Influence of Loading Parameters of Mixed Charge on Ballistic Performance

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Abstract. In order to study the influence of loading parameters of mixed charge on its trajectory performance, the classical internal trajectory optimization model is adopted to control the consistency of other conditions and regularly change the shape, main charge quantity, arc thickness of main charge and arc thickness of auxiliary charge in mixed charge to calculate the internal trajectory performance data. When the main charge weight is 1780g, the arc thickness of the main charge is 1 mm, and the arc thickness of the auxiliary charge is 0.48mm, the data changes of the ballistic performance with the other three variables are analyzed. The results show that the influence of the main charge arc thickness of the corresponding step length on the ballistic properties of the mixed charge is more obvious than that of the main charge quantity and the auxiliary charge arc thickness of the corresponding step length. The increase of arc thickness will lead to the decrease of muzzle velocity, the decrease of bore pressure and the increase of relative combustion position of gunpowder. The increase of charge volume will lead to the increase of muzzle velocity, the increase of bore pressure and the decrease of the end position of gunpowder combustion velocity. Compared with porous powder, tubular powder has higher initial velocity, smaller gunpowder end position and higher bore pressure.

1. Introduction
High muzzle velocity and safe and reliable internal ballistic process are the main objectives of current gun design. The mixed charge structure composed of well-permeable tubular drug as the point powder and the good combustion performance of porous granular drug can not only avoid the safety hazard caused by the high loading density of single granular drug, but also avoid the shortcoming of single tubular drug failing to meet the requirements of combat technology index. Internal ballistic model calculation is the core of internal ballistic theory, which plays an important role in gun design, improvement and problem solving. However, there are many parameters involved in the calculation of internal trajectory. In order to obtain accurate and reliable calculation results of internal trajectory, it is necessary to carry out coincidence calculation of internal trajectory, so that the calculated results are consistent with the test results of internal trajectory. In order to obtain the effect of the influencing factors on the ballistic performance of the mixed charge, the best internal ballistic performance can be achieved. Liu Lin [3] et al. established a howitzer internal ballistic Simulink simulation model based on the classical internal ballistic mathematical model of mixed charge. Taking the coefficient of combustion velocity and the index of combustion velocity of two kinds of gunpowder as the corresponding parameters, and taking the simulation value of maximum bore pressure and muzzle velocity and the average relative error of the fixed value as the objective function, an M file of genetic
algorithm was prepared for the corresponding calculation. Li Kejing [4] et al. established an internal ballistic mathematical model of mixed charge structure of seven-hole and tubular charge. The improved genetic algorithm (GA) was applied to the optimal design model with muzzle velocity, relative end position of gunpowder and muzzle pressure as the targets, and the optimal variables and constraints of the optimal design scheme were determined.

In this subject, the influences of loading parameters of mixed charge were studied more carefully. Ma Yan et al. [6] established the optimization model cycle on the basis of classical internal ballistic calculation, calculated the charging design of propellant, and verified the feasibility of the platform constructed. On this basis, by changing the main charge quantity, the arc thickness of the main charge, the arc thickness of the auxiliary charge, the shape and type of the main charge, and the internal ballistic performance that needs to be met in the setting, the scheme that meets the requirements under different circumstances is calculated. Then plot and compare the obtained scheme data, analyze the effect of each variable on the trajectory performance, and the reasons for the influence.

2. Experiment and basic data

Based on the equation of internal trajectory in the combustion process of gunpowder, an optimized physical and mathematical model of internal trajectory was established. The model based on the following assumptions is established:

(1) Gunpowder combustion follows van der Waal's equation of state for gases.
(2) The combustion of gunpowder follows the law of geometric combustion.
(3) The combustion formula of gunpowder is based on exponent combustion formula. Different combustion coefficient and pressure index are used in high-pressure and low-pressure combustion.
(4) Let's think about the other subcritical work in terms of the coefficient ϕ.
(5) The recoil rifling is instantaneous and does not consider the engraving process.
(6) After the cartridge belt has punched the rifling, it is well sealed and there is no air leakage phenomenon.

Based on the above assumptions, the following basic equations can be obtained:

(1) Geometric combustion law shape function:

\[ \psi = \chi Z(1 + \lambda Z + \mu Z^2) \]  

(2) Gas state equation:

\[ (p + \frac{a}{v^2}) (v' - a) = RT \]  

(3) Combustion velocity equation:

\[ \frac{dz}{dt} = \frac{u_m n^a + k_v y}{e_1} \]  

(4) Projectile motion equation:

\[ (p - p_R)S = \Phi m \frac{dv}{dt} \]  

(5) Basic equation of interior ballistic:

\[ Sp\left(h + l\right) = f_\omega \psi - \frac{\theta \phi mv^2}{2} \]  

The above model is calculated programmatically.

In this paper, type 54 122mm gun is used, and its gun structure and charging parameters are shown in Table 1.

| Physical quantities | Numerical value | Physical quantities | Numerical value |
|---------------------|----------------|---------------------|----------------|

Table 1 122mm gun structure and charging parameters
The letters in the table above mean as follows: S-Muzzle cross-sectional area, \(V_0\)-Chamber volume, \(l_s\)-The full stroke of the projectile is long, m-The mass of the projectile, \(p_0\)-engraving pressure, \(f\)-Gunpowder impetus, \(\rho_p\)-Gunpowder density, \(\alpha\)-Covolume, \(k\)-Specific heat ratio, \(\phi\)-The calculation coefficient of the second work, \(u_1\)-Burning rate coefficient, \(n\)-Gunpowder burning rate index, \(\omega\)-Explosive charge.

### Table 2 Constraint condition setting

| Constraint condition | Constraint value | Variable step-size |
|----------------------|------------------|--------------------|
| \((v_0)\)min/m \cdot s^{-1} | 515               |                    |
| \((p_m)\)max/MPa    | 258               |                    |
| Arc thickness variation range of main charge \(2e_1\) (mm) | 0.6–1.3            | 0.05               |
| Arc thickness variation range of auxiliary charge\(2e_1'\) (mm) | 0.3–0.6            | 0.03               |
| Main charge\(\omega_0\) (g) | 1600–1780         | 20                 |
| Type of gunpowder | Tubular powder; Cylindrical gunpowder with 7 holes; Cylindrical gunpowder with 19 holes |

### 3. Result and analysis

The basic data in the above table is used for calculation, and the obtained data results are plotted for analysis.

First, the main charge quantity was controlled at 1760g, and the three-dimensional scatter diagram of the relationship between the maximum bore pressure, initial velocity, relative end point of gunpowder and the shape of the charge, arc thickness of the main charge and arc thickness of the auxiliary charge was drawn, as shown in Figure 1- Figure 3.
When the main charge quantity is controlled unchanged, the trajectory performance of mixed charge varies with other variables, as can be seen from Figure 1- Figure 3: For different gunpowder shapes, the change of muzzle velocity, bore pressure and relative combustion end position with main charge arc thickness is more obvious than that with auxiliary charge arc thickness, because the main charge volume is much larger than that of auxiliary charge. Under the same condition, the muzzle velocity and bore pressure of tubular drug, cylindrical gunpowder with 7 holes and cylindrical gunpowder with 19 holes decrease successively, while the bore pressure and bore pressure of tubular drug are much larger than those of cylindrical gunpowder with 7 holes and 19 holes. Under different gunpowder shapes, the relative position at the end of combustion increases first and then reaches a platform with the increase of the arc thickness of the main charge. The arc thickness of the auxiliary charge has little effect on the relative end position of combustion. The end position of the relative combustion of the cylindrical gunpowder with 19 holes is always above the cylindrical gunpowder with 7 holes and 19 holes. Under different gunpowder shapes, the relative position at the end of combustion increases first and then reaches a platform with the increase of the arc thickness of the main charge. The arc thickness of the auxiliary charge has little effect on the relative end position of combustion. The end position of the relative combustion of the cylindrical gunpowder with 19 holes is always above the cylindrical gunpowder with 7 holes and 19 holes. Under different gunpowder shapes, the relative position at the end of combustion increases first and then reaches a platform with the increase of the arc thickness of the main charge. The arc thickness of the auxiliary charge has little effect on the relative end position of combustion. The end position of the relative combustion of the cylindrical gunpowder with 19 holes is always above the cylindrical gunpowder with 7 holes and 19 holes. Under different gunpowder shapes, the relative position at the end of combustion increases first and then reaches a platform with the increase of the arc thickness of the main charge. The arc thickness of the auxiliary charge has little effect on the relative end position of combustion. The end position of the relative combustion of the cylindrical gunpowder with 19 holes is always above the cylindrical gunpowder with 7 holes and 19 holes.
Control the arc thickness of the main charge at 1mm, and draw the three-dimensional scatter diagram of the relationship between the maximum bore pressure, muzzle velocity, relative end point of gunpowder and the shape of the charge, the main charge amount, and the arc thickness of the auxiliary charge, as shown in Figure 4- Figure 6.

![Figure 4](image1.png)  
Figure 4 The relationship between bore pressure and shape, main charge quantity and arc thickness of auxiliary charge.

![Figure 5](image2.png)  
Figure 5 The relationship between initial velocity and shape of charge, main charge quantity and arc thickness of auxiliary charge.

![Figure 6](image3.png)  
Figure 6 The relationship between the end position of gunpowder relative to combustion and the shape of the charge, the amount of the main charge and the arc thickness of the auxiliary charge.

The arc thickness of the main charge remains unchanged, and the trajectory performance of the mixed charge varies with other variables, as can be seen from Figure 4- Figure 6: The muzzle velocity and bore pressure increase gradually with the increase of main charge quantity and decrease slowly with the increase of arc thickness of auxiliary charge. Under the same conditions, the muzzle velocity and bore pressure of the tubular charge are much higher than those of the cylindrical gunpowder with 7 holes and the cylindrical gunpowder with 19 holes. The arc thickness of the auxiliary charge has little effect on the relative position of the end of combustion. For the gunpowder with 7-hole cylinder and 19-hole cylinder, with the increase of the main charge, the relative position at the end of combustion decreases gradually. However, for tubular drugs, with the increase of the main charge, the relative position of gunpowder to the end of combustion first decreases, and when the main charge reaches 1720g, it suddenly increases and then decreases.
The arc thickness of the auxiliary charge is 0.48mm, and the three-dimensional scatter diagram of the relationship between the maximum bore pressure, muzzle velocity, relative position of gunpowder at the end of combustion and the shape of the charge, the main charge amount, and the arc thickness of the main charge is drawn, as shown in Figure 7 - Figure 9.

The arc thickness of the auxiliary charge remains unchanged, and the trajectory performance of the mixed charge varies with other variables, as shown in Figure 7 - Figure 9: The influence of arc thickness of main charge is more obvious than that of main charge. With the increase of the arc thickness of the main charge, the muzzle velocity gradually decreased, and the bore pressure gradually stabilized after a large decrease at the beginning. However, with the increase of the main charge, the bore pressure and muzzle velocity were almost unaffected. For 7-hole cylindrical gunpowder and 19-hole cylindrical gunpowder, the relative end position of gunpowder increases first and then reaches the platform point with the increase of the arc thickness of the main charge, and the amount of main charge has little influence on the relative end position of the tubular charge. For tubular charge, the relative position of gunpowder at the end of combustion increases with the increase of the arc thickness of the main charge, and then it reaches a platform. After the arc thickness of the main charge and the main charge increase to a position, the relative position of gunpowder at the end of combustion rises to another platform.
4. Conclusion
From the above experimental data and graph analysis, some conclusions can be found as follows: The ballistic properties of the mixed charge are more obviously affected by the arc thickness of the main charge at the corresponding step length and the arc thickness of the auxiliary charge at the corresponding step length. With the main charge arc thickness increasing, the fire bore pressure and projectile muzzle velocity decrease, and the relative position of gunpowder at the end of combustion increases. The arc thickness of the auxiliary charge has the same change, but the change is small. As the arc thickness of the powder particle increases, the initial combustion area decreases, and the combustion duration increases, the chamber pressure decreases, the initial velocity decreases, and the relative position of gunpowder at the end of combustion increases. When the charge amount increases, the powder energy increases, and then the muzzle velocity and bore pressure increase, and the relative end position of combustion decreases. Compared with the other two kinds of porous gunpowder, the tubular powder has higher initial velocity, higher bore pressure and smaller relative end position of combustion. This is because the tubular powder has constant surface combustion. Compared with the two kinds of porous gunpowder, when the arc thickness and charge amount are the same, the initial burning surface is large and the bore pressure is high, resulting in the rapid combustion of gunpowder. Therefore, by selecting proper loading parameters of the propellant, the better internal ballistic performance can be obtained, and then the safety performance can be improved in the use of the gun and the combat index can be met.

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