Research on establishment and verification of projectile and artillery coupling system virtual prototype

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Abstract. A virtual prototype of a projectile and artillery coupling system was constructed and a virtual shooting test was performed. The virtual prototype of the projectile and artillery coupling system was verified by using key parameters when sitting behind the body tube. The results show that the projectile-artillery coupling model has good consistency with the actual mechanical system, which confirms that the virtual prototype of the projectile-artillery coupling system can basically reflect the dynamic characteristics of the artillery during launch.

1. Introduction

The virtual prototype of the projectile-artillery coupling system is actually a dynamic model that can be used to simulate the firing process of the artillery. It is mainly based on the assumption of certain basic assumptions for three-dimensional solid modeling and load [1]. The virtual prototype of the projectile-artillery coupling system can be realized.

In recent years, it has been widely used in defense and military fields such as weapon loading and launching system simulation, tracked and wheeled vehicle dynamics simulation, heavy tank obstacle surging capability simulation, tank driving stability optimization and turret control, etc. Obvious advantages of prototype technology. The US Navy's M61A1 artillery had a jam phenomenon when firing. Researchers used ADAMS to find out the cause and solved the problem by modifying the projectile guide block and the shell gear. This example shows that ADAMS can effectively solve the problems in the development and testing of artillery. problem. David C. Rutledge [2] conducted research on recoil dynamics physical modeling of light vehicles equipped with artillery in accordance with the requirements of the US Army's "Lightening of Combat Vehicles" and optimized the overall structure of combat vehicles based on simulation results. In the research process of the expansion of the artillery by the US military, the "modeling, simulation, and virtual prototype technology" was used as the key technical means of the entire development plan. The research team led by Kevin Miner successively developed anti-reclining devices and muzzle brakes. The thermal conduction process modeling, post-jet heat conduction modeling and vibration analysis, ablation modeling, shock wave field modeling, etc., the conclusions obtained from the virtual experiments well guided the development of the physical prototype of the expansion wave artillery [3]. The U.S. Army uses modeling and simulation technology in the development of non-direct-looking artillery (NLOS) in the development plan of the Future Combat System. It uses 3D CAD software as a platform to model the...
entire system of the artillery, and uses a variety of technical methods. Complete system design, physical prototype development and test verification [4].

2. Construction of projectile and artillery coupling system virtual prototype

2.1. Solid model of projectile and artillery coupling system
ADAMS has excellent functions in mechanical system dynamics analysis, but the solid modeling function is limited. When modeling complex bodies such as projectile and artillery coupling systems with special structures, use the CAD platform Pro / E to achieve better modeling. Effect [5]. First of all, according to the actual size and shape of each part of the projectile, namely the head part, front centering part, cylindrical part, rear centering part and tail part, the three-dimensional solid modeling is performed in the Pro / E environment; The interface program Mechanism / Pro and the intermediate file format are converted into a solid model with dynamic parameters (mass, center of mass position, moment of inertia, etc.) in the ADAMS environment.

According to the basic composition of a large-caliber artillery and the participation of various parts in the movement, the entire artillery system is divided into 7 subsystem models: recoil subsystem, rocking rack system, high and low machine subsystem, upper rack system, steering machine subsystem, lower rack System and large rack system. During the modeling process, some parts have relatively fixed positional relationships with respect to other parts, so they are merged into the same part, such as muzzle brake, gun body, bolt, tail, and retreating machine, re-entry machine Part of the recoil sits simultaneously during the firing of the artillery, and their relative displacements can be ignored, so they are taken as a whole, the recoil subsystem.

2.2. Virtual prototype of projectile and artillery coupling system
As shown in Figure 1, the mechanical model of the virtual prototype system consists of components that describe the physical and geometrical properties of the entity and the basic mechanical elements such as kinematic constraints, driving constraints, external forces / torques, and force elements acting on them, and contain materials , Unit, and system settings [6].

![Figure 1. The framework of virtual prototype model.](image)
For the convenience of research, the $0^\circ$ firing angle is used in the virtual prototype modeling and subsystem reconstruction. The coordinate system of the projectile and artillery coupling system can be specified as: the axis of the body tube is the X axis, and the intersection point with the end surface of the gun tail is the coordinate origin O. And agreed that the recline direction is positive, the Y axis is vertically upward after the origin, and the axis determined by the right-hand rule is the Z axis.

Determine the degrees of freedom of the parts according to their kinematic relationships:

1. The lower frame can be translated and rotated around the ground (inertial coordinate system), and has three degrees of freedom for translation and three degrees of freedom for rotation;
2. The two large frames each have a degree of freedom of rotation relative to the lower frame;
3. The upper frame has a degree of freedom of rotation relative to the lower frame, and can perform horizontal rotation motion;
4. The cradle has one degree of freedom of rotation relative to the upper frame; it can perform pitching motion in the vertical direction;
5. The high and low machine tooth arc rotates relative to the upper rack, and the high and low machine worms translate relative to the upper rack, so they have one degree of freedom of rotation and one degree of freedom of translation, respectively;
6. Under the combined force of the breech, the projectile rotates forward while the recoiled part is translated backward, so the recoiled part has a translational freedom relative to the cradle;
7. As the rigid medium simplified from the plastic deformation zone of the elastic band is limited in the basic assumption, it advances strictly according to the rifling constraint, and its translation can be achieved through the cylindrical hinge constraint. The elasticity of the elastic band of the elastic band simplifies the elastic movement of the elastic band. Therefore, the elastic deformation of the elastic band has a translational freedom and rotational freedom relative to the recoil of the gun. Freedom of movement and three degrees of freedom of rotation.

High and low power and directional power are important loads when the artillery is launched. The former is used as an example to briefly explain the method of applying it: establish a rotary hinge between the high and low gear tooth arc and the upper frame, the worm gear and the upper frame, and use a coupling pair Coupler pair. It associates to simulate the meshing relationship between the high and low machine tooth arcs and gears; similarly, a rotary hinge and a moving hinge are established between the worm gear and the upper frame, and between the worm and the upper frame, respectively. The coupling pair Coupler is used to associate to simulate the worm and worm Transmission relationship. The two coupling pairs set the transmission ratio according to the actual structure and mechanical transmission relationship of the high and low gear tooth arcs, gears, worm gears, and worms.

So far, the projectile and artillery coupling system has been simplified into a dynamic model consisting of 9 subsystems, and there are hinges and restraint reaction forces corresponding to the degrees of freedom between each subsystem. According to the previous analysis results, the main power and restraint reaction force of the artillery when firing are mainly the combined force of the barrel, the hydraulic resistance of the retreating aircraft, the friction between the gun body and the cradle slide rail, and the re-entry force. These forces can be expressed as the recoil stroke. Or velocity function, use Fortran language to write a custom force program and call it during the virtual prototype operation to solve the dynamics. The combined force of the barrel should be applied between the projectile and the recoil of the artillery, and other forces should be applied to the artillery parts separately. In the above, the effects of high and low mechanical and directional mechanical forces are temporarily simulated by the stiffness and damping of the flexible connection [7] (in the next chapter, the model reconstruction is implemented based on the internal structure of these two important subsystems to improve the virtual prototype) The rifling steering moment acts on the plastic deformation part of the elastic band. Finally, a virtual prototype model of the projectile-artillery coupling system is established.

In short, the establishment of the virtual prototype model of the projectile-artillery coupling system until the dynamic analysis has undergone the evolution of the four phases of physical model-digital
model-mechanical model-mathematical model. The entire analysis process [8] can be briefly described as shown in Figure 2,

![Figure 2](image)

**Figure 2.** The basic process of virtual prototype modeling and analyzing.

First, computer graphics are used to establish a precise physical model of the projectile and artillery, and then it is mapped to a mechanically equivalent digital model based on the theory of multibody dynamics, and then the corresponding artillery launch dynamics model is obtained according to basic mechanical principles. The solver assembles the equation of motion to achieve the transformation from a mechanical model to a mathematical model.

3. Verification of projectile and artillery coupling virtual prototype

Through the comparison of experimental and simulation calculation results of some key indicators of the barrel squat and the vibration response characteristics of the barrel when the artillery was launched, the virtual prototype of the projectile and artillery coupling was verified to ensure the accuracy of the model and the reliability of the virtual test results [9].

![Figure 3](image)

**Figure 3.** Displacement of recoil parts.

![Figure 4](image)

**Figure 4.** Velocity of recoil parts.
Figures 5 to 8 are the curves obtained by the virtual experiment. Table 1 shows the comparison between the simulation calculation results of the virtual prototype and some test data.

It can be found from Table 1 that the variation of the squat displacement, speed, and squat resistance of the body tube is generally consistent with the test data, indicating that the virtual prototype is basically in line with reality.
4. Conclusions
This paper builds a virtual prototype of the projectile-artillery coupling system. Based on the projectile-artillery coupling system, a virtual firing test is performed. The coupling model of the projectile and artillery is verified through some key indicators of sitting behind the barrel. The results show that the projectile-artillery coupling model has good consistency with the actual mechanical system, which confirms that the virtual prototype of the projectile-artillery coupling system can basically reflect the dynamic characteristics of the artillery during launch.

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