Research on low recoil launch technology of small UAV with small arms mounted on it based on floating principle

Li Yongjian¹, Wang Shan², An Jie³, Zhang Junnuo¹

¹Army Engineering University of PLA Shijiazhuang Campus AEU, ²Troop 32301 of PLA, ³Hebei University of Science & Technology

Email: gunlyj@163.com

Abstract: The small unmanned aerial vehicles (SUAV) which is mounted with small arms have both the accurate firing ability of small arms, and the mobility, flexibility and concealment of SUAV. In order to reduce the influence of recoil on SUAV, we put forward a low recoil launch method based on floating principle. Take a certain type of rifle as a study object, we have established a virtual prototype model. Through simulation and firing test, the recoil reduction effect is verified. This method provides a feasible and effective technical way for small unmanned platform to mount weapons in service.

1. Introduction
Small unmanned aerial vehicles (SUAV) have the characteristics of good concealment, strong mobility. The appearance of SUAV has brought significant changes to the military fighting style. Integrating information, detection and strike is the development direction of SUAV in the future. After weaponization, SUAV can carry out traditional reconnaissance missions, make timely response to the battlefield situation, provide effective firepower striking, and its combat effectiveness will be greatly improved.

Small arms are the weapons, which are equipped most widely. The SUAV mounted with small arms have both the accurate firing ability of small arms, and the mobility, flexibility as well as concealment of small unmanned aircraft. It is not only applicable to special operations, urban warfare and anti-terrorism operations, but also can be used to anti-UAV on the information battlefield in future.

But small arms will produce greater recoil in firing, especially automatic weapons. The effects of recoil keep in the process of automatic firing. This force will not only affect the firing accuracy, but also have a great impact on the flight stability of SUAV, even can cause flip or fall. Small arms developed only for SUAV, loses the characteristics of generality and universality of small arms. So, developing the technology of SUAV mounted with small arms firing of low recoil is very important for integrating information, detection and strike of SUAV.

Based on the floating principle, we put forward a low recoil launch method for SUAV. A certain type of rifle as the study object, a theoretical model and a virtual prototype model are established. Through simulation and firing test, the recoil reduction effect is verified. This method provides a feasible and effective technical way for small unmanned platform to mount weapons in service.

2. Theoretical model
The firing way of automatic weapons in the process of recoil is called floating technology. When the weapon is firing, the forward energy of the floating body will partially offset the backward energy of
gunpowder and gas, thus the recoil force of shooting is reduced. Based on the floating principle, we put forward a low recoil launch method for small unmanned platform, which uses the weapon as a recoil body and gives it a certain speed before shooting in order to offset the recoil energy of the weapon, so as to reduce the impact of recoil on the flight stability of SUAV. The theoretical model is shown in the Figure 1.

It works as follows:
During firing, rifle moves forward a distance $\Delta$ under the action of spring, then the trigger hits the cocking lever, when the pressure is greater than the trigger force, the hammer is released, the hammer hits the firing pin, and the primer is fired. After firing, the rifle stops moving forward, and begins to move back under the recoil force. At the same time, the weapon completes the actions, such as unlocking, pulling the shell, throwing the shell, pushing the shell and locking. When the rifle is rear-seated, and then spring force make the riffle to the starts position, a shooting cycle completed.

3. Establishment visual prototype
Virtual prototype technology can replace the physical model of the product for testing and improvement, which can not only shorten the time of research and development, but also reduce its expenditure. Therefore, we use ADAMS multi-body dynamics simulation software to build a virtual prototype of rifle shooting based on floating principle.

3.1. The basic assumptions
Movement of various components in the process of rifle shooting is complex, so it is impossible to take all the possible factors into account in the building virtual prototype. According to the purpose of this paper, we ignore the secondary factors and make the rifle virtual prototype, which does not affect rifle’s normal shoot.
- Ignore the factors that have little effects on the motion of automat;
- Do not consider the resistance of the bullet to the barrel;
- Gunpowder gas exerts loads on the corresponding parts as an external force directly.

3.2. Visual prototype establishment
The model of visual prototype is shown as Figure 2:
3.3. **Load analysis**

The forces that rifle bears in the process of shooting basically are resultant force of guns, air chamber pressure, air chamber pressure reaction force, all sorts of spring force.

3.3.1. **Resultant force of guns**

Resultant force of guns is the force of gunpowder gas acting on the muzzle, which can be divided into internal ballistic period and after-effect period. The resultant force can be got by converting the average chamber pressure to the chamber bottom pressure.

3.3.2. **Pressure of gas-operated chamber**

The chamber pressure can be calculated by Braven’s empirical formula:

\[ p_s = p'_d e^{\frac{a(t'-t)}{b}}(1 - e^{-\frac{a(t'-t)}{b}})(t' \leq t'') \]  

In the formula, \( p_s \) pressure of gas-operated chamber, \( p'_d \) average pressures in the chamber when the bullet passes the gas-operated hole, \( a \) parameters relating to structure size of gas-operated device, \( t \) time, \( t' \) the time of the bullet from start to gas hole, \( t'' \) the time of end of aftereffect period.

3.3.3. **Extraction Resistance**

Extraction resistance can be calculated by approximate calculation formula.

\[ F_\phi = \pi \left( f_0 l_k \left[ p d_1 + 2 E_1 \delta (\Delta - \frac{2 x \alpha}{d_{p_0}}) \right] - \frac{1}{4} d_1^2 p \right) \]  

In the formula, \( F_\phi \) extraction resistance, \( f_0 \) friction coefficient between shell and chamber, \( l_k \) the length of shell, \( p \) pressure of propellant gas in cartridge case, \( d_1 \) diameter of cartridge case, \( E_1 \) inertial modulus of shell material, \( \delta \) thickness of cartridge shell, \( \Delta \) relative compaction between shell outer surface and shell wall, \( d_{p_0} \) average diameter of shell, \( \alpha \) semi-taper angle of conical part of shell, \( x \) backward travel of cartridge case.

3.4. **Determination of Key Parameters**

After the virtual prototype is built, it is necessary to optimize its key parameters so as to optimize the key parameters. Because the parameters of rifle can not be adjusted, so through sensitivity analysis, we determine the stiffness of the forward spring \( k_2 (N m^{-1}) \), forward spring preload \( F_2(N) \), and forward distance \( \Delta (mm) \) as optimization variables.

| Variable     | Initial value | Lower limit | Upper limit |
|--------------|--------------|-------------|-------------|
| \( k_2 (N m^{-1}) \) | 200          | 100         | 500         |
| \( F_2/N \)   | 90           | 10          | 100         |
| \( \Delta/mm \) | 7            | 0           | 50          |
Using multi-island genetic algorithm, based on Isight software, a multi-disciplinary optimization platform, the dynamic simulation software Adams is invoked in batch mode to optimize the calculation.

| Variable | \( k_q (N \cdot m^2) \) | \( F_{q0} / N \) | \( A / \text{mm} \) | \( F_{\text{max}} / N \) |
|----------|-----------------|----------------|-----------------|-------------------|
| Initial values | 200 | 90 | 7 | 94.6 |
| Optimization results | 350 | 60.1 | 28.2 | 65.6 |

4. Simulation analysis

The dynamic simulation of the virtual prototype is carried out, and the velocity curve of the gun body is obtained as shown in Figure 3, and the recoil force curve of the shooting platform is shown in Figure 4.

![Figure 3. Velocity change curve of gun body](image1)

![Figure 4. Recoil change curve of design platform](image2)

Mark 1 indicates that the rifle starts to move forward under the action of the forward spring; after marking 2 triggers impact the trigger rod, they collide with the casing under the action of the trigger spring, so there are two sudden changes in the speed of the rifle body; Mark 3 indicates that the combined force of the rifle chamber begins to work; Mark 4 indicates that the speed of the rifle body suddenly decreases, because the pressure reaction force of the gas-operated chamber is greater than the pressure in the rifle after the action of gunpowder gas. Mark 5 indicates that the rifle has been unlocked; Mark 6 is caused by shell throwing resistance; Mark 7 indicates that the hammer driven by the frame of the rifle collides with the buffer and begins to compress the buffer spring; Mark 8 indicates that the buffer collides with the butt driven by the frame and the hammer, and the frame of the rifle starts to recoil in place; Mark 9 marks that the rifle recoils and starts to recoil, and then strikes. The collision between hammer and single blocking iron results in sudden change of rifle speed; the collision between frame and casing occurs in location 10; the rifle restores in location 11, and the whole shooting is completed.

In order to compare the recoil reduction effect of the shooting platform, the maximum recoil force of the shooting platform during the shooting is compared with the maximum of the recoil force of the shoulder-proof shooting obtained from the experiment as shown in the table 3. The maximum recoil force of the shooting platform is only 16.2% of the maximum shoulder force, which shows that the recoil reduction effect of the low recoil shooting platform based on floating principle is very obvious.

| Force \( f_{\text{max}} / N \) | Recoil force of the platform | Shoulder force |
|-----------------|-----------------|--------------|
| 65.6 | 404.9 |
5. Firing test
In order to test the recoil reduction effect of the shooting platform, an experiments is designed to verify it. Firing test is shown as Figure 5. The velocity curve of rifle body during simulation and test is shown in Figure 6. The variation curve of recoil force of shooting platform is shown in Figure 7.

![Figure 5. Firing test](image)

**Figure 6. Comparison of gun body velocity simulation and test data**

The simulation data of several representative points of rifle are compared with the data in the firing test as shown in Table 4. $v_1$ the maximum forward speed of rifle, $v_2$ the maximum recoil speed of rifle, $v_3$ the maximum recoil speed of rifle, $f_{max}$ the maximum recoil force of shooting platform. The error range between simulation data and test data is less than 2%, which meets the needs of engineering calculation, the result of virtual prototype is credible. Therefore, it can be concluded that the rifle shooting platform, based on floating principle, has a good recoil reduction effect.

| Simulation data | Test data | Error  |
|-----------------|-----------|--------|
| $v_1$ (m/s)     | 0.63      | 0.62   | 1.6%   |
| $v_2$ (m/s)     | 1.12      | 1.10   | 1.8%   |
| $v_3$ (m/s)     | 0.53      | 0.52   | 1.9%   |
| $f_{max}$/N     | 65.6      | 64.8   | 1.2%   |

6. Conclusion
In this paper, based on floating principle, a method of reducing recoil of the firing platform for the whole front impact firing is proposed, and a theoretical model is established. The virtual prototype model of rifle firing, based on the principle of whole rifle front impact firing, is established and simulated by adapting virtual prototype technology. The results show that the recoil force of rifle shooting decreases to 65.6N, which is only 16.2% of that of shoulder-to-shoulder shooting. The effect of recoil reduction is
very obvious. On this basis, firing test was carried out to verify the credibility of the simulation results. It is further illustrated that the rifle shooting platform based on the principle of whole-gun front-impact firing can effectively reduce the recoil force effect, which provides a feasible and effective technical way for the small unmanned platform to mount weapons in service.

References
[1] LAN Zhimin. Research on the Function of Unmanned Combat Platform in the Future War[D]. Harbin: Harbin Engineering University, 2012.
[2] WANG Ruilin , LI Yongjian, ZHANG Junnuo. Modeling technology and application of light weapons based on Virtual Prototyping[M]. Beijing: National Defense Industry Press, 2014.
[3] YANG Xiao-yu, WANG Ruilin, LI Yong-jian, CHEN Jin-xi. Methods of decreasing recoil of a pistol based on virtual prototype.[J], Journal of Machine Design, 2012, 29(3):61-64.
[4] GONG Penghan, ZHOU Kedong, KANG Xiaoyong, et al. Simulation of Launch Dynamics of a Rifle[J]. Journal of Ballistics, 2014, 26(1):94-97.