Parameter optimization of a certain grenade launcher using virtual prototype technology

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Abstract. In order to further reduce the recoil force of a certain grenade launcher and improve man-machine ergonomics, the parameter optimization was studied. According to the topological relations among the components of the weapon system, the constraints between the main components and their mechanical relations were analyzed, the key forces were calculated, the virtual prototype model was established and its credibility was verified. The sensitivity of each parameter of the model was analyzed, and the design variables were determined. In the way of integrating Adams software into Isight platform, the relevant parameters of the weapon were optimized by using multi-island genetic algorithm, and the obtained optimal solution was simulated and analyzed. The results show that the extreme value of the recoil force is reduced by 18.6% after optimization, and the optimization scheme effectively improves the man-machine ergonomics and system stability of the weapon.

1. Introduction
A certain type of grenade launcher has a multi-stage and multi-buffer mechanism, which greatly reduces its recoil and makes it capable of shoulder-fired. With the increasing demand of weapon system's striking ability, effective range and shooting accuracy are also in urgent need of improvement. Therefore, it is necessary to further study the recoil reduction technology of this weapon, improve its man-machine ergonomics, and lay a foundation for its ability to launch more long-range missiles.

Isight is a powerful platform for the computer aided optimization, widely used in aviation, spaceflight, automobile, shipbuilding, electronics components, optimization subsystem and complex products in the field of multidisciplinary design optimization, a wide range of CAD/CAE program interface, users can quickly build complicated simulation analysis, set and modify the design variables, the automatic analysis of multiple cycle and find the optimal results\[1\].

Multi-island genetic algorithm was adopted, and Isight was integrated with Adams to optimize the parameters of the automaton, ammunition feeding mechanism and other components of an automatic grenade launcher\[3\]. Based on the Isight software, the parameters of the seeker servo control system were optimized by integrating the structural model, dynamic model and control model and using the multi-island genetic algorithm as the optimization method. To save your\[4\] taking the simulation model of launch dynamics of a certain type of multi-barrel rocket launcher based on virtual prototype technology as the core, the isight optimization software as the overall control framework, and the MIGA algorithm as the control strategy, the optimization research on reducing the ammunition consumption was carried out.

Grenade launcher as the research object in this paper, the type, analyze the movement process of main components, and establish a virtual prototype model of multi island, genetic algorithm (ga) optimization model was constructed based on the isight platform, the minimum recoil peak value as
the goal, optimize the main parameters affect the recoil of the study, the optimal solution, effectively improve the ergonomic.

2. Establishment of virtual prototype
The transmitter is mainly composed of barrel and casing assembly, floating guide rail assembly, automatic motor assembly, transmitter assembly, drum and bipod. Considering that the modeling function of Adams software is relatively weak due to the large number of transmitter parts and complex models, the 3d model is established by using Pro/E software and imported into Adams software through the Mechanism/Pro module to ensure the accuracy of the model.

2.1 Simplification and hypothesis of the model
In the research process, the following simplification and assumptions are mainly made for the weapon system:
   (1) Parts without relative motion are merged, small weight non-reitical parts are neglected;
   (2) Inertia of all springs is not considered, spring parts are replaced by spring dampers in software.

2.2 Calculation of muzzle force
According to the relevant parameters of the ammunition used in the weapon and the theory of internal ballistic, the average chamber pressure in the period of internal ballistic is calculated, and the relation between the pressure of chamber bottom and the average chamber pressure is

\[ p_t = \left(1 + \frac{1}{2} \frac{\omega}{\omega + 3\phi_1} \right) p_{Chamber bottom} \]

In the formula: is the loading quantity, phi1 is the resistance coefficient, q is the mass of the projectile, p is the average chamber pressure, p_tChamber bottom pressure.

The calculation formula of the after-effect period is

\[ P = P_t e^{-\alpha t} \]

Where, p is the average pressure in chamber in the after-effect period, p_tIs the average pressure in the chamber at the beginning of the after-effect period, e is the base of the natural logarithm, t is the time from the beginning of the after-effect period, and A is the constant coefficient.

2.3 Determination of boundary conditions
The damping and elasticity of human body are obviously nonlinear, which depends on the amplitude of external force applied on human body. Studies have shown that the human body's response to a small impact can be considered as a linear problem. As a shoulder-fired weapon, the grenade launcher mainly relies on each buffer mechanism to absorb the recoil energy and has a small impact on the shooter. Therefore, the one-degree-of-freedom linear elastic time-invariant system represented by lumped parameters is adopted to simulate the human shoulder force, and the shoulder force is used to represent the recoil force of weapon system. By the method of system identification, the parameters in the sense of minimum variance of the system are obtained:

\[
\begin{align*}
  m &= 9.85(Kg) \\
  C &= 560.63 \left( \frac{N}{m/s} \right) \\
  K &= 290135(\text{N/m})
\end{align*}
\]

2.4 Rubber cushion force
The relationship between axial displacement and acting force of the deformation surface of cushion was imported into Adams software to become spline function that can be called by the software, and the X-axis distance between two points was used as the variable to call spline function value to realize the addition of acting force of rubber material parts in rigid virtual prototype model.
2.5 Virtual prototype simulation and verification

Dynamic simulation was carried out on the established virtual prototype, and the velocity curves of the launcher's firing cycle, the guide rail and the body were shown in figure 1. The emitter chamber mouth direction as the negative direction of movement, weapon is fired, the automaton in the blocking state with motivation sat together, the magazine in the logo 1 machine box took in place, in the rear cushion contact with guide rail, automata body under the action of inertial continue to sat, atresia lock, at this time the body will continue to drive the head took; Mark 2 indicates that after the casing makes contact with the guide rail, the guide rail starts to accelerate and sit back under the force of the buffer pad. Under the action of shoulder force, its speed rapidly declines and moves forward after a short rise. After the casing contacted and interacted with the guide rail for the first time, it continued to sit back at a slow speed. Under the action of the resetting spring, the reseating speed gradually decreased until the forward reduction was achieved. The automaton continuously sat back. At the four marks, it came into contact with the end of the casing and interacted with it. As a result, the casing sat back again relative to the guide rail and then compressed the resetting spring. Under the action of the recharging spring force, the automaton continuously accelerates the recharging. Under the combined action of the recharging spring force, the resetting spring force and the shoulder force, the casing and the guide rail are reset in place at mark 5, and then tiny movements occur together. Mark 6 indicates that the automaton reenters into position, the nose hits the end of the body tube, and the body continues to reenter to complete the locking plate, after which the speed drops to zero and the whole shooting process is completed.

![Figure 1 Casing Speed curve of casing, guide rail and automatic body](image)

The matching of several representative instantaneous velocity simulation results and experimental data of the automaton body is shown in table 1.

| Speed of the body       | Simulation calculation value/(m·s⁻¹) | Experimental data/(m·s⁻¹) | error  |
|-------------------------|-------------------------------------|---------------------------|--------|
| Took the biggest        | 10.35                               | 10.73                     | 3.7%   |
| Sat in place            | 5.48                                | 5.92                      | 8.0%   |
| After into the start    | 0.34                                | 0.33                      | 3.0%   |
| The complex into place  | 4.47                                | 4.76                      | 6.5%   |

It can be seen from table 1 that the error between the simulation results and experimental data of the motion speed of the automaton body is less than 10%, which meets the needs of engineering design and the established virtual prototype is credible.

3. Maximum optimization of recoil force

Gunpowder gas exerts recoil force on the gun body directly or indirectly. Large-calibre individual weapons often use buffer devices to reduce the recoil collision of the automaton, improve the stability
of the shooting process and reduce the psychological burden of the shooter. But the buffer can not change the total recoil impulse of the weapon, it can only reduce the peak value of the impact and prolong the action time. Therefore, the maximum weapon recoil force is minimized as the target to optimize the parameters of the grenade launcher.

### 3.1 Objective function

In the weapon system, the recoil and recoil of the automaton play an important role in reducing the recoil of the weapon under the action of the reentrant force. Therefore, the optimization objective of this paper is to achieve the maximum value of recoil force by coordinating and coordinating the recoil and recoil of automaton and barrel assembly. Therefore, the complex spring stiffness \( k \) is taken here; And the refeed spring prepressure \( F_1 \); And the reset spring prepressure \( F_2 \); automatic recoil stroke \( d_1 \); rear travel \( d_2 \) of casing assembly; body mass \( m_1 \); casing mass \( m_2 \) Is the design variable. The objective function is

\[
F = \min f_{\text{max}}(X) \\
X = [k_1, k_2, F_1, F_2, d_1, d_2, m_1, m_2]
\]

### 3.2 Sensitivity analysis

When calculating the sensitivity of each structural parameter, the finite difference method can be adopted. According to the change amount of the target variable when the structural parameter changes slightly while other parameters remain unchanged, the sensitivity of the structural parameter at the point can be obtained as

\[
f_{\text{max}}(x) = \frac{\partial f_{\text{max}}}{\partial x_i} = \frac{f_{\text{max}}(x + \Delta x_i) - f_{\text{max}}(x)}{\Delta x_i}
\]

On a smaller scale, there is the following approximation \( \Delta x_i \)

\[
S_i = \frac{\Delta f_{\text{max}}}{\Delta x_i} = \frac{f_{\text{max}}(x + \Delta x_i) - f_{\text{max}}(x)}{\Delta x_i}
\]

The central difference formula can get more accurate results, and the expression is

\[
S_i = \frac{1}{2\Delta x_i} \left( f_{\text{max}}(x + \Delta x_i) - f_{\text{max}}(x - \Delta x_i) \right)
\]

In this paper, due to the different dimensions of each parameter, including stiffness, force and mass, the relative sensitivity calculation method is adopted to determine the influence degree of each parameter on the target. The ratio of the relative change of the target variable and the parameter variable is the relative sensitivity, and the formula is as follows

\[
S_i = \frac{1}{2 \Delta x_i} \left( f_{\text{max}}(x + \Delta x_i) - f_{\text{max}}(x - \Delta x_i) \right) / f_{\text{max}}(x)
\]

The relative sensitivity of each parameter at the design point can be obtained by calculating the relatively small variation of parameter, which is 0.2% in this paper. The results are shown in Table 2. The magnitude of the absolute value of relative sensitivity indicates the degree of influence of the parameter on the target variable.

| Parameter sensitivity | Relative sensitivity |
|-----------------------|----------------------|
| Feed spring stiffness | 0.00384              |
| Reset spring stiffness| 0.664056             |
| Refeed spring prepressure | 0.51136           |
| Reset the spring prepressure | 0.6363         |
| Automatic recoil stroke | 0.0012             |
3.3 Optimization model

In general, the fewer design variables, the simpler the optimization. Independent parameters that have significant influence on design variables and can be directly controlled should be selected as design variables. According to the sensitivity calculation results, the variable selection and its optimized value range are shown in table 3.

Table.3 Design variables and range of values

| The design variables                  | initial value | lower limit | ceiling |
|---------------------------------------|---------------|-------------|---------|
| Reset spring stiffness k/N/mm         | 8.42          | 6.0         | 10.5    |
| Refeed spring prepressure F₁/N        | 90.0          | 80          | 130     |
| Reset the spring prepressure F₂/N     | 180.0         | 160         | 240     |
| The rear-seat stroke of the casing is d/mm | 22.0         | 20          | 40      |
| Body mass m₁/kg                      | 1.096         | 0.8         | 1.4     |
| Casing mass m₂/kg                    | 1.583         | 1.2         | 1.9     |

Changes in recoil stroke and component quality will directly lead to changes in the total mass of weapons. For individual weapons, mass has a great impact on portability and maneuverability, and is also a major indicator of man-machine ergonomics. Therefore, it is limited that the total mass constraint condition of weapon system is less than or equal to zero. The expression is

\[ \Delta m < 0 \]

\[ \Delta m = \Delta m_1 + \Delta m_2 + \Delta m_d \]

Where, and are mass variations of automaton, casing and guide rail respectively. \( \Delta m_1, \Delta m_2, \Delta m_d \). The quality change of the guide rail is mainly caused by the change in the rear-seat stroke of the casing, so there is

\[ \Delta m_d = \rho \pi \left( R_d^2 - r_d^2 \right) \Delta d \]

Where, \( \rho, r_d, R_d \) are respectively the density, inner diameter and outer diameter of the guide rail.

In conclusion, the optimization model is established as follows:

\[
F = \min f_{\text{max}} (X)
\]

\[
X = [k, F_1, F_2, d, m_1, m_2]
\]

s.t. \( \Delta m \leq 0 \)

\[ \Delta m_1 = \Delta m + \Delta m_2 + \Delta m_d \]

\[ \Delta m_d = \rho \pi \left( R_d^2 - r_d^2 \right) \Delta d \]

3.4 Optimization scheme

In recent years, some intelligent optimization algorithms have appeared, such as genetic algorithm and neural network, etc., because the mechanism of escaping local extremum has been introduced, which can successfully solve some engineering optimization problems. Multi-island genetic algorithm is an improved genetic algorithm with strong global optimization ability and implicit parallelism. Isight, a multidisciplinary optimization platform, was applied to invoke Adams, a dynamics simulation software, in a batch-processing way, and the island genetic algorithm was used for optimization calculation.

The multi-island genetic algorithm sets the size of the subgroup as 10, the number of subgroups as 10, and the evolutionary algebra as 10. After 1000 iterations, the optimal solution is obtained. The values of the target function before and after optimization are shown in table 4.
Table 4 Comparison of parameters and objective function values before and after optimization

| variable | $K/N/mm$ | $F_1/N$ | $F_2/N$ | $D/mm$ | $m_1/kg$ | $m_2/kg$ | $f_{max}/N$ |
|----------|---------|---------|---------|--------|---------|---------|-------------|
| The initial value | 8.42 | 90.0 | 180.0 | 22.0 | 1.096 | 1.583 | 7994.98 |
| To optimize the | 6.48 | 93.2 | 209.3 | 30.9 | 0.812 | 1.782 | 6507.9 |

The comparison between the recoil curve and the guide rail speed curve before and after optimization is shown in figure 2 and figure 3 respectively. After optimization, the extreme value of recoil force was reduced by 18.6%, the total mass of the launcher was reduced by 51.3g, and the time of a shooting cycle was also reduced from 113ms before optimization to 74ms after optimization. As can be seen from figure 3, the movement of the guide rail before and after optimization varies greatly. If the curve passes through the zero point twice and is vibrated once, the guide rail before optimization vibrates 4 times and vibrates 2.5 times after optimization before 0.074s, and the extreme value of its speed decreases by 8.7%. And the transmitter bipod, drum, transmitter, scope and other parts are fixed in the guide rail, the human body against the shoulder is also directly acting on the guide rail. This shows that the optimization results can effectively reduce the impact of the collision on the weapon system, reduce the vibration of the components, and improve the stability of the system.

Figure 2 Comparison of recoil curve before and after optimization

Figure 3 Speed curve of guide rail before and after optimization

4. Conclusion
In this paper, a high reliability dynamic simulation model of a grenade launcher is established based on virtual prototype technology. The optimization parameters were determined according to the sensitivity analysis of each parameter, and the optimization model was established with the goal of minimizing the extreme value of the recoil force. Relying on the Isight optimization platform, the parameters of the weapon system were optimized and calculated with multi-island genetic algorithm, and the optimal solution was obtained. The results show that the extreme value of the recoiling force is reduced by 18.6%, the vibration frequency of the guideway is reduced, and the man-machine efficiency and system stability are improved effectively.

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