Numerical Simulation of Asynchronous Ignition Time Series with Multi-gas Generator

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Abstract. Multi-gas generators, multi-sequence ignition and modular charge are effective method to solve general ejection. An integrated CFD simulation model with high-pressure chamber, low-pressure chamber and nozzle is proposed, in which, the mass source term and energy source term are considered in the field flow during the charge combustion. Based on moving-mesh technology, the key problem involved the burning surface and the moving piston is solved. The numerical simulation on integrated CFD simulation model with dual gas generators and asynchronous ignition time series is carried out, and the coupling calculation of charge combustion and the change of the flow field are realized. Simulation results show that the numerical simulation model and method are accurate.

Introduction

The universal ejection technology based on multiple gas generators, multiple timing ignition, and modular charge can effectively solve the general ejection of multi-type projectile. Reference [1] proposed the idea of modular charging for long-range artillery. Reference [2] proposed the use of a universal projectile catapult composed of multiple gas generators and an ignition control combination. The gas generator uses a modular design with the same Structural parameters and charging parameters. For different types of projectile, the requirements of small overload and high speed of the projectile ejection process are achieved by increasing or decreasing the number of gas generators and adjusting the timing of relay ignition of each gas generator. References [3]-[7] carried out simulation research on the internal ballistic characteristics of projectile catapults. Based on this, a multi-gas generator ejection internal trajectory model was established, and an optimization algorithm for the ignition sequence of multi-gas generators was proposed to solve the problem. Use the optimal ignition sequence of multiple gas generators to achieve the highest pressure utilization in the low-pressure chamber that meets the overload requirements. In this paper, an integrated flow field model of a single gas generator, a dual gas generator's high-pressure chamber, low-pressure chamber, and nozzle is established to realize the coupling calculation of the charge combustion process and flow field changes.

Charged Mass Combustion Model

Because the movement and deformation of the flow field grid during the simulation calculation, the grid conservation equation of the flow field needs to be satisfied in order to avoid additional calculation errors. For a general scalar \( \phi \) on an arbitrary control volume \( V \) of a moving boundary, the moving grid conservation equation can be written as:

\[
\frac{d}{dt} \int_V \rho \phi dV + \int_{\partial V} \rho \phi (\vec{u} - \vec{u}_e) \cdot d\vec{A} = \int_{\partial V} \Gamma \nabla \phi \cdot d\vec{A} + \int_V S_\phi dV
\]  

(1)

where, \( V \) is the control volume whose shape changes with time in space, \( \partial V \) is the motion boundary of the control volume, \( \vec{u} \) is the velocity vector of the fluid, \( \vec{u}_e \) is the motion velocity vector of the motion grid, \( \Gamma \) is the diffusion coefficient, and \( S_\phi \) is the Source term of the scalar \( \phi \).
In the flow field simulation of charge combustion, it is necessary to write a UDF program of the charge source term. The DEFINE_SOURCE macro in the model designation macro is used to define the source term of the charge combustion gas, including the mass source term, energy source term and momentum source term. The UDF program is called in the flow field calculation, so as to realize the charge combustion of the charge. The equations of each source term of gas are:

Mass source term:

\[
\dot{S}_m = \rho_p r A_i V_i \\
\]

(2)

where, \(A_i\) is the area of the burning surface of the cell, \(V_i\) is the volume of the cell, and \(\rho_p\) is the charge density.

Energy source term:

\[
\dot{S}_H = \rho_p r A_i c_p T_i V_i \\
\]

(3)

where, \(c_p\) is the constant pressure specific heat of the gas, and \(T\) is the adiabatic temperature of the gas.

UDF Implementation of Burning Process

In the process of charging surface transition, it is necessary to write a UDF program for burning surface transition. The DEFINE_GRID_MOTION macro in the dynamic mesh model DEFINE macro is used to define the change law of the combustion surface. By extracting the pressure on the surface of the charging and in the equation of the charging and burning rate, calculating the burned thickness in a step time, thereby accurately controlling the movement of each burning surface point, and realizing the real-time update of the flow field grid with the burning surface of the movement.

During the charging process, the moving grid technology is used to realize the transition of the burning surface. The algorithm for increasing the burning powder is as follows:

Step1: Take any point \(S\) on the surface of the charge, and subtract the origin coordinate from the coordinate of \(S\) to get the vector \(r\) of the current point;

Step2: Let the unit vector on the \(y\)-axis be \(P\), so \(\bar{u} = r - p\);

Step3: The modulus length of \(\bar{u}\) obtained by using the mag function is \(|\bar{u}|\), and let \(d = \bar{u}/|\bar{u}|\), that is, \(\bar{d}\) be a unit vector;

Step4: Then let \(\bar{w} = \bar{u} + de \cdot \bar{d}\) (where \(de\) is the thickness of the gunpowder burning per unit time, that is, \(\bar{w}\) is the vector that points to the point after burning, and then use the function to find the coordinates of the point in reverse, that is, complete the coordinate of the charging surface after increasing the combustion update.

Numerical Simulation of Ejection Process of Two Gas Generators

Calculation Model and Mesh

Place a gas generator on the left and right sides of the low-pressure chamber, and ignite them in sequence at a certain time interval. A single tubular powder is placed in the combustion chamber, and the inner surface burns. The high-pressure chamber is connected to the low-pressure chamber through a duct. The inner side of the charge is a moving boundary. From the normal combustion of the charge, the burning surface of the charge is continuously moving outward, and the calculation field of the flow field changes accordingly. The two ends are deformed boundaries, the nozzle is a wall boundary before opening, it is set as an internal boundary, and the piston is set as a moving boundary, as shown in Figure 1.

In terms of grid processing, the method for structural grid is used, which is divided into O-Grid grid types in the circular area. The grain area and the nozzle area are locally encrypted. The total number of grids is 229,176, as shown in Figure 2.
Numerical Simulation Analysis

Temperature distribution of the symmetrical cross section of the catapult after 0.008s, 0.0124s (combustion chamber 1 diaphragm is opened), 0.0161s (combustion chamber 2 diaphragm is opened), 0.02768s, 0.04482s after the gas generator has started ignition is shown in Figure 3. At the beginning, the gas generator 1 first ignites and the temperature rises first. The temperature of the low-pressure chamber and the gas generator 2 remains at normal temperature. When the gas generator 2 starts to ignite, the temperature in the internal area rises and is lower than the internal temperature of the gas generator 1. In 0.04482s At this moment, the maximum temperature of the low pressure chamber is close to the temperature of the internal area of the two gas generators.

Pressure distribution of the symmetrical cross-section of the internal ejector after 0.008s, 0.0124s (combustion chamber 1 diaphragm is opened), 0.0161s (combustion chamber 2 diaphragm is opened), 0.02768s, and 0.04482s after gas generator 1 starts ignition is shown in Figure 4. At the
beginning, the gas generator 1 ignites, and the internal pressure of the gas generator 1 increases. At this time, the pressure of the low-pressure chamber and the gas generator 2 is maintained at 1 atm. At the moment of 0.02768s, the pressure at the piston of the low-pressure chamber reaches 6637760 Pa and the piston stroke is 0.2 m. At 0.04482s, the pressure at the low-pressure chamber piston reached 12225400 Pa, and position of the piston was 0.46 m.

![Pressure distribution of the ejector's symmetrical section at different moments.](image)

Mach number distribution of the cross section of the nozzle inside the high and low pressure chamber of the ejector at 0.0161s (combustion chamber 2 diaphragm opened), 0.02768s, and 0.04482s after the gas generator starts to ignite is shown in Figure 5. After the orifice diaphragms are all opened, part of the gas flow injected from the gas generator 1 flows into the gas generator 2 and flows at subsonic speed; at 0.04482s, the gas flow at the outlet of the gas generator 1 expands to supersonic speed and then compresses to subsonic speed. The flow is repeated, and after intermingling with the gas flow from the gas generator 2 outlet, a more complex wave system is formed, which is finally compressed into a subsonic flow. At this time, the gas flow from the gas generator 2 outlet is compressed into a subsonic flow at the outlet.

![Mach number distribution of ejector nozzle section at different moments.](image)

From Figure 6, we can be seen that the gas flow in the entire flow field area of 0.02768s, 0.034s, and 0.04482s. At several corners of the high and low pressure chambers, the gas flow hits the wall surface to form multiple vortices. In the initial stage of the nozzle opening, the pressure at the nozzle is stronger than the internal pressure of the gas generator, and a reverse flow occurs in the nozzle of the gas generator 2. At the time of 0.034s and 0.04482s, the gas flow flows from the two gas generators respectively, and part of the gas flow intersect near the nozzle of the gas generator 2 and flow toward the piston.
Summary

Aiming at the high-pressure chamber, low-pressure chamber and nozzle integrated numerical simulation scheme, the physical models of the ejector including single-gas generator and dual-gas generator were established respectively, and the structured calculation grid was divided by using O-Grid technology. Energy enrichment technology in combustion process, combustion surface push grid technology, piston motion grid technology, with the help of FLUENT software, the UDF file is compiled, and the entire ejection process is numerically simulated. From the results of numerical simulations, the ignition mode of the dual gas generator can effectively increase the pressure in the low pressure chamber of the catapult and the speed of the piston.

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References

[1] Wang Zeshan. Propelling charge and modular charge systems for the extended firing range[J]. Journal of Nanjing University of Science and Technology, 2003, 27(5): 466-472.
[2] He Xiao-ying, Peng Xue-ming. Temperature Adaption Study of Missile Ejecting System with Multi-Gas Generators [J], Modern Defence Technology, 2017, 45(2): 56-60.
[3] Tong Jian-lu, Liu Shao-wei, Wang Jie. The Model Simulation of Ejection Device of Certain Tactical missile[J], Tactical Missile Technology, 2005, 1:63-65.
[4] Wang Tian-hui, Chen Qing-gui, He Chao. Design and Computation of Interior Ballistic for Gas Generator[J], Modern Defence Technology, 2014, 42 (2): 56-60.
[5] Chen Qing-gui, Qi Qiang, Zhu Bao-yi. Numerical Simulation of Launching Inner Trajectory of one Missile[J]. Journal of Naval Aeronautical and Astronautical University, 2010, 25(5):501-504.
[6] Bai Peng-ying, Qiao Jun. Analysis about the Interior Trajectory of Two Step Cylinder Ejection Device[J]. Modern Defence Technology, 2007, 35(4): 44-49.
[7] Xie Wei, Wang Han-ping. Influential Factors Analysis on Interior Ballistic Performance of Lift-Draw Ejecting Device[J], Journal of Solid Rocket Technology, 2016, 39(1):146-150.