Optimization Design on Impact Parameters of Gun Firing Simulation System

Yuliang Yang¹, Zhonghua Du¹⁺, Peng Li¹, Yezun Sun²

¹ Shijiazhuang Campus of Army Engineering University, Shijiazhuang 050003, China;
² Equipment Support Team, Beijing, 430311, China

*corresponding anthor: dzh1973@sohu.com

Abstract. It is a feasible method to simulate the gun firing process through muzzle strong impact. In order to ensure simulation precision, a virtual testing environment was developed based on ADAMS platform. The impact mass, impact velocity, initial pressure and length of pneumatic buffer were selected as design variables. The average relative error of dynamic responses was set objective function. The GRG algorithm was used to optimize the impact parameters.

1. Introduction

The gun firing simulation system refers to a system that makes the recoil parts produce similar dynamic characteristics as the live firing without launching live ammunition¹².

The working principle of the gun firing simulation system was shown in Figure 1. Firstly, the impact head was accelerated by the air pressure system. Secondly, the impact head separated from the air pressure system, when it reached a certain speed. Thirdly, the impact head impacted the gun muzzle, pushed it to simulate the recoil and recuperation process. The test method used the impact force instead of the gun bore resultant force. In order to ensure that the test method had high simulation accuracy, it was necessary to optimize the impact parameters.

2. Simulation environment development

Based on the dynamic simulation software ADAMS, the simulation environment of firing simulation system was developed, shown in Figure 2. Firstly, the Pro/E software was used to establish the solid model of gun system. Then the solid model was introduced into the ADAMS. And the constraints and loads were added to establish the gun dynamics model. The impact head was added in front of gun barrel, and an interaction force was placed between the impact head and the muzzle to indicate the interaction of the pneumatic buffer.
The pneumatic buffer played the role of buffer and load matching during the impact process. The working principle was shown in Figure 3.

During the compression process, the pneumatic buffer satisfied the following equation.

\[ p_0 W_0^n = p_x W_x^n \]  

Where, \( p_0, W_0 \) were respectively the initial pressure and volume of buffer chamber; \( p_x, W_x \) were respectively the chamber pressure and volume when the compression length was \( x \); \( n \) was the adiabatic coefficient.

Set the cross-sectional area of chamber as \( A_0 \), the equation (1) can be converted.

\[ p_0 L_0^n = p_x L_x^n \]  

Where, \( L_0 \) was the initial length of buffer chamber; \( L_x \) was the chamber length when the compression length was \( x \).

The initial force provided by pneumatic buffer \( F_0 \) was

\[ F_0 = A_0 p_0 \]  

During the compression process, the force \( F_x \) was

\[ F_x = A_0 p_x = A_0 p_0 \left[ \frac{L_x}{L_0} \right]^n \]  

3. **Optimization design of impact parameters**

The impact parameters of simulation system affected simulation accuracy. In order to ensure simulation accuracy, the impact parameters needed to be optimized.
3.1. Impact parameters
Four parameters, such as impact head mass, impact head speed, initial pressure and length of pneumatic buffer, were selected as design variables. Considering the actual situation, the initial values and ranges of design variables were set, shown in Table 1.

Table 1. Initial values and ranges of design variables

| Design variable       | Initial value | Upper value | Lower value |
|-----------------------|---------------|-------------|-------------|
| Impact mass/kg        | 1200          | 1400        | 1000        |
| Impact speed/(m·s⁻¹)  | 15            | 17          | 13          |
| Initial pressure /MPa | 50            | 70          | 30          |
| Initial length /mm    | 80            | 100         | 60          |

3.2. Objective function
The recoil movement law of gun firing simulation system should be consistent with live firing. The average value of four relative errors, such as the maximum recoil displacement, the maximum recoil speed, the recoil displacement and time corresponding to the maximum recoil speed, was set as objective function³,⁴.

3.3. Optimization algorithm
The reduced gradient method was a simplex method of nonlinear programming, applied to nonlinear programming problems with only linear constraints. Extending the reduced gradient method to nonlinear constrained optimization problems, the generalized reduced gradient method (GRG method) was generated. The GRG method was one of the most effective methods for solving nonlinear constrained optimization problems⁵,⁶.

The nonlinear programming problems solved by the GRG algorithm can be summarized as follows.

\[
\begin{align*}
\min & \quad F(X) \quad X \in E^n \\
\text{s.t.} & \quad H(X) = 0 \\
& \quad L \leq X \leq U \quad L,U \in E^n
\end{align*}
\]

Where, \( H(X) = [h_1(X), h_2(X), \ldots, h_m(X)]^T \); \( L = [l_1, l_2, \ldots, l_n]^T \); \( U = [u_1, u_2, \ldots, u_n]^T \).

3.4. Optimization results analysis
The optimization results of impact parameters and objective function were shown in Table 2.

Table 2. Optimization results

| Optimization variable | Initial value | Optimization value | Change amount |
|-----------------------|---------------|--------------------|--------------|
| Impact mass/kg        | 1200          | 1140               | 5%           |
| Impact speed/(m·s⁻¹)  | 15            | 14.6               | -2.67%       |
| Initial pressure /MPa | 50            | 56                 | 12%          |
| Initial length /mm    | 80            | 68                 | -15%         |
| Objective function    | 10.47%        | 3.52%              | -66.4%       |

After the optimization design of impact parameters, the objective function was only 3.52%, which indicated that the test method can accurately simulate the live firing. The comparison between the impact force generated by the impact process and the gun bore resultant force was shown in Figure 4.
4. Conclusion
A certain type of gun firing simulation system was studied. Firstly, the virtual testing environment was developed based on ADAMS software, using the interaction force simulate the working principle of pneumatic buffer. Secondly, to ensure precision of the simulation method, four impact parameters, objective function and optimization algorithm were selected. Finally, optimization parameters were obtained, and the objective function was only 3.52%. The optimization results indicated that the test method can accurately simulate the live firing. This study laid a foundation for the design of gun firing simulation system.

References
[1] ZHANG Fu-san. Theory and practice on gun type testing [M]. National Defense Industry Press, 2000.
[2] Mike Cast. Army test move to ‘virtual proving ground’ [J]. National Defense, 2001, 11: 62-64.
[3] LIU Lin, DI Chang-chun, QIAO Liang, et al. Experimental design and optimization research on parameters of firing simulator[J]. Journal of Gun Launch & Control, 2010(3): 99-102.
[4] GJB 2173-94, Dynamic recoil simulation test method for gun[S]. 1994.
[5] CHEN Bao-lin. Best optimization theory and algorithm[M]. Beijing: Tsinghua University Press, 2005.
[6] BU Xiang-jian, HOU Liang, GUO Tao, et al. Optimization design of backhoe working device based on generalized reduced gradient algorithm[J]. Journal of Ximen University (Natural Science), 2014, 53(3): 368-372.