Dynamic numerical simulation analysis of a large caliber artillery projectile extrusion process

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Abstract: Taking a large-caliber gun as the research object, a projectile and gun coupling finite element numerical simulation model during the extrusion process is established according to the finite element simulation technology. The dynamic simulation of the extrusion process is carried out by using ABAQUS/EXPLAICT solver, and the stress variation law of the projectile belt during the groove and the barrel during the extrusion process is obtained. In the post-processing module of the finite element software, the data of displacement, velocity and acceleration at the center of mass of the projectile in the extrusion process are extracted, and the motion law of the projectile in the extrusion process is analyzed, which provides some reference value for the study of the extrusion process of large caliber artillery projectile.

1. Introduction
The ablation wear of the inner bore of the tube is mainly concentrated in the slope bore and the beginning of the rifling [1]. During the period when the rifling was squeezed into the bore, the slope bore of the barrel was subjected to the huge extrusion pressure and shear force of the rifling, and the elastic plastic deformation of the bore occurred. The whole large deformation process lasted until the bore was squeezed into the full deep rifling. At present, finite element simulation technology is the most widely used method to study the extrusion process of large caliber artillery projectile. The simulation model established at present has some problems, such as low simulation accuracy and difficult convergence of calculation. In this paper, the Johnson-Cook material constitutive model combined with ALE mesh adaptive technology is used to obtain the projectile coupling finite element model with good computational stability, and the numerical simulation of the projectile extrusion process of a gun is carried out by using this model.

2. Force analysis of extrusion process
When the projectile is loaded in place, the projectile belt is against the grooves. With the increase of the gunpowder gas pressure, the projectile is forced to accelerate along the barrel axis, and the
projectile belt is squeezed by the grooves to produce elasto-plastic deformation and gradually squeeze into the rifled [2]. Taking the elastic belt as the research object, as shown in Fig. 1, the main forces of the elastic belt bearing the barrel in the extrusion process include normal contact force $N$ and tangential friction force $\mu N$.

Fig. 1. Slope bore resistance of projectile belt during extrusion

3. Simulation Model Establishment

3.1 Finite element meshing

Grid quality will affect the results of the finite element model, a large caliber gun tube taper bore 1/10 slope, and the finite element mesh node displacement method [3], XianTang body tube finite element mesh model shown in figure 2, and then use C3D8R unit grid, slope chamber take encryption processing part of the grid, slope bore the grid size is 2mm. The projectile is a concave projectile, and the divided finite element mesh model is shown in Figure 3. The structure of bullet belt is shown in Fig. 4.

In order to better seal the gunpowder gas in the bore, the diameter of the outer flange of the ammunition belt is generally slightly larger than the diameter of the negative line of the bore [4].

3.2 The projectile material model

The barrel material is gun steel, the projectile body material is projectile steel, and the projectile belt material is brass. The material parameters are shown in Table 1.

| Table 1 Material parameters |
|-----------------------------|
| Density Kg/m$^3$ | E/GPa | $\mu$ | $\sigma_s$/MPa |
|-----------------|-------|-------|----------------|
| barrel          | 7800  | 210   | 0.3            |
| projectile      | 6000  | 206   | 0.27           |
| band            | 8500  | 110   | 0.32           | 90   |
Large elastoplastic deformation and damage will occur in the extrusion process. A large number of tests and simulations have found that the Johnson-Cook model can better simulate the mechanical behavior of materials during the extrusion process of elastic belt [5], and the Johnson-Cook model constitutive mainly includes: plastic deformation constitutive and fracture failure constitutive.

3.3 Loading and boundary conditions
The pressure curve calculated by the internal ballistic equation is applied to the missile bottom, as shown in Fig. 4. The boundary condition is the full constraint of the barrel tail (Fig. 5), and the gravity is loaded in the model as the normal force during the extrusion process. In order to make the numerical simulation model more easily convergent, the ALE grid adaptive technology is used to control the distortion of the grid in the simulation process, so as to improve the simulation efficiency and accuracy.

![Fig. 4 Bottom pressure curve](image1)

![Fig. 5 Boundary conditions](image2)

The contact algorithm between the elastic belt, the front centering part and the barrel bore was set as the penalty function contact algorithm, the Coulomb friction model was selected as the friction model, and the friction coefficient between the contact surfaces was set as 0.1. The established projectile and gun coupling finite element model is shown in Figure 6.

![Fig. 6 Gun coupling finite element model](image3)

4. Numerical simulation results and analysis
The extrusion model is simulated numerically with ABAQUS/Explicit solver. The simulation time is set at 4.5ms, and the whole extrusion process is 3.9ms. The stress nephogram of the elastic belt and barrel at different moments in the extrusion process is shown in Fig. 7 and Fig. 8 respectively. The barrel contact force curve in the extrusion process is shown in Fig. 9.

![Stress nephogram at different moments](image4)
As can be seen from Fig. 7-9, at the beginning of the extrusion, the back elastic belt first contacts with the inner wall of the groove chamber. With the deepening of the extrusion, the front elastic belt begins to contact the inner wall of the barrel about 1ms. At about 2ms, the front projectile belt squeezes the beginning of rifling and begins grooving. At this time, the deformation of the front projectile belt per unit time reaches the peak and the contact force appears an extreme value. As the extrusion goes on, the deformation of the elastic belt increases gradually. Because the extrusion force of the back elastic belt is larger than that of the front elastic belt, the plastic deformation is also larger, so the interaction force between the back elastic belt and the slope bore is greater than that of the front elastic belt. At about 2.75ms, the grooving of the front elastic belt was basically completed. At this time, the flange of the back elastic belt was flattened and began to squeeze the beginning of the rifling. At this time, the deformation of the back elastic belt per unit time was the maximum and the contact
force appeared a peak. At about 3ms time, the rear bullet belt was cut by rifling and gradually squeezed into rifling. At about 3.9ms, the rifling was completely squeezed into the full deep rifling and grooving of the rifling was completed. The two peaks in Fig. 9 respectively correspond to the moments when the deformation rate of the projectile belt reaches the maximum before and after it.

In the extrusion process, the axial displacement, velocity and acceleration curves of the projectile's centroid are shown in Fig. 10 ~ 12, and the projectile's extrusion resistance curve is shown in Fig. 13.

As can be seen from Figure 10 to Figure 12, when the projectile hits the slope bore, the projectile belt pushes into the full deep rifling about 108.4mm axially. At the end of the squeeze, the velocity of the projectile reached about 87m/s. The figure 13 shows that packed into the early, playing with the chamber and the slope of contact area is small, frictional resistance and deformation resistance is small, and packed into resistance rises slowly, with the deepening of the squeeze into, the projectile movement rate is accelerated, and play with the chamber and the slope of contact area increased rapidly, to overcome resistance to deformation and friction resistance increases gradually, lead to squeeze into resistance increases rapidly, It reaches the maximum value at about 2.75ms, and the maximum extrusion resistance is about N. With the penetration of the rifling, the extrusion resistance gradually decreased, and when the projectile was fully pressed into the full deep rifling, the friction resistance instantly decreased to the frictional resistance value of rifling motion, which was about half of the maximum extrusion resistance.

5. Conclusions
Based on the finite element numerical simulation theory, a finite element numerical simulation model for the extrusion process of a large-caliber gun barrel projectile is established. The results show that the Johnson-Cook model can better simulate the deformation and grooving process of the projectile belt extrusion process, and has better mechanical simulation for the large deformation process of the
material. In addition, it is found that the ALE adaptive mesh technology has a good effect on the distortion control of the material mesh of the projectile during the projectile extrusion process. The accuracy of the simulation model was verified by analyzing the axial application law of the projectile's center of mass during the extrusion process.

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