Finite element modeling of bullet-barrel interaction and mechanism analysis of swing phenomenon of bullet

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Abstract. The process of bullet-barrel interaction refers to the following physical process: after the gun is fired, the bullet moves forward under the push of powder gas, interacts with the barrel by extrusion, friction, contact and collision, and finally leaves the barrel. The swing phenomenon of bullet, which has a great influence on the shooting accuracy, is formed in this process. In order to study the formation of swing phenomenon and effect of barrel structure on swing, a finite element simulation model for the interaction process of a sniper rifle is established and calculated in this paper. The movement and stress distribution of bullet and barrel in bullet-barrel interaction process are obtained by simulation calculation, the swing of the bullet under different bore throat taper and rifle type is compared, and the intuitive process of the swing phenomenon of the bullet is obtained. Based on the calculation results, the following conclusions are obtained: Firstly, the dynamic process of bullet swing formation and amplification is obtained. In pre-shooting stage and extrusion stage, because of eccentricity of structure and other reasons, the bullet’s axis deviates in the process of embedding to form initial disturbance, called formation stage. In post-extrusion stage, the initial disturbance is continuously amplified due to the combined action of bullet structure, contact between bullet and barrel, and the pressure of powder gas, finally, the swing phenomenon of bullet is formed, called the amplification stage. Secondly, the effects of bore throat angle and rifle type on bullet swing are obtained.

1. Introduction

The process of bullet-barrel interaction refers to the following physical process: after the gun is fired, the bullet moves forward under the push of powder gas, interacts with the barrel by extrusion, friction, contact and collision, and finally leaves the barrel. The swing phenomenon of bullet, which has a great influence on the shooting accuracy, is formed in this process. In order to study the formation of swing phenomenon and effect of barrel structure on swing, a finite element simulation model for the interaction process of a sniper rifle is established and calculated in this paper. The model uses explicit analysis method because the bullet-barrel interaction process has following characteristics: it is a high-speed dynamic process, the bullet deforms and frictions under the extrusion of the barrel, contact
surfaces are constantly changing with the advance of bullet. In order to study the influence of barrel structure on bullet swinging movement, two parameters, rifle type and bore throat taper, are selected in this paper.

2. Modeling of Bullet-Barrel Interaction

2.1. Global Coordinate System
The global coordinate system is described as follows: the X axis is the axial direction of the barrel, the X positive direction points to the muzzle, the Y axis is vertical direction, the positive direction of the Y axis is upward, and the Z axis is horizontal, the positive direction is determined by right hand rule.

2.2. Meshing
The finite element mesh of the model consists of four parts: rifled barrel, simplified cartridge case, bullet jacket and bullet core (the latter two together constitute bullet). The assembly relationship is shown in figure 1.

![Figure 1. Assembly Relationship.](image)

The four parts are all divided into hexahedron elements, the element type is C3D8R which performs well in this case. The minimum mesh size is about 0.5 mm, the cartridge case and bullet jacket are divided into six layers of meshes in the thickness direction, the number of meshes in the circumferential direction of the bullet jacket and bullet core is the same, shown in figure 2.

![Figure 2. The Mesh of Cartridge Case and Bullet Jacket.](image)

The barrel is divided into about 1500 meshes in the axial direction. The mesh of bore throat is more densely in the X direction, totally 20 grids. In the circumferential direction, it’s divided into 9 part in each internal line part, and 10 in each external line part, shown in figure 3.
The total number of elements and nodes are as follows: barrel element 841500, node 955170, cartridge case element 42480, node 54000, bullet jacket element 266230, node 315122, bullet core element 633936, node 651105. The material barrel and cartridge case is steel, the material of bullet jacket is copper, and the material of bullet core is lead. The material parameters and friction coefficient between them are set according to different materials.

2.3. Loads and Constraints
The magnitude of Gravity is $9.8 \, N/\, m^2$. The curve of bore pressure is calculated based on ammunition parameters, the maximum bore pressure is about $350 \, MPa$. The pressure is applied to the surface of bullet base and boattail, shown in figure 4.

According to the actual working state of barrel, constraint is applied at the tail end of barrel to constrain the degrees of freedom in three directions.

3. Formation Mechanism of bullet Swinging Movement

3.1. Deformation of Bullet in the process of Engraving
In the process of engraving, because there is a small taper in the cylindrical part of the bullet, after extrusion and deformation, the stress between the bullet and barrel is mainly distributed in the tail of cylindrical part, shown in figure 5.
3.2. Force Structure

It can be seen from the stress distribution that the deformation space of the tail of cylinder part is small and the deformation space of the head of cylinder part is bigger. The force structure of bullet is like a long pole which is constrained in the tail part, shown in figure 6. There has been a initial disturbance in the process of engraving, and the bullet has deviated from the equilibrium position. Under the action of pressure, the long pole will deviate from the center position.

![Figure 6. Mechanical Structure of Bullet.](image)

3.3. Amplification Process of Swing Angle

The force structure of bullet shows that the initial disturbance will become lager and lager once it is produced. Due to the swing of bullet, the stress between bullet and barrel presents an uneven distribution in circumferential direction. In the following, the amount of bullet swing is continuously enlarged due to the effect of bore pressure, shown in figure 7.
4. The Influence of Barrel Structure on Bullet Swing

4.1. The Influence of Rifle Type

The bullet swing angle when the rifle type are rectangle and polygonal arc are compared, shown in figure 8.

It can be seen from above figure, the bullet swing angle with polygonal arc rifle is lower than that with rectangle rifle in vertical direction, and the bullet swing angle with polygonal arc rifle is larger than that with rectangle rifle. On the whole, the polygonal arc rifle is better than rectangle rifle.

4.2. The Influence of Bore Throat Taper

The bullet swing angle when the bore throat taper are 3° and 1.5° are compared as shown in figure 9.
It can be seen from above figure, the bullet swing angle is larger when the bore throat taper is 3° in vertical direction, and there is no significant difference in horizontal direction. On the whole, 1.5° taper is better.

5. Conclusion
Through the above research, the conclusions are as follows:

(1) In the process of engraving, a initial disturbance is produced, and the bullet deforms to form a special force structure. Then the swing angle is constantly increasing under the action of bore pressure.

(2) The bullet swing angle with polygonal arc rifle is lower than that with rectangle rifle in vertical direction, and the bullet swing angle with polygonal arc rifle is larger than that with rectangle rifle. On the whole, the polygonal arc rifle is better than rectangle rifle.

(3) The bullet swing angle is larger when the bore throat taper is 3° in vertical direction, and there is no significant difference in horizontal direction. On the whole, 1.5° taper is better.

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