Introduction
Small size, light weight, long range, great power, and various types of strikes are important directions for the development of unmanned combat vehicles. However, the increased power of the weapon also increased its recoil, which limited the further improvement of the power of the light unmanned artillery. At present, all unmanned combat vehicles below the 5T level in the world are only equipped with machine guns. Their small combat radius, weak damage, and few types of targets can be attacked. Therefore, they are mainly used for reconnaissance and communication. In order to improve the fire strike capability of unmanned vehicles, the commonly used method is to add missiles, but the number of missiles carried is small, resulting in insufficient continuous combat capability. Small-caliber guns have the advantages of small size, light weight, high rate of fire, multiple types of bombs, high accuracy, and fast response. However, due to the large recoil, the application of automatic guns to light vehicles is limited. In order to greatly reduce the recoil force of automatic guns, so that light unmanned vehicles can be installed with larger caliber guns to improve their combat effectiveness, the structural design and simulation analysis of high-efficiency brakes were carried out, and the processing and testing of prototypes were carried out.
2. Structural design of muzzle brake

According to the structural form, the muzzle brake can be divided into three types: impact type, reaction type and impact reaction type. According to the expansion degree of gunpowder gas in the muzzle brake, it can be divided into open cavity type and semi-open cavity type. The diameter of the chamber of the impact muzzle brake is large. After entering the muzzle brake, the gas first expands and accelerates along the axis of the breech to form a high-speed jet, which impacts the front reflection surface of the muzzle brake. It is discharged to the side and rear through the side hole, and a retraction force is generated. Another part of the gas is ejected forward through the central bullet hole, causing recoil.

There are two kinds of muzzle brake efficiency: impulse efficiency and energy efficiency. Generally, energy efficiency is indicated when there is no special instruction. However, if artillery, projectiles, and gunpowder gas are considered as a system (hereinafter referred to as the launch system), the impulse of the launch system is conserved during the process of free reclining, so the analysis and calculation using the impulse is simpler and more intuitive. When there is no muzzle brake, the impulse efficiency of the projectile and the gunpowder gas is divided into two parts: one is the impulse generated by the projectile, and the other is the impulse generated by the gunpowder gas.

\[
T_0 = qv_0 + \beta \omega
\]  

Among them:  
- \(T_0\) —— Impulse forward of artillery system without muzzle brake  
- \(q\) —— Projectile mass  
- \(v_0\) —— Projectile velocity  
- \(\beta\) —— The coefficient of action of gunpowder gas, its physical meaning is the average forward velocity of gunpowder gas.  
- \(\omega\) —— Gunpowder mass

According to the law of conservation of momentum, the recoil part of the gun will produce the same backward impulse. The impulse is constant when the artillery and ammunition are unchanged. When the muzzle brake is installed, a part of the gunpowder gas flows out of the side hole of the muzzle brake, and its movement direction and average speed have changed, as shown in figure 1.

![Figure 1. Gas change in the side hole of the muzzle brake.](image)

If the mass of the gas flowing out of the side hole is \(\omega_T\), its average speed is \(v_T\), and the average angle between the gas flowing out of the muzzle brake and the axis of the barrel is \(\alpha\), then the forward impulse generated at launch consists of three parts: the impulse generated by the projectile, the
impulse generated by the gunpowder gas flowing directly forward from the central bullet hole of the muzzle brake, and impulse by the gas flowing out of the side hole.

$$T_T = qv_0 + \beta(\omega - \omega_T) + v_T\omega_T\cos\alpha$$  \hspace{1cm} (2)

The resulting impulse efficiency is:

$$\eta_T = 1 - \frac{T_T}{T_0} = \frac{\beta\omega_T - v_T\omega_T\cos\alpha}{qv_0 + \beta_0}$$  \hspace{1cm} (3)

It can be seen from formula (3) that the greater the amount of gas flowing out of the side hole of the muzzle brake, the larger the angle between the average gas outflow direction and the bore axis, and the higher the average velocity, the higher the efficiency. Due to the short diameter of the small-caliber automatic gun barrel and the close distance between the muzzle and personnel and equipment, in order to avoid the damage of the muzzle shock wave, the impact muzzle brake is generally not used. In addition, due to process limitations, small-caliber muzzle brakes generally use straight slots or holes, as shown in figure 2. The ideal shape of the exhaust port is that the inlet angle $\alpha_g$ is small, which can increase the exhaust volume, while the outlet angle $\alpha_a$ is large to increase the backward impulse component. The muzzle brake of some products uses a welding process, and the exhaust port is designed in the shape of figure 3, which can greatly improve the efficiency of the brake. However, because the exhaust passage is not smooth, the airflow is likely to generate vortices at the corners, causing airflow velocity loss.

In order to further improve the efficiency of the retarder, a high-efficiency exhaust hole scheme as shown in figure 4 was designed with a certain aviation gun automaton as the research object. Its characteristics are as follows: First, it has a small inlet angle $\alpha_g$ and the exhaust volume is relatively small. Large; Second, the exit angle $\alpha_a$ is large, and the backward impulse component is large; Third, the exhaust channel is smooth, and the loss of air velocity is small; Fourth, the area of the exhaust channel is gradually increased, the gas is gradually expanded, and the pressure is reduced, which is beneficial to reduce Muzzle noise.

Figure 2. Side hole is straight hole. Figure 3. Side hole is V-hole hole.
3. Multi-program simulation comparison analysis
The three structural schemes shown in figure 2 to figure 4 were selected, and the software Fluent were used for modeling and analysis, and the muzzle pressure and velocity distribution of each scheme at different times were obtained. The first scheme shown in figure 5a is the muzzle brake of the US M230 automatic gun, and the side hole is a straight hole. The second scheme shown in figure 5b is a scheme designed with reference to the 100 slide anti-tank gun muzzle brake. The side hole is a V-shaped hole; the solution three shown in figure 5c is a solution using an efficient exhaust hole.

Figures 5 are the pressure and velocity distributions of the muzzle of the three scenarios at the time of 1.2ms (taken from the time when the projectile exits the muzzle).
Using the above simulation results, the force curves of the barrel and the muzzle brake of the three schemes are extracted, as shown in figure 6-8. And calculate the stress curve of the barrel without the brake, as shown in figure 9.
Figure 8. Axial force curve of barrel and muzzle brake for three schemes three.

Figure 9. Force curve of the barrel without muzzle brake.

The speed of the projectile of a certain aviation gun automaton is 810m / s, the mass of gunpowder gas in the bore is 0.046kg, and the mass of the projectile q is 0.236kg. Assuming that the velocity of the gas in the bore is linearly distributed from the bottom of the bore to the mouth, the average velocity is 405 m / s. From the theory of conservation of momentum, it can be known that at the moment when the projectile exits the muzzle, the barrel is subjected to a backward impulse \( T_g \):

\[
T_g = qv_0 + 0.5ωv_0 = 200.5 \text{ Ns}
\]  

(4)

Integrating the total force of the artillery in figure6 can obtain the total impulse \( T_{Hi} \) (negative to the muzzle) of the after-effect period of each scheme. Then the impulse efficiency \( \eta_{Ti} \) and energy efficiency \( \eta_{Ei} \) of the retarder are:

\[
\eta_{Ti} = \left(1 - \frac{T_g + T_{Hi}}{T_g + T_{H0}}\right) \times 100\%
\]

(5)

\[
\eta_{Ei} = \left[1 - (1 - \eta_{Ti})^2\right] \times 100\%
\]

(6)

Among them: \( T_{H0} \) —— the total impulse received by the barrel during the after-effect period without brake, which is integrated from figure7 to obtain \( T_{H0} = 40.12\text{Ns} \).

The calculation results are shown in table 1:
|                             | Schemes One | Schemes Two | Schemes Three |
|-----------------------------|-------------|-------------|---------------|
| Total impulse received by the artillery during the aftereffect period $T_{H}/N$s | -9.88       | -25.74      | -55.44        |
| Impulse efficiency of the muzzle brake $\eta_{Ti}/\%$ | 20.8        | 27.4        | 39.7          |
| Energy efficiency of the muzzle brake $\eta_{Ei}/\%$ | 37.2        | 47.2        | 63.7          |

### 4. Processing and testing of prototypes

Due to the irregular contour surface in the exhaust channel, traditional machining methods cannot be used. Therefore, in this paper, a new method of precision casting is used. Firstly, the blank of the part is made, and then the inner and outer surfaces and the connecting thread are finished. The completed model, the real object and the connection diagram with the barrel are shown in figure 10.

![Figure 10. Model and actual drawing of the muzzle brake.](image)

Artillery firing tests were performed on a certain 30mm automaton. In order to measure the efficiency of the muzzle brake, a pressure sensor is installed between the recoil section and the left and right recoil buffers, as shown in figure 11. During the automaton firing process, the recoil force-time curve can be measured. The impulse received during the recoil process can be obtained by integrating the recoil portion (From the beginning of recoil to recoil speed 0) of the curve.
Tests were performed in three states: state one: no muzzle brake; state two: installation plan one muzzle brake; state three: installation plan three muzzle brake. Among them, the actual shooting of state two and state three is shown in figure 12.

The test results of the recoil impulse in the three states are: $T_0 = 237.4\text{Ns}, T_1 = 183.7\text{Ns}, T_3 = 139.6\text{Ns}$. The calculation formula for the energy efficiency of the muzzle brake is:

$$\eta_{T_i} = \left(\frac{T_0 - T_i}{T_0}\right) \times 100\%$$

Substituting the test results into the above formula, we get:

$$\eta_{T_1} = 22.6\%, \quad \eta_{T_3} = 41.2\%.$$  \hspace{1cm} (8)

Then the energy efficiency is $\eta_{E_1} = 40.1\%, \quad \eta_{E_3} = 65.4\%.$
5. Conclusion
The simulation and experimental results show that the designed new structure muzzle brake retreat efficiency is greatly improved, which can significantly reduce the recoil of the automatic gun, which is conducive to reducing the weight of the artillery weapon system and improving mobility. At the same time, because it reduces the impact on the artillery weapon system, it is also conducive to improving the accuracy of firing.

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